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COST-EFFECTIVE WEED CONTROL IN WINTER OILSEED RAPE

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by

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CONTENTS

1. SUMMARY

The objectives of this project were: a) to investigate the effects of broad-leaved weeds on winter oilseed rape, b) to see how crop vigour, as influenced by agronomy, affected weed competition, c) to investigate the possibility of predicting yield losses from weeds. A total of seventeen experiments was carried out at four sites (Rothamsted, ADAS-Boxworth, Morley Research Centre, and the Scottish Agricultural College-Aberdeen, over three seasons 1991 - 1994. Three weeds of contrasting phenologies were chosen for detailed investigation: chickweed, a prostrate, vigorous but early senescing weed; scentless mayweed, an upright weed with later maturity; and cleavers, a late maturing, scrambling species. A further eight weeds were studied less intensively, mainly in the 1994 'multi-species' experiments.

1.1 Competitive effects of broad-leaved weeds

1.1.1 Chickweed (*Stellaria media*)

This weed was studied most intensively, as it was present in ten detailed investigations and in four less-intensive (multi-species) experiments. The chickweed had a large effect on the yields of the rape in the majority of the experiments. At many sites 10-20 chickweed plants/m^2, in the autumn reduced yields by 5% or more. This was surprising, as previously published data suggested that it was not very competitive. In one trial (Aberdeen 1992) the rape was particularly vigorous and the chickweed was much less competitive (5% yield loss from 348 plants/m^2). Thus, it appears that there may be a general relationship between crop vigour and yield loss caused by chickweed but it is not clearly defined by the programme. It must be concluded that, especially in crops of low vigour in autumn and winter, it would be economically justified to control this weed, because of the risk of yield losses.

1.1.2 Scentless mayweed (*Matricaria perforata*)

In contrast to the chickweed, scentless mayweed was not very competitive in the majority of the four detailed and four multi-species experiments. In most experiments, despite the lack of vigour of many of the rape crops in the autumn and winter mentioned above, the mayweed never managed to break through the rape canopy in the early summer and so was never very competitive. Although some flower heads were noticed in the crops in mid-summer, the mayweeds rarely caused significant yield loss. Only at Rothamsted in 1992, where the rape was grazed by rabbits in early winter, was the mayweed really competitive. In most situations it would appear that mayweed is not a damaging weed, and would rarely warrant treatment.

1.1.3 Cleavers (*Galium aparine*)

The growth pattern of this weed differed completely from the other species. The plants remained small until early summer and then grew very rapidly, forming a dense mat of plant material on top of the rape canopy. As a consequence, cleavers caused substantial yield losses at very low densities in the three experiments that studied this weed in detail. Yield losses of 5% were caused by less than 10 cleavers/m^2 and in two experiments by less than 2 plants/m^2. In addition, the cleavers caused major problems of crop contamination. Densities of less than 5 plants/m^2 resulted in more than 4% admixture, which would require expensive cleaning. Thus, threshold levels for cleavers

would be very low, such that if cleavers plants were easily found within the crop, whilst crop walking, they should be controlled. At present, no really effective herbicides are available for the control of this weed, so in practice cleavers in rape should be minimised by good control in the previous crops.

1.1.4 Other weeds

A further 8 species were studied less intensively during the course of the project, especially in the four 'multi-species' experiments carried out in 1994. The responses of the crop to these weeds, and the three discussed above, have been ranked, to indicate the most and least competitive species. The relative order of competitiveness is as follows:

Very highly competitive	cleavers
Highly competitive	poppy, chickweed, (charlock)
Moderately competitive	red dead-nettle, mayweed, speedwell, annual meadow-grass, (charlock)
Poorly competitive	shepherd's purse, fumitory
Very poorly competitive	pansy

The effect of charlock depends on how well it survives the winter.

1.2 Effects of crop agronomy

In the chickweed experiments there was evidence of an inverse relationship between crop vigour and weed competitiveness. However, this relationship depended on a limited number of more vigorous rape crops. The generally low vigour of many of the rape crops in the cool, wet autumns of 91 - 93; may have contributed to the apparent high sensitivity to competition from the chickweed. This low vigour may also have affected the conclusions of some of the agronomic studies.

1.2.1 Sowing date

Delayed sowing markedly reduced crop vigour. There was no evidence that this reduction in crop vigour increased the competitive effects of the weeds, as delayed sowing also reduced weed growth and so the balance between crop and weeds remained the same. However, none of early-drilled rape in the sowing date experiments was particularly vigorous and so it is possible that early-sown, particularly vigorous rape would have been more competitive, as it was in earlier experiments studying the competitive effects of grass weeds.

1.2.2 Crop density

In the two experiments that studied this aspect of crop agronomy there was more rape and less weed in December and March on the high density plots. Despite these differences in growth there was little effect of crop density on yield losses caused by weeds. Only at the very lowest crop density (21 plants/m^2) was there a detectable increase in weed competitiveness. Thus, crop density is unlikely to have a marked effect on competition with weeds, unless densities drop well below the accepted minimum of 40 plants/m^2. The vigour of the plants is probably of greater importance than their number. In the absence of weeds there was a tendency for yields to decline at the lowest crop density.

1.2.3 Nitrogen levels

Application of autumn nitrogen increased growth of both rape and weeds and thus did not alter the competitive balance between the two species. Differences in growth due to the 50 kg/ha applied in autumn had almost disappeared by April. Manipulation of spring nitrogen provided no support for the theory that higher levels of nitrogen could increase the competitive ability of nitrophilic weeds such as chickweed. The evidence from the two experiments suggests that the reverse might be true, low nitrogen increasing the competition from the chickweed.

1.3 Predicting yield losses from weeds

The development of low input systems of weed management would be enhanced if it were possible to predict yield losses from weeds, based on the quantity of weeds present in the crop early in the season. Evidence from these trials, largely based on the experiments with chickweed, suggests that relative dry weight of weeds in December (weed weight / (crop weight + weed weight)) was a more reliable predictor of yield loss than weed density. Predictions based on weed density failed to take account of widely differing crop vigour. Predictions based on relative weed dry weights may be acceptable as experimental tools but are not suitable for practical use. The alternative technique of visual assessment of ground cover was studied in the project but, because of variation in assessments between assessors, has not been pursued in this report. The potential for this technique needs further study. Because the application of the major broad-leaved weed herbicides should be done in autumn, predictions would have to be based on assessments in September/October. This would be very early in the crop's development, making the risk of failure of prediction relatively high, because of the long period from assessment of potential weed damage and crop harvest. Despite all these problems these experiments have shown the approximate infestation levels, in terms of plants/m^2, for a range of weed species, that have a high probability of causing economic yield loss.

2. OBJECTIVES

There were three main objectives to this research programme, which interlinked in the 17 experiments that were done. Some experiments provided more information on one of the objectives, but all provided some data on all three:

Objectives

1) To investigate the effects of broad-leaved weeds on the growth and yields of oilseed rape in order to provide farmers with better guidance on the need for weed control.

2) To establish how variation in crop vigour, as influenced by agronomic factors, affects the competition caused by the weeds.

3) To investigate the possibilities for predicting yield losses caused by broad-leaved weeds.

3. INTRODUCTION

The techniques used in the production of oilseed rape have been evolving over the last ten years as a result of economic pressures, legislative requirements, technical progress and changes in EU support for arable agriculture. These changes have influenced priorities and methods of crop protection, including weed control. The profitability of winter oilseed rape has tended to decline during this period putting pressure on variable costs arising from such aspects of husbandry as fertiliser and pesticide usage. This decline has been exacerbated by the removal of EU support from the crop and its replacement by area aid. The consequence of this is that the price paid to the farmer for the crop has been reduced. This means that the benefits arising from the costs of use of insecticides, fungicides and herbicides have to be clearly justified by improved crop yields, or other longer term benefits.

The primary aim of this programme was to identify more clearly the benefits arising from the control of broad-leaved weeds. The most recent published survey by MAFF (Davis *et al.*, 1993) suggested that in 1992 approximately 37% of all herbicides used in rape were for the control of broad-leaved weeds and a further 13% for combined grass and broad-leaved weeds. On average, in 1992 each crop was treated with two products. Thus, as there was over 400,000 ha of rape in 1992, (375,000 ha in 1993) an appreciable national expenditure was incurred for the control of broad-leaved weeds.

Although earlier research had identified a need for the control of grass weeds, such as volunteer cereals, wild oats and black-grass in oilseed rape (Lutman, 1991, 1993; Munzel, 1992; Ogilvy, 1989), it is much less clear as to the need for the control of frequently less competitive broad-leaved weeds. Prior to the initiation of this project information on the effects of broad-leaved weeds on winter rape was limited and confusing. The overall impression was that there was not often an economic yield benefit resulting from the control of these weeds (Dingebaur, 1990; Wahmhoff, 1990; Lutman, 1991). In addition, where yield responses were recorded, the data often related to mixed infestations of different weed species, so it was not possible to identify the important species (Bowerman, 1989; Davies *et al.*, 1989). Research in Germany had begun to identify the competitive effects of some broad-leaved species (Klostermyer, 1989; Küst, 1989; Munzel *et al.*, 1992), ranking species according to their competitiveness. They concluded that chickweed was the most competitive broad-leaved weed of those studied, followed by mayweed and then red dead-nettle, pansy, forget-me-not and shepherd's purse (Table 1). Cleavers were given an arbitrary high value, because of their effects on harvesting. This emphasises the need to consider other effects from weeds, apart from reductions in crop yields, although yield loss is the major consideration. Weeds can also affect harvesting, may contaminate the harvested product or may affect the severity of pests and diseases. In addition, weed control decisions in rape may need to take into account consequences for other succeeding crops. The HGCA-funded programme reported here was primarily concerned with the competitive effects of weeds on crop yield but the other aspects will be discussed where appropriate.

It was clear from the earlier work on volunteer cereals that the vigour of the rape crop was of great importance when considering its ability to withstand competition from weeds (Lutman, 1991). Crop vigour can be influenced by sowing date, crop density and fertiliser levels, the former being the most important. Vigorous, early established rape was much more competitive than weak later sown crops. Interestingly, although yield losses from weed competition were much higher in these later sown crops, yields of late-sown weed-free crops have often not been lower than early-sown ones, unless drilling was after mid-September (Darby & Yeoman, 1994; Jenkins & Leitch, 1986; Lutman & Dixon, 1987). Similarly, although crop density has little effect on yields until populations are reduced below 40-60 plants/m^2 (Ogilvy, 1984), research by Sansome (1989, 1991) suggests that weed competition appears to increase as crop density declines. However, little research had been done on the detailed effects of crop agronomy on competition from broad-leaved weeds.

Table 1 **The relative competitive indices for weeds in winter oilseed rape used in the predictive RAPUS model for identifying the need for weed control in rape in Germany (after Munzel *et al.*, 1992)**

Weed Species	Competitive Index
Cleavers (*G. aparine*)	4.0
Black-grass (*A. myosuroides*)	0.08
Volunteer cereals	0.15
Chickweed (*S. media*)	0.12
Pineappleweed (*C. suaveolens*)	0.05
Scented mayweed (*C. recutita*)	0.03
Red dead-nettle (*L. purpureum*)	0.03
Field pansy (*V. arvensis*)	0.03
Others: competitive	0.05
Others: less competitive	0.03

The aim of this experimental programme was to investigate the competitive effects of weeds on the growth and yield of oilseed rape and to see how weed competition was affected by crop agronomy. It was not possible to look in depth at all common broad-leaved weed species, so the research was concentrated on three weeds, common chickweed (*Stellaria media* L.), scentless mayweed (*Matricaria perforata* (Merat.) ≡ *Tripleurospermum inodorum* (L.) Schultz Bip.) and cleavers (*Galium aparine* L.). These were chosen as representatives of three different types of weeds. Chickweed represented prostrate types such as dead nettle and speedwell. Mayweed was thought to represent more erect, later maturing weeds such as poppy and charlock. In order to have at least some information on other species, a less intensive investigation of a wider range of species was done in the third year of the project, including such species as red dead-nettle, field speedwell, charlock and pansy. The agronomic aspects of the project concentrated on the effects of crop sowing date and density, although some work was done on the effects of nitrogen levels.

4. MATERIALS AND METHODS

The experiments included in this research programme were carried out at four sites, three in Southern England and one in Scotland. The three English sites were at Rothamsted Experimental Station, Hertfordshire, on a silty clay loam, ADAS Boxworth, Cambridgeshire, on a clay soil and Morley Research Centre's Stonham farm site, Suffolk on a sandy clay loam. The Scottish site was at the Scottish Agricultural College's Tillycorthie Farm, Aberdeen on a sandy loam soil. These sites were chosen as being reasonably representative of rape growing areas in the UK. All crops were sown with conventional seed drills and were harvested either after desiccation with diquat or glyphosate, or by direct cutting, with small plot combine harvesters. Rape cultivars were selected by the site managers, ensuring that the ones used were most appropriate for the site (Table 3). It was not considered appropriate to select one cultivar for all sites at the beginning of the programme because of the differing climatic conditions at some sites and the rapid turnover of approved rape cultivars. A variety selected in autumn 1991 was likely to be superseded by autumn 1993.

Weed seeds of the target species were broadcast onto the plots at drilling, or immediately afterwards, at several densities so that a range of plant densities was established, which covered the whole extent of the likely response of the rape to that weed. No attempt was made to investigate the effects of mixtures of weed species. Control of pests and diseases was organised by the site managers and treatments were applied when considered necessary to maintain the health and productivity of the crop. Where necessary herbicides were used to minimise the effects of indigenous weeds which otherwise would have interfered with the crops' responses to the sown weed.

Details of the factors studied in each of the 13 main experiments are given in Table 2. Other general information about the experiments is given in Table 3. All experiments included at least, four densities of the weeds studied plus a 'weed-free' treatment. Chickweed was included in ten experiments, mayweed in four and cleavers in three. In addition, the effects of crop drilling date, rape density and nitrogen levels were studied in a number of trials. These were thought to be the critical aspects of crop agronomy, as far as weed competition is concerned. Because of the complexity of the possible combinations it was not possible to study all aspects at all sites. By splitting the species and agronomic factors between sites, it was possible, with the resources available, to cover most of the main aspects of broad-leaved weed competition in rape.

In addition to the 13 core experiments a further four, one at each site, were carried out in 1994. These investigated the response of rape to a wider range of species, but at a less detailed level, than those studied in the core experiments. Each weed was studied at two densities. Details of the species studied in these 'multi-species' experiments are given in Table 4. The two densities chosen for each species were relevant to the species concerned, thus relatively low densities were used for cleavers and high densities for chickweed, speedwell, pansy, annual meadow-grass and red dead-nettle. As there were only two densities, a regression approach to the analysis of data was not relevant, so simple analysis of variance was used as the basis of the statistical analyses.

Table 2 **Summary of the main features of the thirteen detailed studies included in the experimental programme**

Expt	Site	Harvest Year	Weed species			Agronomic factors		
			Chickweed	Cleavers	Mayweed	Drilling date	Rape density	Nitrogen level
1	Aberdeen	1992	✓					
2	"	1993	✓			✓		
3	"	1994	✓			✓		
4	Rothamsted	1992	✓	✓	✓			
5	"	1993	✓			✓		
6	"	1993		✓		✓		
7	"	1993			✓			
8	"	1994	✓			✓		
9	Boxworth	1992			✓		✓	
10	"	1993	✓		✓		✓	✓
11	"	1994	✓				✓	
12	Morley	1993	✓	✓				✓
13	"	1994	✓					✓

Table 3 Dates of sowing, assessments and harvest and other general agronomic information

Site	Year	Rape Cultivar	Sowing date	Rape density (plants/m^2)	Assessment Dates		Spring nitrogen kg/ha	Harvest date
					Winter	Spring		
AB+	1992	Samourai	28 Aug	133	11 Dec	13 Apr	163	6 Aug
AB	1993	Rocket	treatment*	57-84	4 Dec	28 Apr	180	1 Sept
AB	1994	Rocket	treatment	64-75	14 Dec	2 Apr	180	31 Aug
BOX	1992	Samourai	5 Sept	21-67	7 Jan	20 Mar	189	17 July
BOX	1993	Samourai	4 Sept	44-113	17 Dec	6 Apr	176	22 July
BOX	1994	Bristol	7 Sept	54-222	4 Jan	19 Apr	159	18 July
MOR	1993	Capricorn	•8 Sept	83	16 Jan	14 Apr	200	26 July
MOR	1994	Apex	7 Sept	61	14 Jan	11 Apr	198	29 July
RES	1992	Libravo	11 Sept	89	4 Dec	1 Apr	176	27 July
RES[1]	1993	Falcon	treatment	61-85	8 Dec	4 Apr	187	28 July
RES[2]	1993	Falcon	treatment	65-81	9 Dec	16 Apr	187	28 July
RES[3]	1993	Falcon	15 Sept	77	14 Dec	20 Apr	187	28 July
RES	1994	Falcon	treatment	60-77	8 Dec	22 Mar	175	27 July
Multi-species experiments								
AB	1994	Rocket	30 Aug	80	16 Dec	21 Apr	180	31 Aug
BOX	1994	Bristol	7 Sept	83	11 Jan	25 Apr	159	18 July
MOR	1994	Apex	7 Sept	64	14 Jan	11 Apr	201	29 July
RES	1994	Falcon	7 Sept	78	13 Dec	7 Apr	175	27 July

* Sowing date is a treatment in 5 experiments, see Table 15
+ AB = Aberdeen, BOX = Boxworth, MOR = Morley, RES = Rothamsted
RES[1-3] = 1993 Rothamsted chickweed, cleaver and mayweed experiments, respectively

Table 4 **The weed species studied in the 1994 multi-species experiments**

Weed	Rothamsted	Boxworth	Morley	Aberdeen
common chickweed	✓	✓	✓	✓
field pansy	✓			✓
charlock	✓	✓	✓	
red dead-nettle	✓	✓	✓	
common poppy	*	✓	✓	
cleavers	✓	*		
scentless mayweed	✓	✓	✓	✓
common field-speedwell		✓	✓	✓
shepherd's purse				✓
fumitory				✓
annual meadow-grass				✓

* very low or no establishment of this species

4.1 Assessments

The number of crop and weed plants/m^2 was recorded during the autumn on all trials, using randomly placed quadrats for the weeds and quadrats or counts of metre lengths of row for the rape. Destructive samples were carried out twice, once in December/January and once in March/April. Small areas of the plots (0.25 - 1.0m^2) were harvested and crop and weed weights/m^2 were determined. Details of dates of sampling are given in Table 3. Visual assessments of crop and weed ground cover were also done at intervals during the autumn and winter. Crop yields were determined at maturity and are presented in t/ha at 9% moisture.

4.2 Statistics and data analyses

All experiments were of a randomised block or split plot design with three or four replications. The dry weight and yield data were all subjected to analysis of variance, to establish the basic framework of the responses and standard errors of the treatment means. Subsequently, the data from all experiments, except the multiple weed species trials in 1994, were included in regression analyses to identify, more precisely, the relationships between weed infestation level and crop weight, weed weight and crop yields. The Maximum Likelihood Programme (MLP) (Ross, 1978) was used for these analyses. Using this technique it was possible to identify the crop response to standard weed densities, such as crop and weed weights at 100 chickweed plants/m^2 or number of weeds/m^2 causing a 5% yield loss. In this way the results of individual experiments could be compared directly. The goodness of fit of the data to the tested regression models was identified from the % of variation in the data accounted for by the model (identified as '% va' in the subsequent tables). Two regression models were used, linear and hyperbolic. The former was used unless there was a statistically significant reduction in the error when the hyperbolic model was used (Lutman *et al.*, 1994). In many of the experiments weed density responses followed the hyperbolic model. This was expected as it is now widely accepted that this model predicts the effects of weed density on crop growth and yield most reliably (Cousens, 1985). Other measures of weed infestation levels, apart from weed density (plants/m^2), such as relative dry weights in December/January (weed weight / (crop + weed weight)) have also been used to identify those factors that correlate most strongly with final yields.

The 5% yield loss value was used as the basic determinant of yield loss, as for many crops it equated reasonably well with the cost of a herbicide. Assuming an average yield of 2.8 t/ha and a crop value of £185/t a 5% yield loss would be £26. This is approximately equivalent to a reduced dose of metazachlor (Butisan S). In addition, the weed density giving a loss of 0.2 t/ha was also calculated. This avoids the necessity of knowing the final yield, but in many trials, because of the shape of the response curves, was very close to the density causing a 5% loss.

5. RESULTS AND DISCUSSION

Details of individual experiments are available from the authors. Because of the amount of detail, no attempt has been made in this section to discuss the results of individual experiments. Each part of the Results and Discussion considers one aspect of the study. The results of the detailed experiments and the 'multi-species' experiments have been amalgamated where relevant.

5.1 Overview of the competitive effects of the studied weeds

5.1.1 Chickweed (*Stellaria media*)

This weed was studied most intensively over the three years of the programme. It was present in 10 experiments and in a total of 18 comparisons, including experiments with multiple sowing dates or crop densities. One experiment (Boxworth 1994) failed to yield meaningful results, because the small range of chickweed densities established. Results of the others are presented below.

Tables 5 & 6 show the weight of chickweed and response of the rape in December/January and March/April to densities of 0, 100 and 500 chickweed plants/m^2. All the data are in g/m^2. There was a clear increase in the weight of chickweed as the density increased, at both harvests on all nine experiments. Differences between the amounts of chickweed at the two densities were large in December/January but by the spring the 5-fold differences in chickweed densities never resulted in more than a 2-fold increase in dry weights. This clearly shows the compensatory growth of the low densities of chickweed, resulting from the absence of intra-specific competition. There were differences in the weight of the chickweed at the different sites and as a result of differences in sowing date. These agronomic effects will be discussed later, in section 5.2.1. The rape was rarely appreciably reduced in vigour by the presence of chickweed in mid-winter, and in many comparisons there was no statistically significant effect. However, by March/April there was appreciable reduction in rape weights on almost all experiments, due to competition from the chickweed. The main exception to this was at Aberdeen in 1992, where the rape was very vigorous and the chickweed never became competitive.

The chickweed had a considerable effect on the yield of the rape at most sites. Both of the densities included in Tables 5 & 6 reduced yields appreciably, except at Aberdeen in 1992 (Table 7). Yield reductions, even from the lowest density, were often appreciable. At Rothamsted in 1994 the rape responded similarly to all densities of chickweed, largely as result of the level of intraspecific competition at the higher chickweed densities. As a result, regression analysis was not possible, but the mean of all the chickweed treatments had significantly lower yields than the chickweed-free plots (Table 7). Fig. 1 and Table 8 show the responses of the rape to this weed, presented on the basis of the number of chickweed plants/m^2 causing a 5% yield loss. At many of the sites less than 10 chickweed plants/m^2 caused a 5% yield loss. However, at a minority of sites even several hundred plants had little effect. When the programme was started the evidence from published research was that many broad-leaved weeds had only a small effect on the yield of winter rape and as a consequence many treatments were uneconomic (Davies *et al.*, 1989; Wahmhoff, 1990; Lutman, 1991). The data collected over the three years of the project does not support this conclusion for chickweed, as even quite low populations could have substantial effects on yields.

The reason for the variation in response between sites requires explanation because in some sites the control of this weed was uneconomic. There seems to be a general relationship between the vigour of the rape in the autumn and winter and the effect of the chickweed (Tables 5-8, Fig. 2). Four of the experiments, Rothamsted (93 and 94) and Aberdeen (93 and 94) attempted to investigate the effect of reduced crop vigour on competition by studying the influence of delayed drilling. However, as is discussed below and in Section 5.2 which reports the effects of crop agronomy, site and year had a greater effect on the crop than manipulating sowing dates. If the dry weight of the weed-free crop in December is plotted against number of chickweed plants causing a 5% yield loss there is a reasonably good relationship (Fig. 2), as the % variation accounted for by the regression of log dry weight against chickweed number is 65%. This line depends very largely for its slope on two sites, Aberdeen in 1992 and Rothamsted in 1991, where the rape was particularly vigorous, 5% yield losses from 348 and 252 chickweed plants/m^2. The latter is an experiment not included in the HGCA programme, as it was carried out prior to its start but as the data were relevant and compatible we have included it in this discussion. It is not surprising that rape vigour in the autumn and winter affected the competitive ability of the chickweed, as it was the major conclusion of previous work on the competitive effects of volunteer cereals. An analysis of 18 separate experiments carried out by ADAS, SAC and IACR clearly showed increase in weed competition with delayed sowing and consequent decline in crop vigour (Lutman, 1993).

However, it is quite clear that low densities of chickweed can have a marked effect on rape, especially if it is not very vigorous. In our experiments this weed clearly reduced crop growth in early spring on most trials, except on the two trials where the chickweed was never competitive (Aberdeen 92, Rothamsted 91). In the trials at Rothamsted in 92 and 93, where further samples were taken in May and July, there were indications that the crop was recovering, particularly in July, at which time the chickweed was dead. However, this recovery was not sufficient to prevent a marked loss of yield. The data from these two Rothamsted trials show that maximum growth of chickweed occurs in spring and that the plants die in early summer once the rape canopy is established and water becomes limiting. The ability of rape to recover from early growth reductions caused by weeds has been recorded previously in the research studying the effects of grass weed competition (Lutman & Dixon, 1990). The absence of recovery in many of these experiments and the consequent appreciable yield losses caused by chickweed are difficult to explain. It may relate to the autumn and winter weather experienced during the three years of the project. With the exception of the Aberdeen site in 1992, the rape never grew with the vigour in the autumn that had been frequent in earlier years. In the paper on grass weed competition (Lutman & Dixon, 1990) all of the crops exceeded 100 g/m^2 by the end of the year and many exceeded 200g/m^2. In this HGCA programme only the rape in Aberdeen 92 exceeded 100 g/m^2 in December (Tables 5 & 6). Many of the crops were less than 20 g/m^2 at this time. This lack of vigour in the winter gave the chickweed a great advantage in the spring, as it was able to compete vigorously with the small rape plants, once the spring nitrogen had been applied and increasing temperature encouraged growth.

Table 5 <u>Effect of 0, 100 and 500 chickweed plants/m^2 on the weight of rape and chickweed in December/January and March/April</u> (* AB = Aberdeen, BOX = Boxworth, MOR = Morley: E, M, L, = early, mid and late sown; T, S, D, = low, standard and high crop density)

Site	Year	Agronomy	December/January dry wgts (g/m^2)								March/April dry wgts (g/m^2)							
			Rape			% va	Chickweed			% va	Rape			% va	Chickweed			% va
			0	100	500		0	100	500		0	100	500		0	100	500	
AB*	1992		152+				1.4	21.8	42.1	60	560	551	512	13	1.2	43.8	82.8	44
AB	1993	E	21.2				0	6.2	42.3	66	161	131	80	52	0	399	471	85
		M	7.5				3.3	9.0	31.7	43	190	42	29	0	0	371	557	84
AB	1994	E	19.0				2.8	11.2	44.9	76	81.8				0	225	300	77
		M	10.4	9.1	3.8	43	1.9	12.0	52.4	56	62.1	50.9	6.3	29	0	237	431	87
		L	2.6				4.0	8.6	27.3	43	30.0	25.0	4.7	22	0	128	194	82
BOX	1993	T	44.6				0	34.2	62.3	72	326	252	206	33	0	295	358	77
		S	65.3				0	27.9	40.3	80	420	259	219	88	0	226	326	89
		D	73.5				8.2	12.9	31.3	79	391	373	300	73	0.4	205	269	94
MOR	1993		40.6	33.0	21.8	69	1.8	18.9	51.4	85	320	183	92	84	0	323	458	77
MOR	1994		44.8	26.8	13.8	70	0.2	41.8	73.6	60	278	124	61.8	67	110	362	364	44

+ single figures indicate that the weights of the rape plants were similar at all weed densities (0, 100, 500 plants/m^2)
% va = % variation in the data accounted for by the regression analysis

Table 6 Effect of 0, 100 and 500 chickweed plants/m^2 on the weight of rape and chickweed in December/January and March/April at Rothamsted (* RES = Rothamsted: E, M, L, = early, mid and late sown)

Site	Year	Agronomy	December/January dry wgts (g/m^2)								March/April dry wgts (g/m^2)							
			Rape			% va	Chickweed			% va	Rape			% va	Chickweed			% va
			0	100	500		0	100	500		0	100	500		0	100	500	
RES*	1992		53.9	53.3	50.5	31	1.6	7.9	20.4	73	293	224	149	77	0	138	184	86
RES	1993	E	20.6	17.8	12.6	48	1.6	12.3	27.0	83	98.1	69.9	44.7	58	5.8	145	155	92
		M	16.2	12.7	10.1	55	1.0	7.0	17.3	87	136	89.2	59.5	75	6.6	148	169	89
		L	2.6				0.2	1.7	6.1	91	52.4	37.9	23.6	80	2.8	79.8	135	86
RES	1994	E	54.1				8.2	30.6	52.9	71	122	97.2	86.4	30	23.3	74.7	80.8	42
		M	17.6	16.8	13.6	24	3.8	20.6	42.7	89	76.1	49.9	36.5	44	36.5	60.4	86.0	66
		L	2.9				0	6.7	19.8	85	24.6	11.7	7.5	65	7.7	43.2	77.8	89

% va = % variation in the data accounted for by the regression analysis

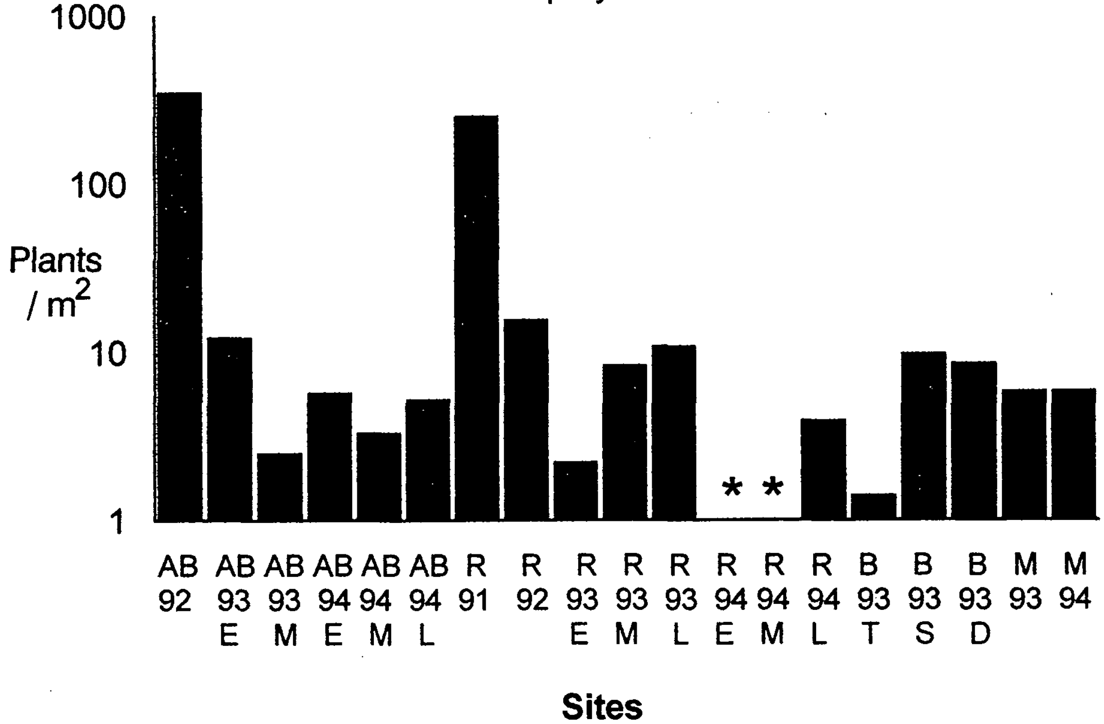
Table 7 Effect of 0, 100 and 500 chickweed plants/m^2 on the yield of oilseed rape (* E, M, L, = early, mid and late sown; T, S, D, = low, standard and high crop density)

Site	Year	Agronomy	Rape yields (t/ha)			% va+
			0	100	500	
Aberdeen	1992		3.82	3.77	3.55	34
Aberdeen	1993	E*	2.29	1.69	1.15	72
		M	3.02	1.18	0.65	71
Aberdeen	1994	E	5.08	3.00	1.87	61
		M	4.25	1.75	0.64	86
		L	4.70	2.35	0.84	58
Boxworth	1993	T	3.61	2.58	2.52	51
		S	3.99	3.13	2.78	60
		D	4.12	3.05	2.56	75
Morley	1993		4.63	2.66	1.47	90
Morley	1994		4.09	2.70	2.14	59
Rothamsted	1992		2.97	2.38	2.38	37
Rothamsted	1993	E	3.57	1.79	1.45	84
		M	3.67	2.72	2.31	73
		L	3.37	2.47	1.83	88
Rothamsted	1994	E	4.12	*	*	
		M	4.00	*	*	
		L	4.08	3.28	3.20	57

* RES 94 There was no relationship between weed density and yield for these two treatments, but there were significant differences between the mean of all the plots with chickweed and those without weeds. Chickweed on early sown plots reduced yields to 3.70 and on mid-sown plots to 3.59 t/ha (SED = 0.150), reductions of 8.9 and 11.6%, respectively.

\+ % va = % variation accounted for by the regression analysis

Fig. 1 The number of chickweed plants/m² to cause a 5% reduction in rape yield



Sites: Ab = Aberdeen, R = Rothamsted, B = Boxworth, M = Morley
Agronomy: E = early, M = mid, L = late drilled
T = low, S = standard, D = high crop density

* no relationship between density and yield loss

Fig 2. Relationship between rape weight in December and number of chickweed plants to cause a 5% yield loss

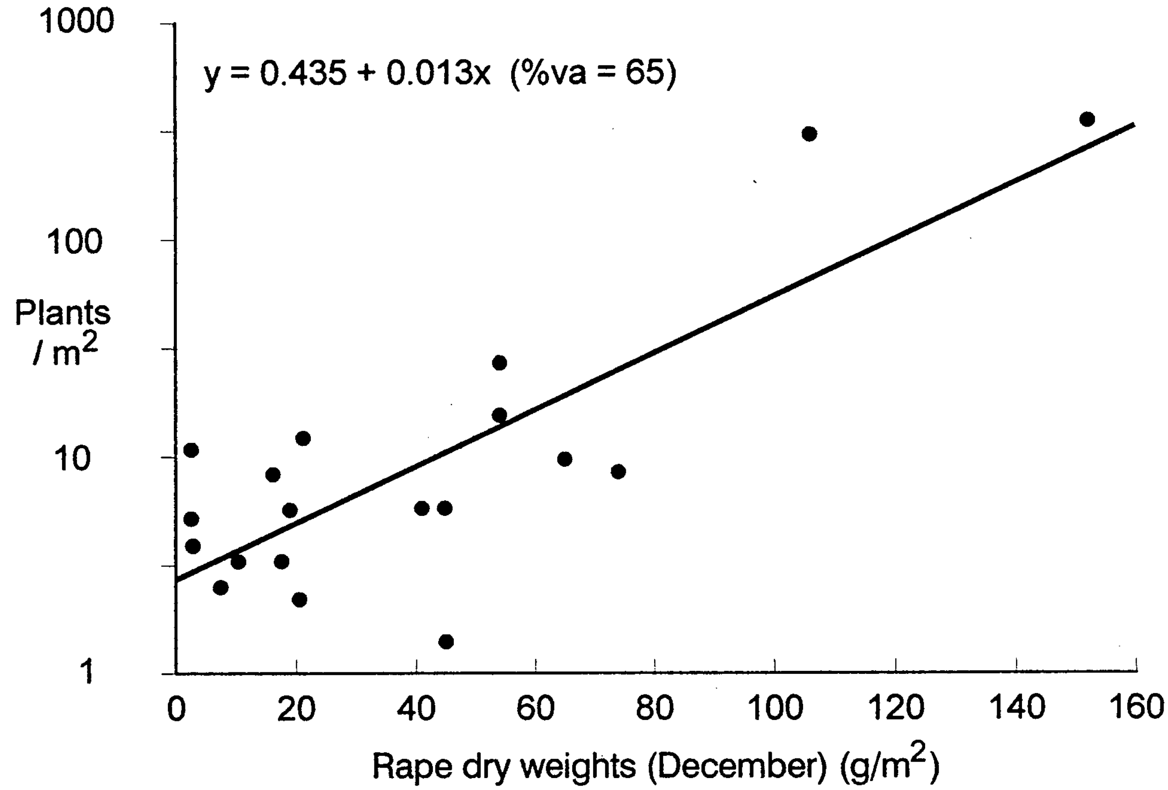


Table 8 Comparison of the number of chickweed plants/m^2 to cause a 5% yield loss and the relative dry weight (%) of chickweed in December/January to cause the same yield loss

Experiment	Chickweed plants/m^2		% dry weight of chickweed*	
	number	% va^x	% weight	% va
Aberdeen 92	348	34	9.0	28
Aberdeen 93 (E)$^+$	12.2	72	1.8	90
Aberdeen 93 (M)	2.5	71	0.5	96
Aberdeen 94 (E)	5.7	61	6.3	57
Aberdeen 94 (M)	3.3	86	5.4	70
Aberdeen 94 (L)	5.2	58	6.2	58
Rothamsted 91	252	41	9.6	56
Rothamsted 92	15.2	37	8.8	39
Rothamsted 93 (E)	2.2	84	1.4	94
Rothamsted 93 (M)	8.3	73	8.2	88
Rothamsted 93 (L)	10.8	88	7.6	94
Rothamsted 94 (L)	3.9	57	7.4	79
Boxworth 93 (T)	1.4	51	9.4	82
Boxworth 93 (S)	9.7	60	7.6	85
Boxworth 93 (D)	8.5	75	5.4	94
Morley 93	5.9	90	3.0	66
Morley 94	5.8	59	8.8	90

* % dry weight chickweed
= (dry wt chickweed / (dry wt chickweed + dry wt rape)) x 100

\+ for details of individual experiments see legends in Tables 5 & 6

x % va = % of the variation in the data accounted for by the regression model

The three autumns of 1991, 1992 and 1993 were all cooler and wetter than many of those experienced in the 1980s. At Rothamsted in September and October, the critical months for rape establishment, 1991, 1992, and 1993 were 0.6, 1.8 and 1.1^{0}C below the 30 year average, respectively. Similarly, although autumn 91 was not particularly wet, in 1992 and 1993 rainfall in September and October was 78 and 128 mm above the 30 year mean.

A further aspect of the competitive nature of chickweed lies in its ability to compete with itself. Intraspecific competition was a feature of all the trials. By the end of the winter the differences in weed weight between the higher and lower densities were much reduced. The reason for this was that at high densities the individual chickweed plants competed vigorously with each other and so there were many small plants. It is likely that individual plant mortality was also high. In contrast, at low densities the plants grew large, filling all the space available and so by the end of the winter they had a similar biomass to the originally higher density plots. This behaviour of the chickweed often made it difficult to carry out regression analyses, as the large differences in weed density only had small effects on the vigour of the weed and consequently on its affect on the crop. This was particularly a problem on the Rothamsted experiment in 1994. This response of the weed to increasing density had the consequence that the regression lines showed a very steep loss of yield at low weed densities, thus accounting for the low weed densities predicted to cause 5% yield losses. However it cannot be ignored that in many trials very low weed densities would have caused economically significant loss of yield.

The general conclusion on the need for the control of this weed, is that in many situations yield losses from even very low infestations of chickweed will warrant treatment, In 89% of the 19 chickweed comparisons in Table 8, less than 20 plants/m^2 in the autumn, reduced yields by more than 5%. The precise economic threshold infestation level will depend on the cost of the herbicide to be used, the value of the rape and the potential yield of the crop. The need for weed control will be higher where crop vigour is low. In contrast, in fields where the crop is particularly vigorous the treatment threshold will be much higher. Further consideration of this aspect is given in Section 5.3 which considers the prediction of yield losses.

5.1.2 Scentless mayweed (*Matricaria perforata*)

Mayweed was chosen at the outset of the project, as representative of weeds that were erect in growth and could become very visible late in the season in rape crops. Similar species would be common poppy and charlock. Scentless mayweed was selected in preference to other mayweed species because it was particularly common and was more erect than the other common species, pineappleweed (*Chamomilla suaveolens*). It was expected at the outset of the programme that mayweed, because of its erect habit, would be particularly competitive. Wilson & Wright (1990) demonstrated mayweed to be more competitive in winter cereals than most other broad-leaved weed species. Earlier work in Göttingen, Germany (Munzel, 1992; Munzel, Wahmhoff & Heitefuss, 1992) also showed scented mayweed (*Chamomilla recutita*) to be more competitive than many species, but interestingly they assigned a higher value to chickweed. They thought pineappleweed to be less aggressive than scented mayweed. Unfortunately, they did not study scentless mayweed, so we cannot make direct comparisons with their data.

Scentless mayweed was included as a significant part of two experiments at Boxworth (BOX 92, BOX 93) and two at Rothamsted (RES 92, RES 93). It was also included in all four of the 1994 multi-species experiments. It is clear from the summary of the four main trials presented in Table 9 that only in the experiment at Rothamsted in 1993 was there a major effect of the mayweed on the growth of the rape in April and on the final yield. In 1992, at Boxworth, the lowest crop density was only 21 plants/m^2 (Table 16) and at this density the mayweed also affected yields. Where the crop density was higher no crop response was detectable. At Rothamsted in 1992 the mayweed plants were never large, never emerged through the rape canopy and so never affected rape yields. There were substantial numbers of mayweed plants on the plots at Boxworth in 1993. The mayweed had a small effect on the weight of the rape in April and appeared from its relatively high weight at this time, especially at the lower crop density, that it ought to have affected crop yield. However, the response of the rape to the mayweed was low at harvest. So it appears that even quite high densities of mayweed in the autumn had little or no effect on the rape. The reason for this seemed to be that the plants were always beneath the rape canopy and never, except at Rothamsted in 1993, grew large enough to break through the canopy, early in the summer and compete with the crop. It seems that, unless the mayweeds are very vigorous, they are unlikely to have a marked effect on crop yield, despite their presence in the rape in late summer.

This conclusion is supported by the results of the four multi-species experiments where mayweed at densities in the autumn of 20 - 210 plants/m^2 caused only small reductions in rape growth in the spring and had no detectable effect on rape yields at three of the four sites (Table 10). At Morley, where mayweed growth was most vigorous an almost statistically significant reduction in yield was detected.

Overall, these results suggest that a mayweed weight of approximately 100 g/m^2 is needed in late March - early April to cause a serious reduction in yield. Less mayweed may cause yield losses when crop density is particularly low, as at Boxworth in 1992, permitting good light penetration down to the weed during the spring and summer.

This lack of effect from the mayweed was surprising but the dry weight data in winter and spring do appear to explain why. Compared to chickweed, the mayweed plants rarely became big enough to affect rape yields. This lack of competition found in our trials concurs with the conclusions from Germany, where Munzel (1992) and more recently Bodendörfer *et al.* (1994) rated chickweed more competitive than mayweed.

Table 9 Effects of scentless mayweed at 50 and 200 plants/m^2 on the growth of rape in winter and spring and on yield of rape in four experiments (Rothamsted = RES, Boxworth = BOX: T = low, S = standard, D = high crop density

Year	Site	Max. weed numbers (plants m^2)	December/January					March/April					% Yield Loss	
			Rape (g/m^2)			Mayweed (g/m^2)		Rape (g/m^2)			Mayweed (g/m^2)			
			0	50	200*	50	200*	0	50	200*	50	200*	50	200*
1992	RES	187	56			2.0	6.6	289			12.3	41.3	None detectable	
1993	RES	400	10.9			2.2	7.5	198	117	106	98	188	41	59
1992	BOX (T)	92	5.6			1.0	1.9*	52			24	49*	15	29*
	BOX (S)	104	10.3			0.9	1.9*	86			18	32*	None detectable	
	BOX (D)	96	18.2			0.8	1.7*	136	105	74	16	28*	None detectable	
1993	BOX (T)	937	43			4.0	14.3	324	317	296	46	119	2	7
	BOX (S)	994	70			4.8	6.1	385	379	358	36	102	1	4
	BOX (D)	824	76			2.1	3.8	410			17	51	5	6

* In 1992, at Boxworth, because the maximum mayweed density was only approximately 100 plants/m^2, the estimated effects of 200 plants/m^2 were reduced to 100 plants/m^2

Table 10 **Dry weights of rape and mayweed in winter and spring (g/m^2) and % yield loss caused by the weeds in the four 1994 multi-species experiments**

Site	Mayweed density plant/m^2	Dec./Jan.		March/April		% Yield Loss
		Rape	Weed	Rape	Weed	
Aberdeen	56	21	0.1	164	28	None detectable
Boxworth	20	11.5	0.2	242	3.6	None detectable
Morley	156	34	6.6	255	227	18$^+$
Rothamsted	210	32	7.0	208	58	None detectable

+ This % yield loss is not quite statistically significant ($p = 0.05$)

5.1.3 Cleavers *(Galium aparine)*

Cleavers is arguably the most competitive weed to be studied in this series of experiments. This is not surprising as earlier work in the UK in cereals (Wilson & Wright, 1987, 1990) and in Germany in rape (Bodendörfer *et al.* 1994) all demonstrated high levels of competition from this weed. Intrinsically one might assume that this weed was not a very competitive species as it makes very little growth during the autumn, winter and early spring and therefore should have been eliminated by competition from the larger rape plants. It seems that cleavers has the ability to grow in and under the rape canopy at a time of year when other weeds such as chickweed and speedwell are starting to senesce. Having scrambled through the canopy it then forms a vigorous mat of plant material on top of the crop. This inhibits pod filling, reduces 1000 seed weights, delays ripening and interferes with harvesting. The cleavers seeds are harvested with the crop and so there will be increased cleaning costs as well as increased drying costs. All these factors contribute to the overall detrimental effect of this weed. Bodendörfer *et al.* (1994) conclude that only 1 cleavers plant/m^2 will cost the farmer approximately 220 DM/ha (c. £100/ha).

In the experiments described in this report we were mainly concerned with the effects of cleavers on rape yields, but we also collected data on the crop contamination caused by the seeds. Three experiments looked in detail at cleavers and one of the multi-species experiments in 1994 also included this weed. The detailed experiments clearly showed the lack of growth by cleavers during the autumn, winter and early spring (Table 11). The rape was virtually unaffected by the cleavers even in April. In the two Rothamsted trials further samples in May and July demonstrated the ability of the cleavers to grow vigorously during the summer, as 5 cleavers/m^2 could produce 100-200 g/m^2 of plant material in July (Table 12). In spite of the late growth of the cleavers, the results show that a very few plants could have a great effect on yields. At the two Rothamsted trials only 0.4 - 2.8 plants/m^2 caused a 5% yield loss (Table 13). The cleavers plants were slightly less competitive at Morley in 1993. This may have been caused by the presence of other weeds on the weed-free plots, reducing the yield of these plots and thus apparently the competitive effects of the cleavers. In summary, densities of only 0.4 - 10 cleavers/m^2 had a marked effect on yields.

There was no evidence that delayed sowing altered the competitive effect of the cleavers, although late planting resulted in much smaller rape plants in winter (Table 11). The absence of a response to delayed drilling may be for two reasons:

1) cleavers emerged later in the autumn on the late sown plots and so were not able to make full use on the slower growth of the rape.

2) as the major competition from cleavers occurs in mid-summer, their competitive effect was probably mainly influenced by differences in crop vigour in May-July. The differences in rape growth between drilling dates were much smaller in May than they had been earlier. Thus, a 550% difference in rape weight in December between the earliest and latest sown crops had declined to only a 33% difference by 26 May (Tables 11, 12). Consequently, cleavers competition was only slightly affected by delayed drilling.

Table 11 <u>The effect of 0, 5 and 20 cleavers plants/m^2 on the weight of rape and cleavers in December/January and March/April</u>
(RES = Rothamsted, MOR = Morley: E = early, M = mid, L = late sown crop)

Site	Year	Agronomy	December/January dry wgts (g/m^2)								March/April dry wgts (g/m^2)							
			Rape			% va	Cleavers			% va	Rape			% va	Cleaver			% va
			0	5	20		0	5	20		0	5	20		0	5	20	
RES	1992		53.5				0	0.4	1.3	62	283				5.3	6.4	10.5	89
MOR	1993		38.9				2.8	3.3	4.7	22	278				70*	77	99	25
RES	1993	E	18.6				0.8	1.3	2.8	97	205	201	190	44	0	20.7	49.3	77
		M	16.5				0.5	0.6	1.0	57	204				2.0	5.5	15.9	83
		L	3.4				0.1	0.2	0.4	92	93				3.0	5.4	12.2	83

* the high weight of weeds on the weed-free plots was due to indigenous chickweed, which may have influenced the growth of these plots.

Table 12 <u>The effect of 0, 5 and 20 cleavers plants/m^2 on the weight of rape and cleavers in May and July.</u>
(RES = Rothamsted: E = early, M = mid, L = late sown crop)

Site	Year	Agronomy	May dry wgts (g/m^2)								July dry wgts (g/m^2)							
			Rape			% va	Cleavers			% va	Rape			% va	Cleavers			% va
			0	5	20		0	5	20		0	5	20		0	5	20	
RES	1992		906				4.9	12.9	37.1	78	1535	1409	1224	42	0	98	222	84
RES	1993	E	692	550	454	69	0	126	237	78	1009	837	660	60	0	260	477	63
		M	703	689	646	27	0	42	124	93	1182	991	846	44	9	164	333	77
		L	526	521	505	27	7	69	172	94	1050	947	766	86	13	111	286	94

Table 13 Effect of 0, 5 and 20 cleavers plants/m² on rape yields and the number of cleavers plants/m² to cause a 5% loss in yield and 4% admixture in the rape seed

Site	Year	Rape yields (t/ha)			% va	plants/m² giving a 5% yield loss	plants/m² causing a 4% admixture
		0	5	20			
RES	1992	2.97	2.72	2.28	52	2.8	1.7
MOR	1993	4.12	3.92	3.67	44	9.9	2.5
RES (E)*	1993	3.48	2.30	1.25	88	0.5	0.8
RES (M)	1993	3.92	3.26	2.18	88	0.4	4.7
RES (L)	1993	3.17	2.64	1.82	94	1.3	2.9

* E,M,L = early, mid and late sown

Not only did low densities of this weed have clear effects on yield they also contaminated the harvested grain. Densities of only 0.8 - 4.7 plants/m² caused the contamination of the rape seed to reach the 4% admixture limit acceptable to the EU (Table 13). As cleaning costs are in the region of £15-20/tonne these costs, which in the case of cleavers would only be partially effective, should be added to the yield losses caused by this weed.

Yield thresholds were very low for cleavers and if allowance is made for difficulties of assessment related to spatial variation in the distribution of the weed, and for the likely seed production by surviving plants, the conclusion must be that effective thresholds are so low that in reality they are not practical. Wilson & Wright (1987) reached the same conclusion for the control of cleavers in winter wheat. Küst (1989) in his decision model for weed control in rape assigned an arbitrary high competition value of 1.0 to cleavers to ensure that its presence at very low densities in fields triggered the threshold to apply a herbicide for its control. This was increased by Munzel (1992) to 4.0 in his revision of the model. Thus, cleavers is a particularly damaging species.

The discussion in the previous paragraph assumes the availability of an effective herbicide for the control of cleavers in rape. At present this is not the case, as no currently approved herbicides will reliably control this weed. Consequently, control must be maximised in the preceding crop. However, a herbicide mixture based on metazachlor and a new herbicide, quinmerac appears to have the potential to control cleavers (Lainsbury & Cornford, 1995). Once this receives approval it will be possible to control cleavers in rape and alternative management strategies could be considered.

5.1.4 Multi-species experiments

Eleven different species, ten broad-leaved weeds and one grass (annual meadow grass) were studied in the four experiments. Full details of the results are given in the four tables in the Appendix. In general, chickweed and charlock produced the largest amounts of biomass and caused the greatest reductions in rape growth, but on some trials red dead-nettle and common field speedwell were also vigorous in April. The other species tended not to produce as much plant material and so were less competitive. Despite the use of appropriately selective herbicides and hand weeding, the indigenous weeds sometimes were rather too vigorous on some plots. These may have influenced the results but have been taken into consideration in the overall assessment of the results given below. Table 14 presents an overview of the results of the four trials, putting the studied species in order of competitiveness (1 = most competitive, 6 = least competitive). There was reasonable conformity between trials with the species tested at more than one site. Cleavers were rated the most competitive followed by chickweed and poppy. The rating for poppy is based on only two trials, as is that for cleavers, and so could be questioned. Unfortunately, the poppies failed to establish at Rothamsted. Charlock was estimated to be high or moderate in its competitive effect, depending on how well it survived the winter. At Rothamsted it was almost as competitive as cleavers, as it survived the winter very successfully, whereas at Morley it was completely killed between January and March, causing it to be much less damaging. Mayweed, red dead-nettle, speedwell and annual meadow-grass were estimated as moderately competitive. Mayweed, which had been investigated in more detail in other trials, never broke through the rape canopy until late summer and was much less competitive than the poppy, which has a similar growth habit. The three prostrate species, speedwell, dead-nettle and meadow-grass, were less aggressive than chickweed and never had as much effect on crop growth as the chickweed. In Aberdeen, shepherd's purse and fumitory, at the high densities tested (265 and 124 plants/m^2, respectively) never affected the rape to any marked extent. This conclusion may have been influenced by the presence of other weeds on these plots and by somewhat uneven weed distribution, and needs confirmation in further trials. Pansy was tested at higher densities than the shepherd's purse and fumitory and it too had little effect on the rape in Aberdeen. Similarly, it was not competitive at Rothamsted. Thus, although the competitive ability rating of the studied species is mainly based on the competitive ability / plant, it also takes some account of the likely densities that can arise in fields in practice.

The relative order of competitiveness of the species derived from the trials is as follows:

Very highly competitive	cleavers
Highly competitive	common poppy, chickweed, (charlock)
Moderately competitive	red dead-nettle, scentless mayweed, common field-speedwell, annual meadow-grass, (charlock)
Poorly competitive	shepherd's purse, fumitory
Very poorly competitive	field pansy

This order equates well with the competitive indices quoted by Munzel (1992) of 4.0 for cleavers, 0.12 for chickweed and 0.03 for mayweed and speedwell (Table 1). He also gives field pansy the same rating as speedwell, which is not in agreement with our conclusions. The order of competitiveness in these trials do differ somewhat from the order derived by Wilson & Wright (1990) for weeds in winter cereals. In their experiments cleavers were the most competitive followed by mayweeds, chickweed, dead nettle and pansy. The high rating for mayweed does not agree with our data. This may relate to the differing growth patterns of rape and wheat and is discussed in more detail in the section on mayweed.

One must conclude from these experiments that farmers should be most concerned about the presence of cleavers, chickweed and poppy and possibly charlock in their winter rape crops. As three of these (cleavers, poppy and charlock) are not easy to control with herbicides approved for use in rape, the practical guidance must be that these species should be fully controlled elsewhere in the rotation. The control of the other species is less important and a more relaxed attitude can be taken, as far as rape yield loss is concerned.

Table 14 **Order of competitiveness and relative competitive abilities of the weeds, based on experiments with more than one species (integrating density and competition/plant)**

Weed Species	Order of competitiveness				Competitive ability
	Rothamsted	Boxworth	Morley	Aberdeen	
chickweed	3	2	1	1	High
field pansy	6			4	Very Low
charlock	2	3	4		High-Mod.*
red dead-nettle	4	4	5		Moderate
common poppy		1	2		High
cleavers	1		(2)+		Very High
mayweed	5	3	5	5	Moderate
field speedwell	(5)+	2	5	2	Moderate
shepherd's purse				5	Low
fumitory				5	Low
a.meadow-grass				3	Moderate

* competitive effect of charlock affected by degree of over-winter survival
\+ data derived from the 1993 Morley experiment

5.2 The effect of crop agronomy on weed competition

5.2.1 Drilling date

Much research has shown that the vigour of the rape crop in autumn and winter is affected by its date of emergence and by temperatures during September and October. Early emergence coupled with high temperatures and, of course, an adequate supply of moisture, will result in a very vigorous rape crop. Conversely, late emergence and low temperatures will reduce rape growth appreciably. Many agronomic and physiological investigations have studied the autumn growth of rape and its subsequent performance in the following spring and summer (Mendham *et al.,* 1981; Jenkins & Leitch, 1986; Leach *et al.*, 1994). This research demonstrates that, despite poorer growth in winter, late sowing does not necessarily result in lower yields. Extrapolation of the conclusions of this research into rape physiology to consideration of the effects of weeds would suggest that less vigorous late-sown rape would be more sensitive to weed competition in the autumn and winter. This conclusion was supported by research in the late 1980s on the competitive effects of volunteer cereals on the growth and yield of rape, which clearly showed that delayed drilling increased the competitive effect of the weeds, such that crops sown at the end of August would tolerate over 100 barley plants/m^2 whilst those sown in mid September, less than 10 plants/m^2 (Lutman, 1991). For similar reasons the Göttingen research group weight their threshold calculations according to the vigour of the crop (Munzel *et al.*, 1992). Prior to the establishment of this research programme little work had been done on the effect of sowing date on competition between rape and broad-leaved weeds but it seemed likely that delayed sowing would increase the competitiveness of the weeds.

Table 15 includes data on the growth of rape in competition with chickweed (four experiments) and cleavers (one experiment). These values are taken from the analyses of the raw data from each trial. In all five trials late sowing resulted in smaller rape in winter and/or early spring. Similarly, there tended to be less weed on the late September sown crops. It must be remembered that the weeds were sown at the same date as the crops and so late-sown crops had late-sown weeds. It was felt that this reflected what would happen in practice, as it is the pre-sowing cultivations that stimulate the weed seeds to germinate. Although there are differences in the proportions of crops and weeds, between the drilling dates, these do not follow any clear pattern. This is reflected in the absence of greater yield reduction from weeds on the latest sowing. There were indications in the Rothamsted trials that late sowing (after mid-September) reduced weed-free yields, but as has been found by other researchers the differences were not great. Detailed comparisons between experiments are confounded by differences in the dates of assessment. This did not matter too much in December, as 10 days span the assessments (4-14 December) and the rape only grows slowly at this time of the year, but in March/April it was of much greater significance, as the spread of sampling dates was longer (22 March - 28 April) and the rape was growing rapidly at this time. Consequently, it is not possible to identify clear differences between experiments.

The conclusion from this series of experiments must be that although delayed sowing reduced crop vigour it did not seem to affect the competitive ability of the weeds. This may be due to the fact that delayed sowing also reduced the growth of the weeds (Table 15). Secondly, in only one comparison (Rothamsted 1994, sown 25 August) was the weight of rape in December in excess of 25g/m^2 and so in all 5 trials rape growth in autumn was very slow. Therefore, it is possible that there was insufficient difference in rape vigour to show increased competition from early established rape. However, in the comparison of all the chickweed experiments there does seem to be a relationship between rape weight in December/January and yield loss caused by chickweed (Fig 2).

Table 15 Effect on sowing date on the growth (g/m^2) and yield (t/ha) of rape and on the competitive effects of weeds

Site	Year	Weed species	Sowing date	Assessment Dec/Jan		Assessment March/April		Yield of weed free rape t/ha	Number of weeds/m^2 causing a 5% yield loss
				Weed free rape weight g/m^2	weight (g) of 100 weeds /m^2	Weed free rape weight g/m^2	weight (g) of 100 weeds /m^2		
Rothamsted	1993	chickweed	3 Sept	20.6	12.3	98.1	145	3.57	2.2
			15 Sept	16.2	7.0	136	148	3.67	8.3
			29 Sept	2.6	1.7	52.4	79.8	3.37	10.8
Rothamsted	1993	cleavers	3 Sept	18.6	1.3*	205	20.7*	3.48	0.5
			15 Sept	16.5	0.6*	204	5.5*	3.92	0.5
			29 Sept	3.4	0.2*	93	5.4*	3.17	1.3
Rothamsted	1994	chickweed	25 Aug.	54.1	30.6	122	74.7	4.11	no values
			7 Sept	17.6	20.6	76.1	60.4	4.19	no values
			23 Sept	2.9	6.7	24.6	43.2	4.08	3.9
Aberdeen	1993	chickweed	28 Aug.	21.2	6.2	161	399	2.29	12.2
			3 Sept	7.5	9.0	190	377	3.02	2.5
Aberdeen	1994	chickweed	30 Aug.	19.0	11.2	81.8	225	5.08	5.7
			6 Sept	10.4	12.0	62.1	237	4.25	3.3
			14 Sept	2.6	8.6	30.0	128	4.70	5.2

* = weight of 5 cleavers/m^2 (not 100 weeds/m^2)

The shape of this response curve is largely dependent on two experiments where the rape was particularly vigorous, but neither included sowing date as one of their treatments. A third relevant factor was the compensatory growth by the later-sown rape during the late spring and summer, which may have reduced differences in yield responses due to sowing date.

This apparent absence of a relationship between sowing date and weed competition conflicts with the conclusions of our earlier work on competition from volunteer cereals, where delayed sowing greatly increases the damage caused by the weeds. Explanation of the lack of a relationship between drilling date and weed competition in the experiments in this programme, in contrast to the research on volunteer cereals seems to be related to the following factors:

a) the low vigour of the rape in autumn/winter at all sowings in the five experiments which included drilling date.

b) the reduced growth of chickweed and cleavers after late sowing, which contrasts with volunteer cereals which seem to have the ability continue to grow at low temperatures.

c) the compensatory growth of the rape in spring and summer.

Further work is needed to resolve this apparent contradiction.

Support for the conclusion that the lack of differences due to drilling date was caused by the overall lack of vigour of the early sown rape in autumn 1991, 92 and 93, is provided by comparisons with other rape experiments. Firstly, the two chickweed experiments (RES 91, AB 92), which produced the most vigorous rape crops, clearly reduced the competitive effect of chickweed (Fig 2). Secondly, the weight of early sown rape in other autumns has been shown frequently to exceed 150 g/m^2 by early December and in some cases to exceed 300 g/m^2 (Leach *et al.*, 1994; Lutman & Dixon, 1990). In these experiments delayed sowing reduced rape weights by at least 50% and in some cases by 75%, causing dramatic differences in rape's competitive ability in the winter. The differences in competitive ability of rape weighing 20g/m^2 in December and that weighing 7 g/m^2 were small, in contrast to the differences seen in the other experiments discussed above. The poor growth of the early sown rape seems to be associated with the cool conditions experienced in autumn 1991, 1992 and 1993. This has been discussed in the section reviewing the competitive effects of chickweed.

In spite of the results of the five experiments that studied drilling date, we still believe that early sown rape is likely to be more suppressive of weeds than late sown crops, provided the early sown crops form large and vigorously competitive plants.

5.2.2 Crop density

Crop density as well as sowing date can influence the water, nutrients and light available to weeds. Thus, a thin stand of large plants may well have similar effects on the weeds as a denser stand of smaller plants. Invariably when asked to comment on crop vigour, observers will integrate in their mind size and density. Attempts to disentangle the effects of density can be confounded by differences in crop vigour. A series of ADAS experiments reported by Sansome (1991) investigated the effects of crop density on weed competition and yields. He reported that weed densities were lower on plots with higher crop densities, but there was no clear response of the crop to the increased weediness of the lower density plots. There were indications in the data of small yield increases in the absence of weeds at the higher densities. Because of the compensatory ability of oilseed rape, agronomic experiments have frequently shown the absence of a yield response to increasing crop densities once they exceed 40 - 60 plants/m^2 (Ogilvy, 1984). At low densities yields can be reduced as a result of uneven distribution and if this can be avoided then densities of less than 10 plants/m^2 can be as productive as 100 plants/m^2 (Scott *et al.*, 1994). Thus, in the absence of weeds, crop density has little effect on rape yields.

The effects of crop density on weed competition was studied in the three Boxworth experiments in this programme. Unfortunately, the 1994 experiment produced little useful data, because of the failure of the weeds to establish, except to show that increases in crop density from 54 to 222 plants/m^2 increased crop yields significantly from 0.98 to 1.46 t/ha. Both the 1992 and 1993 experiments confirmed the results from Sansome (1991), as there was less weed and more rape on the higher density rape plots (Table 16). These differences did not result in large differences in crop yields. In 1992, the mayweeds were never very competitive and there were only indications of yield losses at the lowest density. In 1993, the mayweed again had little effect on crop yields and although the chickweed caused marked reductions, the % yield losses were similar at all three crop densities. There were, however, indications of higher yields on the weed-free plots at the higher densities, in both trials. Similar experiments carried out by Küst (1989) with volunteer cereals showed that crop competition was slightly greater at higher crop densities.

In conclusion, it appears that crop density will have only a small effect on competition from weeds. Crop vigour is of greater importance than plant numbers/m^2.

Table 16 <u>The effect of crop density on the competitive effects of 100 or 200 mayweed and 100 chickweed plants/m^2 on rape growth and yields</u> (Boxworth 1992 and 1993)

Year	Rape (plants /m^2)	Plant weights (g/m^2) (Dec/Jan)			Plant weights (g/m^2) March/April			Rape yields (t/ha)		
		weed -free rape	chick weed (100 /m^2)	may-weed (no*/ m^2)	weed -free rape	chick weed (100 /m^2)	may-weed (no* /m^2)	weed -free rape	with may-weed	with chick weed
1992	21	5.7		1.9	52		49	2.25	1.59	
	37	10.3		1.9	88		32	2.30	2.30	
	67	18.2		1.7	136		28	2.48	2.48	
1993	44	45	34	14.3	325	295	46	3.54	3.24	2.53
	70	65	28	6.1	402	226	37	3.93	3.73	3.13
	113	74	13	3.8	401	205	17	4.13	3.88	3.05

* Estimates of crop yields and mayweed weights based on 100 mayweed plants/m^2 in 1992 and 200 plants/m^2 in 1993

5.2.3 Fertility levels

There has been some discussion in other crops, such as winter wheat, as to the advantages/disadvantages of applying extra fertiliser, particularly nitrogen to suppress weeds. It is clear that there is no general answer to this question. Some weed species are particularly nitrophilic and in winter wheat there is clear evidence that extra nitrogen increases the competitive effects of wild oats and cleavers, but decreases the effects of some other, less aggressive weeds (Wright & Wilson, 1992). In rape there are two aspects that need to be considered. Firstly, does a small amount of autumn nitrogen improve the competitive status of the rape? Secondly, do differences in spring nitrogen levels affect weed competition? Previous work in this area in relation to weed competition has been limited, although the effects of autumn and spring nitrogen on rape growth and yields has been intensively studied. Although autumn nitrogen does increase rape growth it is currently not considered economic, unless the autumn growth of the crop is poor and the overwinter survival of the small plants is in jeopardy. Some earlier work with volunteer barley in rape (Lutman, 1989) indicated that added nitrogen increased the growth of both crop and volunteer weed and so, as the proportions remained the same, had no effect on weed competition. The response of rape to spring nitrogen application is very rapid, once temperatures increase and so for many weeds the nitrogen level is not particularly important. An exception to this conclusion may be chickweed, which also has the ability to grow very rapidly in response to spring nitrogen. Two experiments at Morley (1993 and 1994) and one at Boxworth (1993) examined differences in nitrogen treatments.

The Boxworth experiment looked at the effect of an application of 40 kg/ha nitrogen in the autumn on the competitive effects of chickweed. Both species had higher weights in December after the application of 40 kg/ha N but the chickweed responded more to the added nitrogen than the rape (Table 16). Similarly in April, the rape in the absence of chickweed was bigger when it received the autumn nitrogen. The chickweed was also bigger and there were indications that it might be more competitive at the higher N level. However, no clear trend in the yield response was discernable and so it appears that extra nitrogen in the autumn did not affect yield reductions caused by chickweed. Neither did the additional nitrogen increase weed-free rape yields.

In the two Morley experiments spring nitrogen was reduced from a standard 200 kg/ha to only 130 kg/ha. The reduction in nitrogen reduced rape and chickweed weights in April on both experiments (Tables 17, 18). It also reduced weed-free yields in both experiments and in one experiment (1994) significantly increased the yield loss caused by the weeds. In the other experiment yield losses were similar at both nitrogen levels. So one must conclude that high levels of spring nitrogen are unlikely to increase yield losses from chickweed.

Table 16 **Effect of additional nitrogen on the competitive ability of chickweed at 12 and 1271 plants/m² at Boxworth in 1993. (Data = dry weights of rape and chickweed in December and April (g/m²), and crop yields (t/ha)**

	Chick-weed Density	Normal nitrogen			Additional nitrogen		
		Rape plants/m²			Rape plants/m²		
		44	70	113	44	70	113
17 December Rape weight	12	44	69	77	57	96	131
	1271	35	50	59	51	58	82
	s.e.d. = 12.3⁺						
17 December Chickweed weight	12	0	0	0	0	0	0
	1271	80	53	61	128	132	157
	s.e.d. = 17.9						
6 April Rape weight	12	283	408	380	465	491	473
	1271	196	202	179	206	169	224
	s.e.d. = 36.4						
6 April Chickweed weight	12	0	0	0	0	0	0
	1271	308	313	287	455	478	376
	s.e.d. = 46.8						
Rape yields	12	3.65	3.95	4.02	3.76	3.82	3.79
	1271	2.56 (70)*	2.51 (63)	2.29 (57)	2.12 (56)	2.47 (65)	2.86 (75)
	s.e.d. = 0.29						

* Figures in brackets are yields as a % of weed-free yield
\+ s.e.d. = standard error of a difference between two means

Table 17 **The effects of spring nitrogen level (200 or 130 kg/ha) on the dry weights of rape and weeds in April and on rape seed yields at Morley in 1993 (weed-free and high weed density treatments only)**

Weed	Plants/m^2	130 kg/ha N		200 kg/ha N	
		Rape	Weeds	Rape	Weeds
April dry weights (g/m^2) (s.e.d. rape wgts = 41.2, weed wgts = 52.0)					
Chickweed	10	219	72	296	69
	1037	56	355	81	477
Cleavers	0	262	81	271	81
	34	185	109	270	115
Seed yields (t/ha) (s.e.d. yields = 0.31 t/ha)					
Chickweed	10	3.08		4.14	
	1037	0.77 (75)*		1.15 (72)	
Cleavers	0	3.17		3.97	
	34	2.79 (12)		3.23 (19)	

* Figures in brackets are the % yield losses caused by the weeds

Table 18 **Comparison of the effects of normal (198 kg/ha) and reduced level (128 kg/ha) of nitrogen on the competition between rape and chickweed at Morley in 1994. Data are plant dry weights in April (g/m^2) and rape seed yields (t/ha), for weed-free plots and those with approximately 800 chickweed plants/m^2**

Date	Plant species	Normal nitrogen		Low nitrogen		s.e.d.
		Weed-free	+ Chick-weed	Weed-free	+ Chick-weed	
11 April	Rape	268	39.8	223	31.1	30.2
	Chickweed	216	328	121	300	61.4
Yields	Rape	3.98	2.15	3.50	1.34	0.29
% yield loss			46.0		61.7	

5.3 Prediction of yield responses

In order for the farmer to be able to optimise his weed control strategies he needs some information on the likely damage that the weeds will cause to the crop. This generally means some form of prediction of potential yield loss, crop contamination, and harvesting difficulties. There has been considerable research interest in how to successfully predict yield losses caused by weed competition. The majority of studies have attempted to relate yields to weed density and it is now generally accepted that a hyperbolic model is most appropriate (Cousens, 1985). Although this model is often good at describing the responses in individual situations, it is not so good at predicting responses in others. There is often considerable variation between sites and years in the shape of the response curve, so predictions based on one site are not relevant for others. Some reduction in this variability can be achieved by adjusting the density/yield loss relationship to take account of relative times of emergence (Cousens *et al.* 1987). However, even with this improvement, there is often considerable variation in responses to given weed densities, between sites.

Despite the problems associated with the relationship between weed density and yields most of the data presented in this report has attempted to use this relationship, using the Cousens hyperbolic model (see Materials and Methods). This approach to the study of weed competition is still the accepted approach and is still widely used. As can be seen from the chickweed data there are very large differences between experiments in the number of weeds causing a standard level of yield loss (Table 8, Fig. 1). More detailed study of the data suggests that some of the variation can be attributed to the vigour of the crop, as estimated by dry weight (Fig 2), high vigour resulting in less competition from the chickweed. Consequently, it will be very difficult to reach precise guidelines on the potential yield loss caused by different levels of chickweed, without taking account of crop vigour. This requirement for an assessment of crop vigour also features in the Göttingen system for predicting the level of weed control needed in oilseed rape (Munzel *et al.*, 1992; Bodendörfer *et al.*, 1994).

However, the weed density / yield loss relationships presented in this report do provide data on which to base some more general guidelines on the likely effects of infestations of common weeds in winter rape. This has been possible for the intensively studied species (chickweed, mayweed and cleavers). In addition, broad indications of relative competitive abilities of a wider range of species have been identified from the four 'multi-species' experiments.

The reasons for the variation in responses of the rape to weed density can be attributed to two factors:

a) predictions of yield responses based solely on weed density take no account of the relative vigour of the crop and weed.

b) the predictions of likely yield effects in winter rape have to be made in early autumn and the crop will not be harvested until 9-10 months later, providing considerable potential for variation in subsequent crop growth to nullify the accuracy of the prediction.

In recent years there has been much interest in relating yield losses caused by weeds to the relative leaf areas of crops and weeds, early in the growing season. Kropff & Spitters (1991) proposed that the proportion of plant leaf area attributable to weeds, at early growth stages, correlated well with yield responses. Subsequent research with several spring planted crops (sugar beet, spring cereals) has indicated that their relative leaf area model does provide more accurate prediction of yield responses (eg Lotz *et al.* 1994). The predictions are not completely reliable, but they are an improvement on predictions based on weed density. Current research is investigating the reasons for the remaining variability. However, a practical problem remains; how does the farmer or advisor assess relative leaf areas in the field? There is some indication that relative ground cover fits the Kropff & Spitters model as well as relative leaf area, at early growth stages, and it would be possible for users to visually assess relative ground cover. Alternatively, infra-red detection systems may have potential for mechanising this task. The problem with using subjective visual assessments is the unreliability of assessors. Lotz *et al.* (1994) concluded that visual assessments were too inaccurate to be viable tools, but our work in other crops (Lutman, 1992), indicated that experienced observers could achieve reasonable accuracy.

In an attempt to investigate the value of the relative leaf area model for predicting yield responses in these rape experiments two approaches have been studied. Firstly, the dry weight data collected in December/January from the chickweed experiments has been re-interpreted to estimate the % weed weight in the total plant dry weight (weed weight/m^2/(crop + weed weight/m^2) x100). These % values have been regressed against yield responses using the hyperbolic response curve and the % weed dry weight causing a 5% yield loss calculated. These analyses were done because we believed that, at early stages of growth, dry weight equated well with leaf area and so the basic mechanism of the leaf area model should apply to dry weights. The variation in the yield losses predicted by relative dry weights and the quality of the regression models have been compared with the yield loss predictions based on weed density (Table 8, Figs 1 & 3). The results clearly show that the % dry weights causing 5% yield loss were much less variable than the weed densities causing the same effects. The % dry weights causing a 5% yield varied from 0.5 - 9.4%, whereas the weed densities causing the same effect ranged from 1.4 to 348 plants/m^2, across the 17 comparisons. The relative dry weights removed the extreme variation in the density responses caused by the very high vigour of the rape on two sites. In the majority of cases the % variation accounted for by the model was higher for the % dry weight values. Predictions based on relative dry weights do seem to offer a greater potential for reliability than those based on weed density, but further work is needed to see how this type of assessment could be converted into a farmer usable system.

5.3.1 Visual assessments of ground cover

In a second approach to the study of the potential of the relative leaf area model, visual assessments of ground cover were done on all trials during the autumn and winter. The subjectivity of these data gives cause for concern and as an exercise to estimate the level of variation between assessors, the four site coordinators met at Boxworth in December 92 and independently scored the ground cover on the Boxworth experiment. There was an extremely high degree of variation in the ground cover assessments. Two assessors scored much higher than the other two. On some plots there was more than 20% difference in the estimated weed cover between assessors. Using the % weed dry weight values (see above) collected from the plots in the same month as a fixed base, the % weed covers from the visual scores of the four assessors were regressed against the % dry weight values. Table 19 shows the relationships between the % covers from the visual assessments at 10, 20, 40 and 60% relative dry weights. There was a hyperbolic relationship between the two assessments for all assessors. It is probable that relative cover and relative dry weights did not estimate similar aspects of plant growth. For example, rape with a strongly developed stem would have a higher relative dry weight than leaf ground cover. However, even if 40% cover was not expected from 40% relative dry weight, the four assessors should have given similar results, if their estimates of cover had all been accurate. The results show high variability between assessors. There was at least 10% difference between the highest and lowest assessors. Thus, a 20% relative chickweed dry weight was equated to 42, 43, 29 and 30% chickweed relative ground cover, by the four assessors. Despite these differences all the visual assessments correlated well with the % dry weights, as is shown by the high % variability accounted for by the hyperbolic model. The assessors were therefore consistently different. It seems that the visual assessors were perceiving substantially different % cover values on the same plots. Direct comparisons of the % cover recorded by the 4 assessors clearly show a linear relationship, suggesting that assessors that scored low on a low weed density plot also scored low on a high density plot. Some of the assessors had not done this type of assessment before and so it seems probable that some form of training will be needed to enable observers to produce reliable assessments of cover. This possibility is being investigated in a current research programme at Rothamsted.

Table 19 **Relationship between the relative dry weight of chickweed in December 92 Boxworth experiment and its relative ground cover visually assessed by four observers. Standard % dry weight values were 10, 20, 40, 60%**

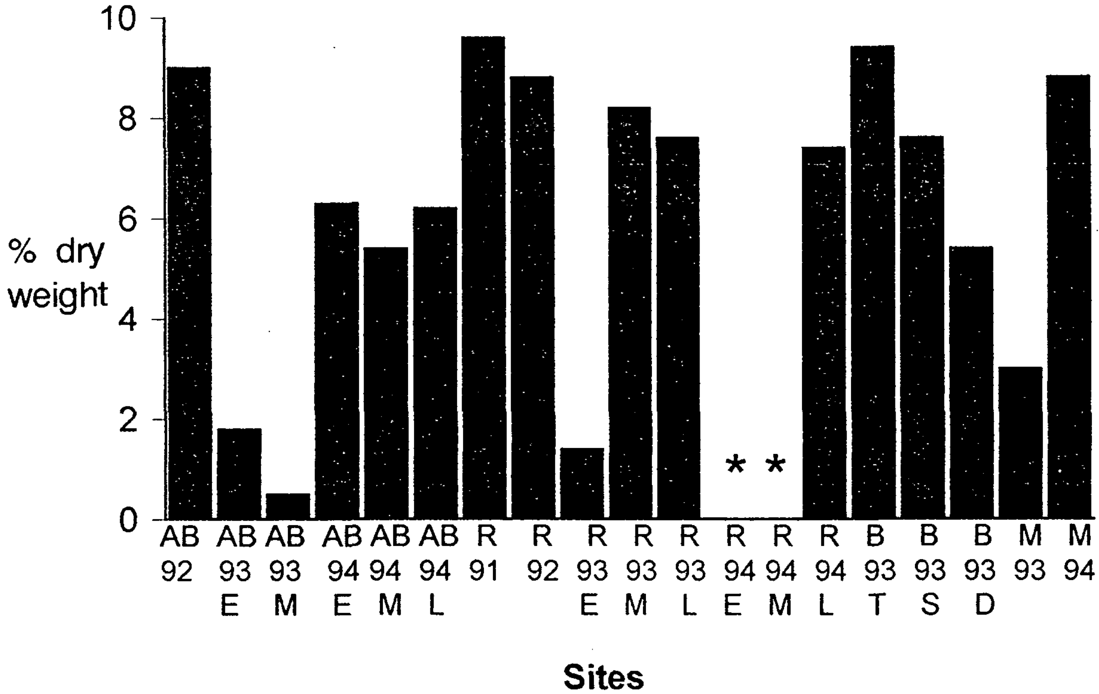
Observers	% va*	% Weed from December dry weight			
		10	20	40	60
1	94	27	42	58	67
2	90	26	43	64	75
3	89	17	29	46	58
4	91	17	30	48	60

* %va = % of variation in the data accounted for by the regression model

Because of the variation between assessors and concern over the accuracy of visual assessments no further use has been made of the visual assessments carried out on all trials, in this report.

The use of a predictive system of weed management in winter rape has a number of problems. The difficulty of developing a reliable practical method of assessing relative weed growth either by leaf areas, ground cover or reflectance has been discussed above. Even if/when a practical method is developed, problems remain for this crop. The predictions must be carried out early in the autumn, as this is the time when most herbicides are applied. If the farmer is using post-emergence metazachlor, for example, the prediction would have to be done in September. If pre-emergence herbicides are to be used, no prediction can be attempted except on the basis of weed infestations in the previous crop. Even if herbicide application was to be carried out in October or November, the prediction of yield response would have to remain valid for the following 9 months. The plasticity of oilseed rape is well-known and can be seen in these trials in the similarity in yields of crops of greatly different vigour in the autumn and winter. This problem is not so severe in other autumn sown crops (eg cereals) where weed control is commonly carried out in spring.

Fig.3 The relative % dry weight of chickweed in December/January to cause a 5% reduction in rape yield



Sites: Ab = Aberdeen, R = Rothamsted, B = Boxworth, M = Morley
Agronomy: E = early, M = mid, L = late drilled
T = low, S = standard, D = high crop density

* no relationship between density and yield loss

In conclusion it seems that the precise prediction of yield responses of winter oilseed rape is unlikely in the foreseeable future, because of:

a) the lack of reliable assessment methods for determining relative weed growth and relating this to yields

b) the long period between assessment and harvest, leading to a high possibility of a failure of prediction due to differences in post-prediction crop growth

c) the lack of broad-spectrum late post-emergence herbicides.

Even if a), above, was achieved the problems with b) and c) would make the practical use of such predictions unlikely. However, general guidance on the relative importance of weed species in this crop can be given, based on the data collected in this series of experiments and other published data. This has been discussed in an earlier section of this report.

5.4 Economics of weed control

It has not been possible to fully evaluate the economic consequences of the presence of weeds. Estimates have been made in each experiment of the weed infestations causing a 5% yield loss or a loss of 0.2 t/ha. Because of the steepness of the response curves, for many of the experiments the two values were quite close. This level of yield loss was chosen because it approximated to the cost of a broad-leaved weed herbicide, at the current price of oilseed rape and average yields (see section 4.2). Inevitably the 'threshold' level of crop yield loss will vary depending on the value of the crop, the potential yield and the price of the herbicide to be used. Some attempt has been made in the German model RAPUS (Bodendörfer *et al.* 1994) to address these issues and they also investigated the effects of extra drying and cleaning costs arising from the presence of cleavers. It would not be difficult to create a similar economic framework for UK conditions, but it would require further funding. Some discussion of the economics of weed control has been attempted in recent papers by Bowerman *et al.* (1994) and by Palmer & Strachan (1994). If the rape price per tonne declines or if the rape is low yielding the level of weed infestation that it is not economic to treat increases. Despite changes in the CAP in recent years, the price of rape in 1994/5 has not been greatly reduced over that common earlier in this decade. If this situation changes, then the need for broad-leaved weed control will have to be considered more carefully.

6. CONCLUSIONS

It is clear when considering the three aims of the programme outlined at the beginning of this report that progress has been made in all areas, but has been greater in some than in others. The problem of variability in rape. highlighted by Scarisbrick *et al.* in 1984 and reiterated ten years later by Leach *et al.* in 1994, remains a feature of current research. It is difficult to carry out detailed experiments in such a way that the treatments have a repeatable effect. In our experiments the weeds did not always 'behave' as we expected. The reason for recording crop and weed weights in winter and early spring was to try to collect information that would help in the interpretation of the yield responses recorded at harvest. In most experiments the body of data does provide a logical explanation of the yield responses recorded.

6.1 Weed competition

When the programme began we believed that many herbicide treatments for the control of broad-leaved weeds were not cost-effective. That is, the yield increase from the control of weeds was less than the cost of the herbicide. Earlier experiments, although limited, all tended to create this impression. After three years work I think we would conclude that **some** herbicide treatments are still uneconomic, but not all.

Chickweed The competitive effect of the chickweed in the ten experiments that included detailed studies of this weed was surprisingly high. The 5% yield loss values shown in Fig 1 and Table 7 are in most cases very low; 10-20 chickweed plants/m^2 causing this level of yield loss. As chickweed densities in autumn are frequently several hundred/m^2 it seems highly likely that this weed is 'worthy of treatment' in most situations. A range of herbicides is available for the control of chickweed but the key ones would be metazachlor, benazolin + clopyralid and propyzamide. Full rates of all three are relatively costly but it appears that the expense is often justified. Reduced rates of metazachlor appear particularly attractive for this weed (Lutman 1991, Palmer & Strachan, 1994). However, one must treat this conclusion with a little caution because of the caveat I alluded to at the beginning of this section, relating to variability in rape. In two of the comparisons shown in Table 8, considerable populations of chickweed had minor effects on yields. These were sites where the rape was most vigorous. So it appears that rape vigour is a key element in determining the effects of chickweed. This will be discussed further in the conclusions related to crop agronomy.

Scentless mayweed In contrast to chickweed, this weed was not very competitive in the three of the four experiments that studied this species in detail. It was also poorly competitive in the four multi-species experiments. The reason seemed to be that the plants were rarely able to break through the rape leaf canopy in spring or early summer and so were unable to affect the growth of the rape plants. In only one trial was it highly competitive and in this the growth of the rape was retarded by a cool autumn followed by grazing by rabbits. This weed is less competitive than chickweed and so densities of even 100 plants/m^2 were unlikely to affect yields to such an extent that they would warrant treatment with a herbicide containing clopyralid.

Cleavers This weed has a two-fold effect on the crop, as it will seriously reduce yields and contaminate the harvested crop, incurring extra cleaning and drying costs. Because of the difficulty of cleaning out all the cleavers, a seriously contaminated crop might still incur price penalties from the purchasers. Substantial yield losses will occur with this weed at densities of less than 10 plants/m^2 and sometimes less than 1 plant/m^2. These levels of infestation also caused serious contamination problems. In reality, if cleavers are present in the field they should be treated with herbicides to prevent economic penalties. However, no currently available herbicides are fully effective on this weed. No product will give the level of control of cleavers achieved by fluroxypyr in cereals. So, the message for this weed must be to minimise the infestation in rape by maximising control in preceding cereal(s) or even set-aside. Better control of cleavers may be possible in the future, when the BASF development product based on a mixture of metazachlor and quinmerac (Lainsbury & Cornford, 1995) receives approval.

Other broad leaved weeds Eight other species were studied in less detail in 1994. It is not possible to give detailed recommendations but the following would be their relative order of competitiveness, based on Table 14.

Very highly competitive	cleavers
Highly competitive	poppy, chickweed, (charlock)
Moderately competitive	red dead-nettle, mayweed, speedwell, annual meadow-grass, (charlock)
Poorly competitive	shepherd's purse, fumitory
Very poorly competitive	pansy

Cleavers were the most damaging species. The damage caused by chickweed, poppy and charlock can be high, but the effects of the latter depends on how well it survives the winter, as it is frost sensitive. Red dead-nettle is nowhere near as competitive as chickweed and would be on a par with speedwell. The position of shepherd's purse and fumitory is based only on one trial and so should be treated with caution. Pansies were not competitive.

6.2 Effects of crop agronomy

It is clear from the trials that crop vigour is a key factor in determining the effects of weeds. It could be concluded that weed control decisions could be purely based on the vigour of the crop. The more vigorous the crop in winter and spring, the less the need for weed control, irrespective of species and level of weed infestation. This is an over-simplification but contains a large element of truth. Previous work on the competitive effects of grass weeds and volunteer cereals showed this effect quite clearly. The aim of the agronomic studies in this programme was to try to identify more clearly how agronomic factors affecting crop vigour influenced the competitive behaviour of broad-leaved weeds. However climatic factors in 1991 - 1994 appear to have played a major role in influencing the results of the experiments. The autumns of 1991, 92 and 93 were particularly cool and wet and as a result the growth of the rape in the autumn and winter, in most experiments, was poor, irrespective of the sowing date and crop density. Subsequently, because of the mild winters, the crops were able to recover from their poor start. As discussed in section 5.2, it was rare for the rape in our experiments to exceed 50 g/m^2 in December and in many it did not exceed 20 g/m^2. In earlier years, as shown in reports of experiments carried out at that time, crop growth often reached 150 g/m^2 and sometimes 200 g/m^2. (eg Leach *et al.* 1994). This general lack of crop vigour may have influenced the conclusions of the experiments.

Sowing date Five experiments studied the effect of delayed drilling on the competitiveness of the rape. In all of them late drilling resulted in smaller rape plants in the autumn and winter (Table 15). But, as discussed above, even the early sown crops were not particularly vigorous. Despite the differences in vigour between the early and late sown crops there was no evidence that this resulted in greater competition from the studied chickweed and cleavers. Late drilling also seemed to reduce the vigour of the weeds and so the relative balance remained the same.

Crop density Intuitively one might expect that when the number of crop plants is reduced there is more room for the weeds to flourish. In general this is true but the compensatory ability of the rape often results in only small differences in crop biomass at widely ranging densities. However, the two experiments that studied this at Boxworth did indicate that very low crop densities could cause a slightly greater competitive effect from the weeds. This should not be considered a major effect and poor establishment, except when densities are appreciably lower than 40 plants/m^2, are unlikely to cause increased weed damage. The vigour of the plants is of greater importance than the number.

Nitrogen Although currently not considered cost-effective in terms of yield improvement, autumn nitrogen can increase crop vigour at this time of the year and thus may have a beneficial effect on the crop's ability to compete with weeds. Limited evidence from this research programme, which confirms earlier work, indicates that autumn nitrogen, although increasing crop vigour, also increased weed vigour and so did not influence the competitive balance. This research was based on chickweed, a particularly nitrophilic species, so other weeds might be less able to respond to the nitrogen and would be more suppressed. This would require further study. Manipulation of spring nitrogen in two other experiments provided no support for the theory that weeds such as chickweed would be more competitive at high nitrogen levels. The evidence from the two experiments would be that the reverse might be true.

The conclusion from this facet of the programme is that crop vigour, as influenced by crop agronomy, drilling date, crop density and nitrogen level, only had small effects on the competitive ability of the weeds. However, because of the overall relatively poor vigour of the rape in all the experiments that studied agronomic factors, during the critical periods in autumn, winter and early spring, it is still possible that such techniques as early drilling, which tend to result in most vigorous crops, would often improve the crops ability to suppress weeds. This trend in most clearly seen in Fig 2.

6.3 Predicting yield losses from weeds

In other crops some attempts have been made to predict yield response from early assessments of weeds, based either on assessments of weed density or on the relative vigour of the crop and weeds. This has met with some success, but still requires further development to establish practical methods of assessment. In winter cereals it is possible to do predictive assessments in early spring, as many herbicides can still be used at this time. This identifies the first problem of predicting the effects of weeds on rape yields, most assessments would have to be done in early autumn, as most herbicides are applied at this time. Therefore the period between assessment and harvest is much longer, than in winter cereals. Secondly, it is still not really possible to estimate yields in rape from the vigour of the crop in the autumn or winter, even in the absence of weeds, because of the crops large compensatory ability in summer. Despite these problems it is clear from Fig. 3 that yield responses to chickweed could be related to the relative biomass of weeds in December. This was a much better estimate of likely yield responses than weed numbers. Thus when chickweed biomass exceeded 10% of the total dry weight of plant material in December, yield losses of at least 5% could be expected. This may not be a very practical method of assessing weed vigour but it does indicate that the technique of relating yield loss to relative weed vigour does have some potential that could be developed in subsequent research. Attempts to estimate weed vigour visually were not so successful, because of variation between assessors, but the potential of this method also warrants further study.

At the moment it is not possible to predict yield loss from weeds, based on relative vigour, but this may be possible in future. Our work has already shown that it seems to be more accurate than predictions based on weed numbers. However, as other methods of assessment are not yet fully developed, weed density was used as the basis for most comparisons of weed competition. It is still the standard method used to estimate biological and economic effects of weeds. The estimates of yield loss caused by the weeds may not be very precise but they do indicate the approximate densities that have a high probability of causing an economic loss of yield. (see Section 6.1, above). Further analysis of the ground cover data generated in this programme is required to determine their potential to predict yield responses. Research on alternative methods to predict yield responses to weeds, from assessments early in the growth of the crop, are in progress in other crops.

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8. APPENDICES - DETAILS OF MULTI-SPECIES EXPERIMENTS

8.1 Aberdeen

Table 20 **The effect of competition from two densities of seven weed species on the weight of rape and weeds in December and April (g/m^2) and on rape yields (t/ha) (figures in bold are significantly different from the weed-free values)**

Weed species		Weed density (plants $/m^2$)	Sample dry wgts (16 December)			Sample dry weights (21 April)			Rape seed yields (t/ha)
			Rape	Sown weed	Total weed	Rape	Sown weed	Total weed	
Chickweed	L+	152	20.8	**7.55**	8.9	43.7	**527**	**642**	**1.89**
	H	320	13.7	**13.6**	**14.6**	**20.4**	**350**	**396**	**1.77**
Mayweed	L	3.0	18.7	0.03	10.3	75.0	0.7	83	3.47
	H	50	20.9	0.09	12.7	164	12.0	119	3.59
Speedwell	L	160	18.0	0.15	5.1	96.3	76.2	103	3.95
	H	728	17.7	**12.0**	**19.6**	35.3	**312**	**356**	**2.16**
Pansy	L	179	19.1	0.10	**22.7**	78.2	6.5	144	**2.56**
	H	748	25.0	1.59	9.9	82.3	75.7	180	**2.89**
Fumitory	L	35	23.5	0.07	2.1	179	0.2	50	4.47
	H	124	19.4	1.61	10.9	56.1	13.6	110	3.00
Shepherd's purse	L	33	25.8	0.06	5.1	97.3	0.4	78	4.40
	H	265	18.1	2.86	**13.2**	96.8	29.9	106	3.35
Annual meadow grass	L	292	31.2	1.60	6.1	148	46.1	156	3.40
	H	773	**11.2**	**7.43**	**25.5**	67.0	**194**	214	**2.87**
Weed-free*		0	22.3		1.2	119		30	4.67
s.e.d.			5.81	3.34	5.80	49.4	52.0	120	0.78

\+ L = low sown weed density, H= high sown weed density
* weed-free plots were treated with metazachlor

8.2 Boxworth

Table 21 The effect of competition from two densities of six weed species on the weight of rape and weeds in January and April (g/m²) and on rape yields (t/ha) (figures in bold are significantly different from the weed-free values)

Weed species		Weed density (plants /m²)	Sample dry wgts (11 January)			Sample dry weights (25 April)			Rape seed yields (t/ha)
			Rape	Sown Weed	Chick -weed	Rape	Sown weed	Other weed	
Chickweed	L+	132	9.6	**11.0**	-	251	**337**	1.4	**0.81**
	H	350	5.3	**53.6**	-	153	**364**	2.3	**0.40**
Mayweed	L	8.7	11.4	0	8.3	435	0.4	82.0	1.69
	H	20.1	11.5	0.2	10.4	242	3.6	111	1.22
Speedwell	L	55	10.4	5.7	10.9	246	**154**	45.3	**0.92**
	H	494	6.2	**19.1**	7.7	146	**347**	6.5	**0.57**
Charlock	L	17.7	7.3	**11.8**	10.5	115	**290**	37.7	1.10x
	H	66.4	6.0	**27.9**	7.3	**84**	**432**	34.2	1.19x
Dead-nettle	L	14.4	10.4	0.4	8.9	317	30.9	80.7	1.40
	H	134	11.7	3.5	7.8	194	106	81.3	**0.90**
Poppy	L	3.3	12.0	0.5	12.9	290	45.8	73.7	1.06
	H	35.1	5.1	0.6	6.9	202	66.2	59.2	**0.60**
Weed-free	OS	0	7.2		5.4	222		88.2	1.34
	OU	0	9.2		9.3	259		289	**0.87**
Mean weed-free		0	8.2		7.4	241			(1.49)*
s.e.d.			2.89	3.91	4.49	65.5	53.2	43.4	0.22

\+ L = low weed density, H= high weed density, OU = unsprayed weed-free plot, OS = weed-free plot treated with benazolin + clopyralid

* = mean yield of sprayed weed-free, mayweed and cleaver plots

x = Rape yields on charlock plots contain approximately 11 % of charlock seeds

8.3 Morley

Table 22 The effect of competition from two densities of six weed species on the weight of rape and weeds in January and April (g/m²) and on rape yields (t/ha) (figures in bold are significantly different from the weed-free values)

Weed species		Weed density (plants /m²)	Sample dry wgts (14 January)		Sample dry weights (11 April)		Rape seed yields (t/ha)
			Rape	Weeds	Rape	Sown weeds	
Chickweed	L+	155	29.9	31.7	**91.5**	**443**	**2.70**
	H	620	**21.7**	**115.5**	**127**	**464**	**2.37**
Mayweed	L	56	38.9	1.3	350	50	4.17
	H	156	34.2	6.6	255	**227**	3.20
Speedwell	L	96	55.3	9.0	**230**	113	4.11
	H	795	**20.4**	**49.7**	**191**	**142**	3.45
Charlock	L	123	**23.9**	**75.0**	**221**	83	3.52x
	H	276	**10.1**	**66.9**	**71.6**	77	3.21x
Dead-nettle	L	104	49.3	11.2	**248**	**130**	3.77
	H	542	29.7	**83.1**	**170**	**296**	**3.07**
Poppy	L	205	33.7	12.8	**165**	**160**	**3.07**
	H	496	38.3	27.2	**254**	**259**	**3.17**
Weed-free		0	49.2	3.4	378	82	3.89
s.e.d.			9.8	15.1	47.5	56.9	0.32

\+ L = low weed density, H= high weed density,
x Rape yields of charlock plots contain an unknown % of charlock seeds

8.4 Rothamsted

Table 23 The effect of competition from two densities of seven weed species on the weight of rape and weeds in December and April (g/m^2) and on rape yields (t/ha) **(figures in bold are significantly different from the weed-free values)**

Weed species		Weed density (plants/ m^2)	Sample dry wgts (13 December)		Sample dry weights (7 April)			Sample dry weights (1 June)			Rape seed yields (t/ha)
			Rape	Sown Weeds	Rape	Sown weeds	Total weeds	Rape	Sown weeds	Total weeds	
Chickweed	L+	59	30.4	**15.9**	**185**	**175**	**183**	**628**	**204**	**206**	**3.19**
	H	328	**15.3**	**24.1**	**142**	**183**	**193**	**544**	**171**	**184**	**3.45**
Cleavers	L	1.4	21.5	0.2	249	5.8	58.5				3.72
	H	6.3	30.7	0.7	270	7.3	63.4	767	88.3	160	**2.42**
Mayweed	L	59	33.7	3.7	261	26.6	65.1				3.94
	H	210	32.2	7.0	208	58.4	113	757	10.8	70.7	4.08
Pansy	L	84	30.6	1.3	284	12.5	58.3				4.02
	H	666	35.3	9.3	295	26.3	56.7	777	16.8	115	3.89
Charlock	L	16	19.9	**21.3**	**159**	**131**	**165**	**567**	**368**	**379**	**2.25**
	H	124	**10.3**	**106**	**70**	**264**	**303**	**199**	**581**	**608**	**0.83**
Dead-nettle	L	42	27.1	3.9	233	26.0	80.3				3.99
	H	294	29.2	12.3	**165**	**163**	**197**	**679**	113	126	**3.42**
Poppy	L	0	21.8		275		65.7				4.07
	H	0	33.4		247		66.9				4.05
Weed-free	OU	0	28.8		252		123				(3.25)
	OS	0	33.6		303		38.6	874		75.3	3.91
Mean weed-free		0	(29.4)*		(269)*		(73.5)*				(4.01)x
s.e.d.			5.27	7.35	27.1	27.9	25.3	91.0	81.3	77.9	0.24

\+ L = low weed density, H = high weed density, OU = unsprayed weed-free plot, OS = weed-free plot treated with propyzamide

* = mean weight of weed-free and poppy plots: x = mean weight of weed-free and poppy plots (excluding treatment OU)