Project Report No. 397

August 2006

Price: £6.50

Effects of husbandry factors and harvest method and timing on oil content and chlorophyll retention in rapeseed

by

S Knight[1] and I J Bingham[2]

[1] The Arable Group, The Old Rectory, Morley, Wymondham, Norfolk, NR18 9DB
[2]SAC, Crop & Soil Systems Research, Craibstone Estate, Bucksburn, Aberdeen, AB21 9YA

This is a combined final report of two related HGCA-funded projects based on the same field trials. Project 2837 (oil content) was funded by a contract of £74,076 to The Arable Group which started in November 2002 and lasted for 42 months. Project 3029 (chlorophyll) was funded by a contract of £10,702 to SAC which started in May 2004 and lasted for 21 months.

Contents

Abstract

A three-year study was undertaken to increase understanding of the agronomic factors that influence the oil and residual chlorophyll content of winter oilseed rape seed. Increases in seed yield or oil content can contribute to improved returns for growers, through the oil premium. Recent varieties on the HGCA Recommended List have differed by up to 4%, but the extent to which growers can alter oil content through crop husbandry has been unclear. High concentrations of chlorophyll in the seed at harvest causes problems during refining and processing of the oil and consequently, crushers may be unwilling to accept seed lots with a high percentage of green seed. To date, the scope for reducing seed chlorophyll retention under UK conditions through agronomic practice has not been established. Field trials were established on a range of soil types in the north, south-west and east of England over three successive seasons, to examine the effects on seed yield, % oil, and chlorophyll content of nitrogen and sulphur fertiliser regime, crop canopy manipulation through plant density and fungicide strategy, and pre-harvest treatment method and timing.

Seed oil contents differed between locations, seasons and varieties. Oil yields for Royal were very similar between 2002/03 and 2004/05, but lower in 2003/04 (when autumn establishment was slow). Increasing total spring nitrogen dose from 150 to 240 kg/ha increased seed yields, but reduced oil contents by an average of 1.1%. Oil yields, output values and margins peaked with 190 kg/ha nitrogen. Delaying part of the nitrogen dose until later, or applying a larger proportion early, had little impact. There was evidence of seed yield penalties from not applying sulphur in most trials, but these were only significant on the lighter soil in the South-West, where reductions in oil content also occurred.

Spring fungicide strategy had no effect on oil content, other than in one trial affected by light leaf spot where the autumn spray was omitted, which showed increases in both seed yield and oil content with spring treatments. In another trial where phoma was present, applying an autumn fungicide increased seed yield whilst maintaining oil content, but there was no advantage to additional spring fungicides. Halving the plant density tended to reduce seed yield but had no consistent effect on oil content. Swathing the crop often resulted in lower harvested seed yields than desiccation with glyphosate, although higher seed losses were in some cases partly responsible and earlier harvesting might have reduced this. Treatment timing had no consistent effect on oil content, but there was a tendency for swathing earlier to result in slightly lower values, whereas desiccating earlier had little effect.

Variety choice is the main method by which growers can improve the % oil content of their rape seed. Nitrogen fertiliser dose was the only factor that consistently affected oil content in this study, and the right balance must be struck between seed yield and oil content to optimise margins. Applying sulphur fertiliser is important to maximise seed yields and oil content in deficient situations. Fungicide

applications in autumn or spring that give increases in seed yield should also benefit oil yield and output value. Swathing too early has the potential to reduce oil content as well as seed yield, whereas timing of desiccation with glyphosate is less likely to be critical.

Seed chlorophyll concentrations differed significantly between sites, but over the three experimental years were, in general, within the range acceptable to the crushers. Harvest method had no significant effect on the concentration. Similarly, the timing of swathing or desiccation also had no consistent effect. In one year (2003/04), early swathing increased the concentration at some sites, but decreased it at others compared to later swathing. Fertiliser regime had the most consistent effect on seed chlorophyll. Concentrations were increased by high N doses and by a failure to apply sulphur.

Summary

Project Overall Aim

To develop a better understanding of the agronomic factors that can influence the oil and chlorophyll content of winter oilseed rape seed.

Introduction

Oil content is a vital consideration in the production of rape seed. Most crushers in the UK pay an oil premium of 1.5% for every 1% oil content above 40%, with a similar payment deduction below 40%. Growers can therefore improve returns by achieving higher seed yields or higher oil contents. The 2006 HGCA winter oilseed rape Recommended List includes varieties with oil contents ranging from 42.3% to 46.1%. Oil content and seed yield are combined on the RL to produce Gross Output, which is seed yield adjusted for oil content, and this single value can be used to compare varieties. Despite its importance, though, the agronomic factors that affect oil content have been less clear to growers and crushers than the factors that affect seed yield.

Results from previous TAG trials indicated that variation in oil content as a result of crop husbandry could be up to 5% within an individual variety. Factors that might be important include:

- Nitrogen dose – higher fertiliser doses were thought to reduce oil content, but effects on oil production per unit area (or oil yield) were unclear.
- Husbandry - strategies that resulted in a longer green canopy duration, or a more favourable canopy structure for light interception during pod and seed fill, were suspected to be beneficial
- Swathing - believed more likely to reduce oil content than desiccation and/or direct combining

Seed chlorophyll concentration is another important, although in a UK context poorly understood, aspect of seed quality. Some chlorophyll and related pigments remain in the seed at harvest and are extracted with the oil during crushing. These must be removed during refining because they interfere with processing and can lead to rancidity of the oil. Consequently, high concentrations in the seed can increase refining costs. In 1999 and 2000, concentrations in crude oil from UK seed were double those normally found, and three times greater than those in seed imported from Continental Europe. Previous research at SAC has shown that concentrations differ widely between varieties and sites, but the effects of other agronomic practices were not examined. However, under North American conditions, factors such as harvest method and timing, fertiliser regime, sowing date and density can influence chlorophyll retention in the seed.

The objectives of this project were to determine the extent to which growers can manipulate and improve the oil and chlorophyll contents of rape seed, and to investigate the individual and combined

contributions of the management factors that had previously been identified as potentially being important.

Methods

Field trials were established at three locations over three successive seasons from 2002/03 to 2004/05. Due to the very dry autumn of 2003, which resulted in crop failure, the East trials had to be moved to a closely comparable site for that season only. The sites were:

North	Bainton, East Yorkshire	Sandy clay loam soil	Annual rainfall: 660 mm
East	Biggleswade, Bedfordshire	Deep calcareous clay loam	Annual rainfall: 590 mm
(2003/04)	Chelmsford, Essex	Deep calcareous clay	
South-West	Cirencester, Gloucestershire	Brashy calcareous clay loam	Annual rainfall: 770 mm

In the first year a single small plot trial was sown at each site, as a pilot study. This examined the effect of nitrogen and sulphur fertiliser strategy, and pre-harvest technique and timing, on the varieties Royal and Elan. In the second and third years, three trials were sown at each site. One of these looked at effects of spring nitrogen and sulphur fertiliser doses, and nitrogen timing, on the variety Royal (Table 1). The second looked at the impact of manipulating the crop canopy through fungicide strategy and plant density, also on Royal (Table 2). The third looked at the effect of pre-harvest treatment and timing on Royal and one other variety (Table 3). Royal was used as the main variety for the trials as it had one of the lowest % oil contents on the HGCA Recommended List. Where a second variety was included for comparison, this was chosen on the basis of having one of the highest oil contents.

Table 1. Treatments applied to trial series 1 in the second and third years of the project

Treatment Number	**1st Fertiliser Dose**		**2nd Dose N (kg/ha)**	**3rd Dose N (kg/ha)**	**Total N (kg/ha)**	**Ratio N:S Applied**
	S (kg/ha)	**N (kg/ha)**				
1	30	90	60	0	150	5.0 : 1
2	30	90	100	0	190	6.3 : 1
3	30	90	150	0	240	8.0 : 1
4	30	90	0	100	190	6.3 : 1
5	30	90	100	50	240	8.0 : 1
6 (year 2)	30	140	100	0	240	8.0 : 1
6 (year 3)	60	90	60	0	150	2.5 : 1
7	60	90	100	0	190	3.2 : 1
8	60	90	150	0	240	4.0 : 1
9	0	90	100	0	190	no sulphur

The target timing for the first fertiliser doses was 20-25th February. The target timing for the second doses was 15-20th March, and 1st-5th April for the third doses. First nitrogen/sulphur fertiliser doses were applied as ammonium sulphate, with additional ammonium nitrate to give the correct total amount of nitrogen. Second and third nitrogen doses were all applied as ammonium nitrate.

Table 2. Treatments applied to trial series 2 in the second and third years of the project

Treatment Number	Plant Density	Nitrogen Dose (kg/ha)		Fungicide Applications			
		1st timing	2nd timing	Autumn	Stem extension	Green bud	Mid Flower
1	standard	70	120	yes	no	no	no
2	standard	120	70	yes	no	no	no
3	standard	70	120	yes	no	yes	no
4	standard	120	70	yes	no	yes	no
5	standard	70	120	yes	yes	no	yes
6	standard	120	70	yes	yes	no	yes
7	half	70	120	yes	no	no	no
8	half	120	70	yes	no	no	no
9	standard	70	120	no	no	no	no

Treatments consisted of three alternative fungicide strategies imposed upon two nitrogen fertiliser timing regimes, plus the effect of halving the plant density (by hoeing-out alternate rows after establishment) again with both nitrogen regimes. In 2004/05, a ninth treatment was added that examined the effect of not applying any fungicides at all. The three fungicide strategies were autumn only (Punch C 0.4 l/ha), autumn plus green bud (Folicur 1.0 l/ha), and autumn, stem extension (Folicur 0.5 l/ha) plus mid flowering (0.5 kg/ha Filan). The autumn applications were omitted in the North trial in 2003/04, and there was no fungicide untreated in the South-West trial in 2004/05.

Table 3. Treatments applied to trial series 3 in the second and third years of the project

Treatment Number	Pre-Harvest Treatment
1	glyphosate early
2	glyphosate late
3	swathed early
4	swathed late
5 (2004/05 only)	no pre-harvest treatment (direct combined)

Two pre-harvest treatments, which were desiccation with glyphosate (Roundup Biactive 3.0 l/ha) and swathing (achieved using a plot swather or a hedge trimmer) were compared at two timings. These were determined by examination of pod and seed colour. The early timing was intended to be about 5 days before the anticipated ‘ideal’ stage for desiccation or swathing. The ideal stage can be defined as when 67% of seeds in 75% pods in the middle third of racemes would have changed colour from green to brown. The late timing was intended to be 3-5 days after the ‘ideal’ stage. The expected numbers of days between pre-harvest treatment and harvest were 18-21 and 10-14 days respectively. The actual number was dependent on the weather, and its impact on speed of ripening and ability to harvest. In 2004/05, a direct-combined approach was added. Treatments were evaluated on Royal (all locations in both years), plus a second variety, which in 2003/04 was Caracas or Winner, and in 2004/05 Lioness.

Assessments carried out on the three trials included:

- Canopy density, green leaf area, height, lodging or foliar/stem disease levels
- Date and growth stage (based on pod and seed colour) at the time of pre-harvest treatments
- Seed losses at harvest (an estimate of the number of seeds/m2 on the ground, to the nearest 1000)
- Seed yield and % oil content at 9% moisture content, and thousand seed weight (g)
- Additional samples were retained for analysis of chlorophyll content

Oil yields were calculated by multiplying seed yield by % oil content, all at 9% moisture content. The value per tonne for the rape seed was based on £135 per tonne for rape seed with 40% oil content, plus a price bonus of 1.5% for every 1.0% oil above 40%. The output value was calculated by multiplying the seed yield by the value per tonne. Margins for each treatment were calculated by deducting the specific treatment costs from the output values, with nitrogen costed at 40p per kg (or 44p for nitrogen with sulphur), and fungicide treatments costed at £9.60 (autumn only), £27.60 (autumn + green bud) and £40.60 (autumn + stem extension + mid flower), all excluding applications costs.

Results

Highest oil contents were obtained in 2002/03 at the two heavier land sites, but in 2003/04 on the lighter soil in the South West. The oil yields obtained were remarkably similar between 2002/03 and 2004/05, at all three locations (Table 4). In the South-West this occurred because very similar seed yields and % oil contents were obtained in the two seasons. However, in the North and East higher seed yields in 2004/05 were balanced by lower oil contents. Oil yields were lower in 2003/04, but the unusually dry autumn which resulted in slow establishment (and necessitated the re-location of the East site) might partly explain this.

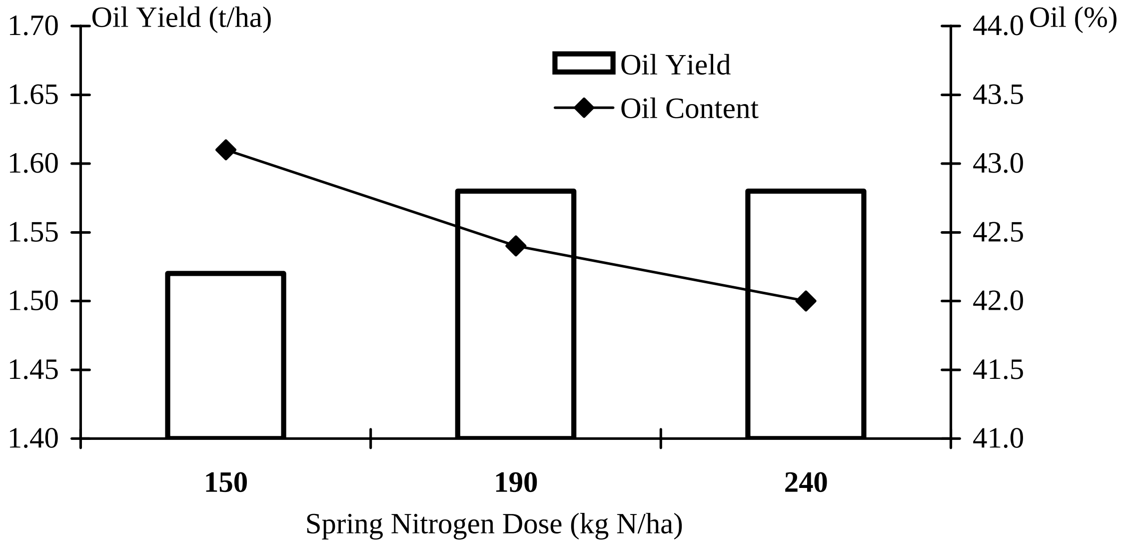
Table 4. Effect of location and season on oil content and oil yield of Royal

Year	Oil Content (% oil at 9% moisture)				Oil Yield (t/ha at 9% moisture content)			
	North	East	S-West	Mean	North	East	S-West	Mean
2002/03	**44.2**	**45.2**	**41.6**	43.7	**1.87**	**1.63**	**1.50**	1.67
2003/04	42.6	(39.6)	43.2	41.8	1.78	(1.21)	1.42	1.47
2004/05	**43.0**	**41.5**	**41.4**	42.0	**1.90**	**1.65**	**1.50**	1.68
Mean	43.3	42.1	42.1	42.5	1.85	1.50	1.47	1.61

Nitrogen and Sulphur Fertiliser Dose

Spring nitrogen fertiliser doses of 150, 190 and 240 kg/ha, and sulphur doses of 0, 30 and 60 kg/ha were compared. All trials showed an improvement in seed yield with a nitrogen dose of 190 kg/ha compared to 150. Increasing the dose to 240 kg/ha did not give a consistent further improvement. With one exception, there was a reduction in % oil content with 240 kg/ha nitrogen compared to 150 kg/ha. The mean reduction over six trials from 2003/04 and 2004/05 was 1.1%. It is probable that this was due to dilution of the oil as a result of higher seed protein yield. In the majority of comparisons, there was no increase in oil yield as a result of applying more than 190 kg/ha nitrogen, but oil yield was reduced by applying only 150 kg/ha (Figure 1).

Figure 1. Effect of nitrogen fertiliser dose on % oil content and oil yield of Royal (mean of 6 trials)



Increasing the N dose from 150 to 240 kg/ha also increased the seed chlorophyll concentration. The effect was statistically significant only in 2003/04, although the same trend was found in 2004/05.

Most of the trials showed evidence of yield penalties from not applying sulphur. These were only significant on the lighter soil in the South-West, where omitting the sulphur application also reduced oil content. In one trial, increasing the sulphur dose from 30 to 60 kg/ha improved seed yield without reducing oil content, and therefore benefited oil yield (Figure 2). Malate testing had shown that the crop at this site was sulphur deficient. When averaged over all sites and at the same dose of N, failure to apply sulphur fertiliser significantly increased seed chlorophyll concentrations in 2003/04. As with N fertiliser regime, the same pattern of response was seen in 2004/05, but the effects were smaller and not statistically significant.

Raising the nitrogen dose from 150 to 190 kg/ha increased output value by an average of £24/ha, and margin by an average of £8/ha. There was no consistent improvement in output value as a result of increasing the dose to 240 kg/ha, and the maximum increase in margin recorded was £7/ha (Table 5). Applying 30 kg/ha sulphur increased output value (by an average of £53/ha) and margin in all but one trial. There was no consistent benefit from applying 60 rather than 30 kg/ha sulphur.

Figure 2. Effect of sulphur fertiliser on % oil content and oil yield of Royal (South-West, 2003/04)

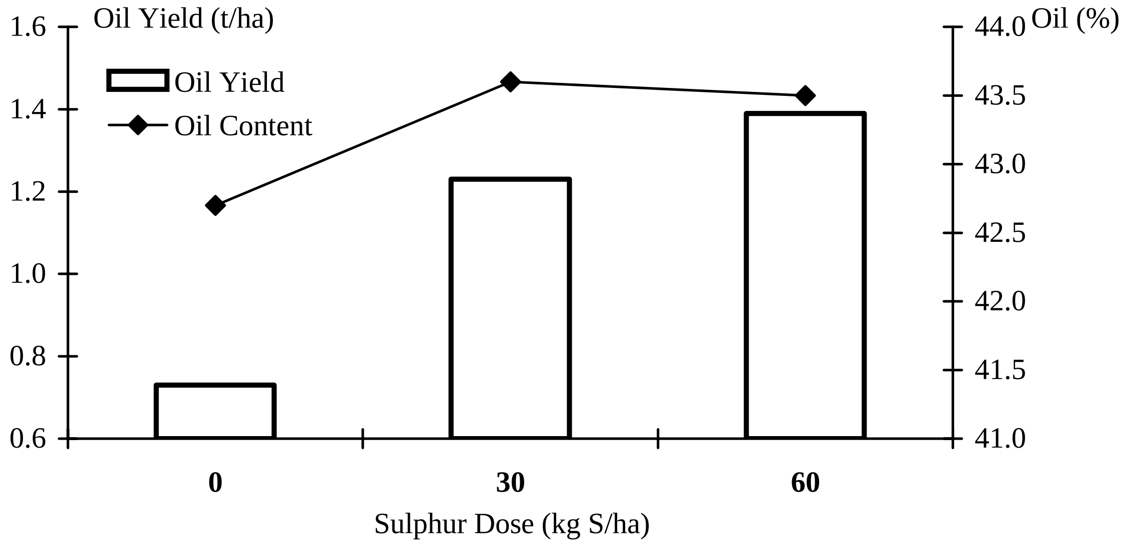


Table 5. Effect of nitrogen and sulphur dose on output value and margin (2 year / 6 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	Output Value (£/ha)		Margin (£/ha)	
		Mean	Max. Increase	Mean	Max. Increase
150	30	498	-	435	-
190	30	522	65	443	48
240	30	520	42	421	7
190	0	469	-	393	-
190	30	522	159	443	157
190	60	521	213	440	207

* Maximum increase recorded in output or margin compared to 150N or 0S

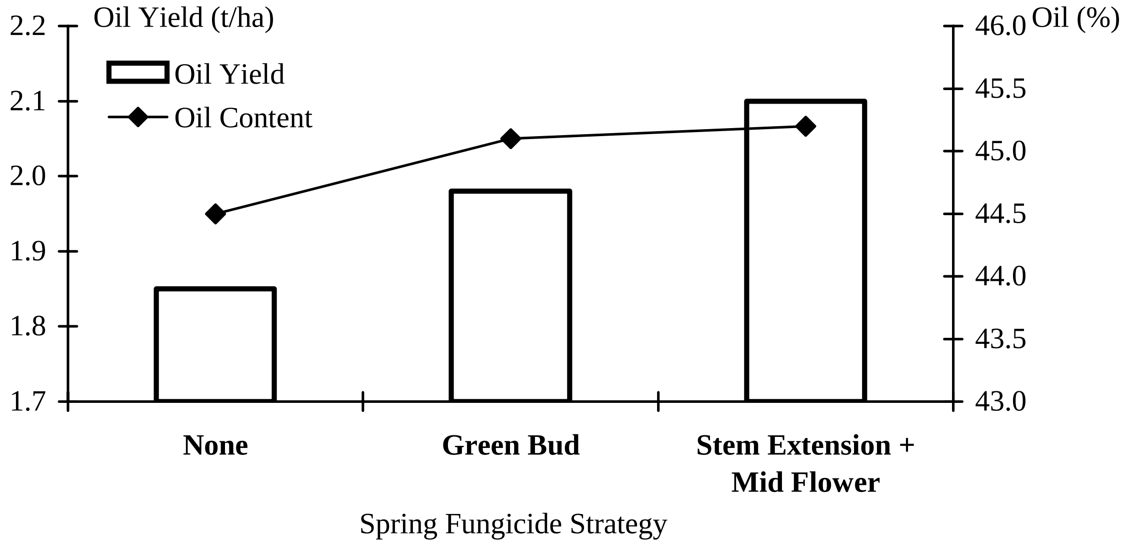
Nitrogen Fertiliser Timing

The effects of delaying part of the nitrogen dose until April (green or yellow bud), or applying a larger proportion at the end of February (typically 8 leaves or rosette stage) were compared on Royal. Nitrogen timing had no meaningful effect on oil content, and no consistent effects on seed or oil yield. In one trial, delaying some of the nitrogen until April or applying more of it in February benefited seed and therefore oil yields, but these had no effects on oil content. There was no clear effect of N timing on seed chlorophyll concentrations.

Fungicide Strategy

Spring fungicide strategy had no significant effect on oil content, other than in one trial affected by light leaf spot where the autumn fungicide spray was omitted. A single green bud spray or a two-spray sequence at stem extension and mid flowering significantly increased oil yields as a result of both increased seed yield and a higher oil content (Figure 3). In another trial where phoma was present, applying no fungicides at all substantially reduced seed yields, but not oil content. An autumn spray significantly increased oil yields, but subsequent spring fungicides were of little additional benefit.

Figure 3. Effect of spring fungicides on % oil content and oil yield of Royal (North, 2003/04)



Compared to an autumn fungicide alone, a two-spray stem extension + mid flower fungicide sequence gave an improvement in output value in eight out of ten comparisons, with a mean increase of £32/ha (Table 6). Allowing for the extra fungicide (but not application) costs, margins would have improved in only four cases, and by an average of £1.50/ha.

Table 6. Effect of fungicide strategy on output value (2 year / 5 trial mean)

N Dose (kg N/ha)		Fungicide	2003/04		2004/05			
Timing 1	Timing 2	Strategy	E	SW	N	E	SW	Mean
			Output Value (£/ha)					
70	120	autumn	512	376	583	487	501	492
70	120	aut + gn bud	515	419	618	498	488	507
70	120	aut + stem ext + mid flower	487	449	680	501	521	528
120	70	autumn	513	385	601	522	471	499
120	70	aut + gn bud	477	412	568	457	493	481
120	70	aut + stem ext + mid flower	504	432	625	539	538	527

Plant Density

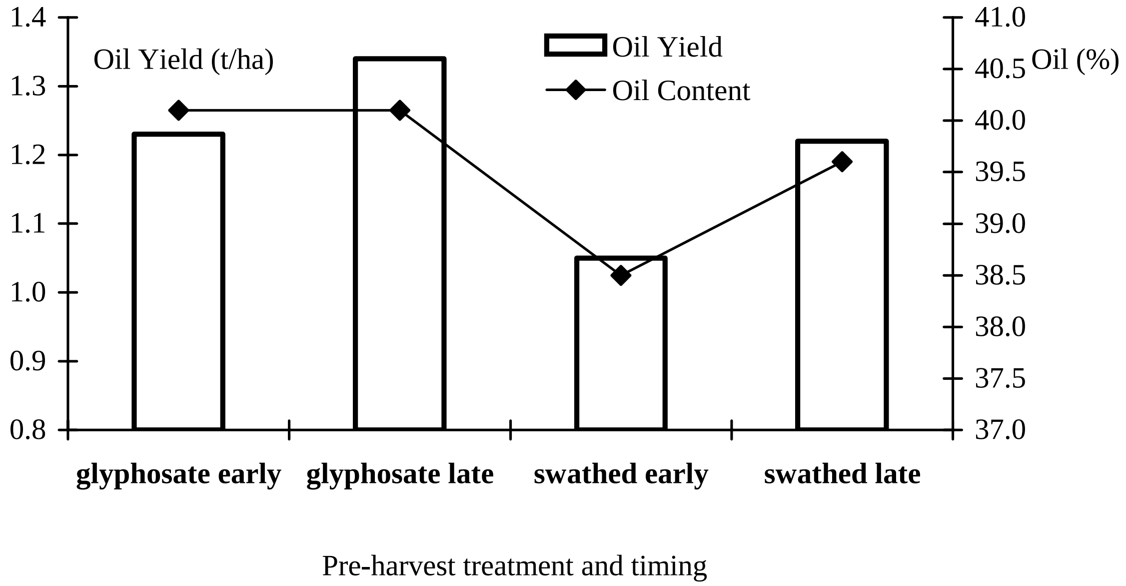
In three out of six trials from 2003/04 and 2004/05, halving crop density (by removing alternate rows after establishment) led to significant reductions in seed yield, but as plant density had no consistent effects on oil content, oil yields reflected seed yields. One trial showed small improvements in seed yield and oil content at lower plant densities, and this was associated with a reduction in crop leaning.

It was hypothesised that low plant densities might increase branching and the proportion of immature seeds in the sample, thereby increasing seed chlorophyll concentrations. However, there was no effect of plant density over the range tested on seed chlorophyll in either 2003/04 or 2004/05.

Pre-Harvest Treatment and Timing

The effects of desiccation with glyphosate and swathing, either early or late relative to the ideal stage, were compared on two varieties over three seasons. Swathing generally resulted in lower harvested yields than desiccation. In some cases higher seed losses were partly responsible for this, and earlier harvesting of swathed treatments might have reduced this. Time of desiccation or swathing had no consistent effect on oil content, but there was a tendency for early swathing to result in slightly lower values. When combined with a lower seed yield, the oil yield was reduced significantly (Figure 4).

Figure 4. Effect of pre-harvest treatment on % oil content and oil yield of Royal (East, 2003/04)



Swathing early reduced output value for Royal in five out of eight trials, and by an average of £20/ha, compared to swathing late. At the same time, swathing early reduced output value in all eight trials compared to desiccation early, and by an average of £45/ha. Only two trials showed a reduction in output value from desiccation early rather than late.

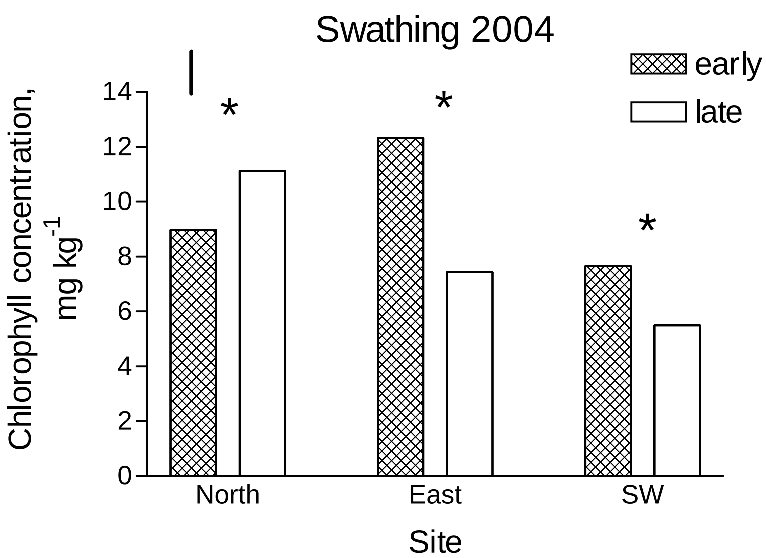
Table 7. Effect of pre-harvest treatment and timing on output value of Royal (3 year / 8 trial mean)

Pre-harvest Treatment	Timing	2002/03		2003/04			2004/05			Mean
		E	SW	N	E	SW	N	E	SW	
		Output Value (£/ha)								
glyphosate	early	531	527	626	415	473	650	555	508	536
glyphosate	late	577	512	611	452	455	650	554	510	540
swathed	early	525	450	543	362	450	555	546	493	491
swathed	late	472	502	567	413	480	646	518	493	511

It is often suggested that premature swathing can lead to high seed chlorophyll concentrations at harvest. However, there was no consistent effect of either harvest method or timing on concentrations in the present study. When averaged over different timings, desiccation and swathing resulted in comparable chlorophyll concentrations, at a given site, in each of the three experimental years. Direct combining, in the one year that it was included as a treatment, also gave concentrations that were comparable to swathing and desiccation.

The timing of swathing or desiccation had a relatively small effect on seed chlorophyll, except in 2003/04. In this year early swathing significantly increased chlorophyll concentrations compared to later swathing in the east and SW, but the reverse was found in the north (Fig. 5).

Figure 5. Effects of timing of swathing on seed chlorophyll concentrations in 2003/04. Values are means averaged over two variety types (Royal, low oil content; Caracas or Winner, high oil content). Vertical bar shows LSD P = 0.05.



Conclusions and Implications

Variety choice is the main method by which growers can improve the % oil content of their rape seed, without necessarily reducing yield. In these trials, differences due to crop husbandry were typically only 1-2%, compared to the 4% that can be achieved through varietal selection. However, even if a high oil content variety is chosen, both location and season will have an impact on oil content as well as seed yield. There is a suggestion that seasonal variation in oil content may be more the result of differences in seed yield (and therefore dilution) rather than differences in oil production.

The only husbandry factor that has consistently affected oil content is nitrogen fertiliser dose, with % oil decreasing as nitrogen dose is increased. This is most likely to be the result of dilution of the oil by a higher seed protein yield. As nitrogen dose is generally the only way of consistently increasing seed yields (assuming that other nutrient deficiencies or specific weed, pest or disease problems have been eliminated), this means that the right balance must be struck between seed yield and oil content.

Trials have shown that applying nitrogen doses in excess of 190 kg N/ha, which is the current RB209 recommendation for crops growing in the majority of situations (SNS Index 1, mineral soils), may reduce oil content and may not increase oil yield or output value, resulting in a lower margin. Altering application timings within the practical window for solid fertilisers is unlikely to be of any consistent advantage.

Applying sulphur fertiliser is important to maximise oil content, as well as seed yield, especially on known deficient sites and soil types. Doses in excess of 30 kg S/ha (the current recommendation in RB209) have not consistently improved oil yield or output value, but where seed yields have benefited from a higher sulphur dose this has not resulted in lower oil content (in contrast to nitrogen dose).

Fungicide applications in the autumn or spring that give significant increases in seed yield are also likely to maintain or increase oil content, and should therefore benefit both oil yield and output value. There may be a more general improvement in oil yield and output value in response to fungicides applied in the spring (in these trials a two-spray sequence at stem extension and mid flowering), but this may not be cost-effective.

Swathing too early (as little as 5 days before the ideal stage according to pod and seed colour) has the potential to reduce oil content as well as seed yield, compared to later swathing or desiccation with glyphosate. However, this risk must be balanced against the risk of increased seed losses as a result of swathing too late. Timing of desiccation with glyphosate is less likely to be critical for seed yield and oil content.

Seed chlorophyll concentrations were lower than those found in the high chlorophyll years of 1999 and 2000, and were in the range generally acceptable to the crushers. Previous research has shown that choice of variety has a significant influence on chlorophyll concentrations, with Apex being one of the worst for retaining high concentrations. The decline in popularity of Apex may have contributed to the general improvement in chlorophyll concentrations reported by the crushers since 2001. The current study has shown that further small improvements may be possible through agronomy. In particular, ensuring crops receive adequate sulphur fertiliser and avoiding high doses of N will help minimise chlorophyll concentrations. Since there was no consistent effect of the method or timing of pre-harvest treatment on seed chlorophyll, no change in harvest practice is required to improve this aspect of seed quality. In conclusion, recommendations made above for maximising oil content through careful fertiliser management and the timing of swathing are compatible with achieving low chlorophyll concentrations.

Technical Report

Part A

Factors that Influence the % Oil Content of Rape Seed

Project Overall Aim

To develop a better understanding of the agronomic factors that can influence the oil content of winter oilseed rape seed.

1. Introduction

Oil content is a vital consideration in the production of rape seed. Most crushers in the UK pay an oil premium of 1.5% for every 1% oil content above 40%, with a similar payment deduction below 40%. Growers can therefore improve returns by achieving higher seed yields or higher oil contents, although interestingly under the above system, a 4.5 t/ha crop with an oil content of 40% (which gives 1.8 t/ha of oil) is worth more than a 4.0 t/ha crop with an oil content of 45% (which also gives 1.8 t/ha of oil). The 2006 HGCA winter oilseed rape Recommended List includes varieties with oil contents ranging from 42.3% to 46.1%. Oil content and seed yield are combined on the RL to produce Gross Output, which is seed yield adjusted for oil content, and this single value can be used to compare varieties. Despite its importance, though, breeding for oil content has often not been considered one of the highest priorities, and the agronomic factors that affect oil content have been less clear to growers and crushers than the factors that affect seed yield.

Results from previous trials by Arable Research Centres had indicated that variation in oil content as a result of differential crop husbandry could reach up to 5% within an individual variety. However, discussions with plant breeders and seed houses revealed uncertainty amongst breeders over the agronomic principles that controlled this. Factors that it was felt might be important included:

- Higher nitrogen fertiliser doses were thought to reduce oil content, but it was uncertain whether oil production per unit area (or oil yield) might still be increased
- Husbandry strategies that resulted in a longer green canopy duration, or a more favourable canopy structure for light interception during pod and seed fill, were suspected to be beneficial
- Swathing was believed more likely to reduce oil content than desiccation and/or direct combining

The objectives of this project were therefore to determine the extent to which growers can manipulate and improve the oil content of rape seed, and to investigate the individual and combined contributions of the management factors that had previously been identified as potentially being important. Trials were planned for three locations across England, to allow for geographical and soil type differences.

2. Materials and Methods

2.1 Overview

Field trials were established at three locations in England and in three successive seasons from 2002/03 to 2004/05, to examine the effect of crop management on seed oil content. In the first year a single trial was sown at each site, as a pilot study. This examined the effect of nitrogen and sulphur fertiliser strategy, and pre-harvest technique and timing, on the varieties Royal and Elan. In the second and third years, three trials were sown at each site. One of these looked at the effect of spring nitrogen and sulphur fertiliser doses, and nitrogen timing, on the variety Royal. The second looked at the impact of manipulating the crop canopy through fungicide strategy and plant density, also on Royal. The third looked at the effect of pre-harvest treatment and timing on Royal and one other variety. Royal was used as the main variety for the trials as it had one of the lowest % oil contents on the HGCA Recommended List. Where a second variety was included for comparison, this was chosen on the basis of having one of the highest oil contents on the HGCA Recommended List.

2.2 Site locations and soil types

The trials were located at sites in north, east and south-west England. Due to the exceptionally dry autumn of 2003, which resulted in crop failure, the east trials had to be moved to a closely comparable site for that season only. Characteristics for each location were as follows:

North

Bainton, East Yorkshire	Soil type:	Panholes series
(2002/03, 2003/04 and 2004/05)		Sandy clay loam
	Average annual rainfall:	660 mm

East

Biggleswade, Bedfordshire	Soil type:	Cannamore series
(2002/03 and 2004/05)		Deep calcareous clay loam
	Average annual rainfall:	590 mm
Chelmsford, Essex	Soil type:	Hanslope series
(2003/04 only)		Deep calcareous clay

South-West

Cirencester, Gloucestershire	Soil type:	Elmton 1 series
(2002/03, 2003/04 and 2004/05)		Brashy calcareous clay loam over rock
	Average annual rainfall:	770 mm

Full site details are shown in the appendix (section 7.4).

2.3 Trial design

Treatments were applied to small plots measuring 10 or 12m long (8 or 10m harvested) x 2.1 m wide, in a fully randomised design with 3 replicates.

2.4 Trial Treatments

2002/03

In the first year a single trial was conducted, involving seven management treatments applied to two varieties (Royal and Elan), giving 14 treatments in all.

Table 2.1 Treatments applied in first year of project

Treatment Number	1st Fertiliser Dose		2nd Dose	Total N	Pre-Harvest Treatment
	S (kg/ha)	N (kg/ha)	N (kg/ha)	(kg/ha)	
1	Std	90	100	190	glyphosate early
2	Std	90	150	240	glyphosate early
3	Std x 2	90	100	190	glyphosate early
4	Std x 2	90	150	240	glyphosate early
5	Std	90	100	190	glyphosate late
6	Std	90	100	190	swathed early
7	Std	90	100	190	swathed late

The sulphur fertiliser doses evaluated were the 'standard' dose for the site (30 kg S/ha for North and East, 44 kg S/ha for South-West) and twice the 'standard' (60 and 84 kg S/ha respectively). The target timing for the first fertiliser doses was 20-25th February. The target timing for the second doses was 20-25th March. Actual application dates are shown in the appendix (section 7.2). First nitrogen/sulphur fertiliser doses were applied as ammonium sulphate (21% N, 24% S), with additional ammonium nitrate (34.5% N) to give the correct total amount of nitrogen for that timing. Second nitrogen fertiliser doses were all applied as ammonium nitrate.

Pre-harvest treatment timings were determined by examination of pod and seed colour. The first timing (early) was intended to be about 5 days before the anticipated 'ideal' stage for desiccation or swathing. The ideal stage can be defined as when 67% of seeds in 75% pods in the middle third of racemes would have changed colour from green to brown. The second timing (late) was intended to be 3-5 days after the 'ideal' stage. The target interval between timings was 8-10 days, with the expected number of days between pre-harvest treatment and harvest being 18-21 and 10-14 days respectively. However, the actual number of days was of course dependent on the weather, and its impact on speed of ripening and ability to harvest the crop. Glyphosate was applied as 3.0 l/ha 'Roundup Biactive' (1080 g/ha glyphosate) in 200 l/ha water. Swathing was achieved using a specialist plot swather, or using a hedge trimmer. All other inputs (herbicides, insecticides) were applied as standard for the site, and these are shown in the appendix (section 7.4).

2003/04 and 2004/05

In the second and third years, three trials were conducted at each location:

Trial Series 1

Nine fertiliser treatments, consisting of different spring nitrogen fertiliser doses and timings, and sulphur fertiliser doses, were compared on the variety Royal. At two locations (North and East) treatment 6 was modified in 2004/05 (Table 2.2).

Table 2.2 Treatments applied in the second and third years of the project

Treatment Number	**1st Fertiliser Dose**		**2nd Dose**	**3rd Dose**	**Total N**	**Ratio N:S**
	S (kg/ha)	**N (kg/ha)**	**N (kg/ha)**	**N (kg/ha)**	**(kg/ha)**	**Applied**
1	30	90	60	0	150	5.0 : 1
2	30	90	100	0	190	6.3 : 1
3	30	90	150	0	240	8.0 : 1
4	30	90	0	100	190	6.3 : 1
5	30	90	100	50	240	8.0 : 1
6 (year 2)	30	140	100	0	240	8.0 : 1
6 (year 3)	60	90	60	0	150	2.5 : 1
7	60	90	100	0	190	3.2 : 1
8	60	90	150	0	240	4.0 : 1
9	0	90	100	0	190	no sulphur

Trials were either desiccated with glyphosate when the ideal stage had been reached in the majority of plots, or were direct-combined without pre-harvest treatment.

The target timing for the first fertiliser doses was 20-25th February. The target timing for the second doses was 15-20th March, and 1st-5th April for the third doses. Actual application dates are shown in Appendix (section 7.2). First nitrogen/sulphur fertiliser doses were applied as ammonium sulphate (21% N, 24% S), with additional ammonium nitrate (34.5% N) to give the correct total amount of nitrogen for that timing. Second and third nitrogen doses were all applied as ammonium nitrate.

Trial Series 2

Eight husbandry treatments were compared on the variety Royal. These consisted of three alternative fungicide strategies imposed upon two nitrogen fertiliser timing regimes, plus the effect of halving the crop density (mostly achieved by hoeing-out alternate rows after establishment) again with both nitrogen regimes. In 2004/05, a ninth treatment was added that examined the effect of not applying any fungicides at all (Table 2.3). The three fungicide strategies were autumn only, autumn plus green bud and autumn, stem extension plus mid flowering, with the following sprays applied at these timings:

autumn = 0.4 l/ha Punch C (125 g/l carbendazim + 250 g/l flusilazole)

stem extension = 0.5 l/ha Folicur (250 g/l tebuconazole)

green bud = 1.0 l/ha Folicur mid flowering = 0.5 kg/ha Filan (50% w/w boscalid)

The autumn applications were omitted in the North trial in 2003/04, and there was no fungicide untreated in the South-West trial in 2004/05.

Table 2.3 Treatments applied in the second and third years of the project

Treatment Number	Plant Density	Nitrogen Dose (kg/ha)		Fungicide Applications			
		1st timing	2nd timing	Autumn	Stem extension	Green bud	Mid Flower
1	standard	70	120	yes	no	no	no
2	standard	120	70	yes	no	no	no
3	standard	70	120	yes	no	yes	no
4	standard	120	70	yes	no	yes	no
5	standard	70	120	yes	yes	no	yes
6	standard	120	70	yes	yes	no	yes
7	half	70	120	yes	no	no	no
8	half	120	70	yes	no	no	no
9	standard	70	120	no	no	no	no

All treatments received about 30 kg S/ha at the first timing. Trials were mostly desiccated with glyphosate (when the ideal stage had been reached in the majority of plots), or were direct-combined.

Trial Series 3

Two pre-harvest treatment methods (desiccation with glyphosate, and swathing) were compared at two timings, as described for the 2002/03 season. In 2004/05, an additional treatment (5) was added, which was direct combined without any pre-harvest treatment (Table 2.4). Treatments were evaluated on Royal (at all three locations in both years), plus a second variety, which in 2003/04 was Caracas (except East where only Winner was available as a result of having to move the trial), and in 2004/05 Lioness (all locations).

Table 2.4 Treatments applied in the second and third years of the project

Treatment Number	Pre-Harvest Treatment
1	glyphosate early
2	glyphosate late
3	swathed early
4	swathed late
5 (2004/05 only)	no pre-harvest treatment (direct combined)

Application dates and growth stages for each trial are shown in the appendix, section 7.2.

2.5 Assessments and Analyses

2002/03

The following assessments were carried out:

- Where present, differences in canopy size / density, green leaf area (mostly recorded on a 1-5 scale, where 1 = lowest density / green area or least green, 5 = largest or most), height (cm) or leaning/lodging (%)
- Date and precise growth stage (pod and seed colour in middle third of main racemes) at the time of pre-harvest treatments
- Where present, differences in crop maturity on the day of harvest (estimated number of days until maturity where treatments were not yet fully fit)
- Seed losses at harvest (an estimate of the number of seeds/m2 on the ground, to the nearest 1000)
- Seed yield at 9% moisture content
- % oil content at 9% moisture content
- Additional samples were retained for analysis of chlorophyll content

2003/04 and 2004/05

Trial Series 1

The following assessments were carried out:

- Available soil nitrogen and sulphate levels in mid February, prior to the first fertiliser timing
- Malate:sulphate tissue test in late March, at the start of rapid stem extension (treatment 9, no sulphur applied, only). See appendix, section 7.3, for soil and tissue analysis results
- Where present, differences in canopy size / density, green leaf area (mostly recorded on a 1-5 scale, where 1 = lowest density / green area or least green, 5 = largest or most), height (cm) or leaning/lodging (%), at mid flowering and at mid pod fill
- Where present, differences in crop maturity on the day of harvest (estimated number of days until maturity where treatments were not yet fully fit)
- Seed yield at 9% moisture content
- % oil content at 9% moisture content
- Thousand seed weight (g)
- Additional samples were retained for analysis of chlorophyll content

Trial Series 2

The following assessments were carried out:

- Where present, differences in foliar or stem disease levels, at mid flowering and pod ripening
- Where present, differences in canopy size / density, green leaf area (mostly recorded on a 1-5 scale, where 1 = lowest density / green area or least green, 5 = largest or most), height (cm) or leaning/lodging (%), at mid flowering and at mid pod fill
- Where present, differences in crop maturity on the day of harvest (estimated number of days until maturity where treatments were not yet fully fit)
- Seed yield at 9% moisture content
- % oil content, adjusted to 9% moisture content
- Thousand seed weight (g)
- Additional samples were retained for analysis of chlorophyll content

Trial Series 3

The following assessments were carried out:

- Date and precise growth stage (pod and seed colour in middle third of main racemes) at the time of pre-harvest treatments
- Where present, differences in crop maturity on the day of harvest (estimated number of days until maturity where treatments were not yet fully fit)
- Seed losses at harvest (an estimate of the number of seeds/m2 on the ground, to the nearest 1000)
- Seed yield at 9% moisture content
- % oil content, adjusted to 9% moisture content
- Thousand seed weight (g)
- Additional samples were retained for analysis of chlorophyll content

2.6 Output and Margin Calculations

Oil yields were calculated by multiplying seed yield by % oil content, all at 9% moisture content. The value per tonne for the rape seed was based on £135 per tonne for rape seed with 40% oil content, plus a price bonus of 1.5% for every 1.0 % oil above 40%. The output value was calculated by multiplying the seed yield by the value per tonne. Margins for each treatment were calculated by deducting the specific treatment costs from the output values, with nitrogen costed at 40p per kg (or 44p for nitrogen with sulphur), and fungicide treatments costed at £9.60 (autumn only), £27.60 (autumn + green bud) and £40.60 (autumn + stem extension + mid flower), all excluding applications costs.

3. Results

Results from the twenty-one trials are presented in six sections, according to the individual management factors that were investigated:

1. The effects of location, variety and season
2. The effects of nitrogen and sulphur fertiliser doses
3. The effects of nitrogen fertiliser timing
4. The impact of fungicide strategy and its interaction with nitrogen timing
5. The effects of plant density
6. The effects of pre-harvest treatment and timing

Each results section includes a two or three-year summary of treatment effects on seed yield, % oil content and oil yield (seed yield x % oil content) of Royal. Where there were significant effects on seed or oil yield, output (seed yield x price per tonne) and margin (output less specific treatment cost) are also shown. Full results from each individual trial are given in section 7.1 of the appendix.

3.1 The Effects of Location, Variety and Season

The impact of location and season on the seed yield, oil content and oil yield of Royal are summarised below. Differences between the low (Royal) and high (Elan or Lioness) oil content varieties are also shown. The values for 2003/04 and 2004/05 are based on the means for Trial Series 3. Note that the East site in 2003/04 was at a different (but comparable) location.

Lowest seed yields were recorded in 2003/04, and highest in 2004/05, at all locations (Table 3.1.1). The North site was consistently higher yielding than the East and South-West.

Table 3.1.1 Effect of location and season on seed yield of Royal

Year	Seed Yield (t/ha at 9% moisture)			
	North	East	South-West	Mean
2002/03	4.24	3.62	3.60	3.82
2003/04	4.18	(3.06)	3.28	3.51
2004/05	4.42	3.98	3.63	4.01
Mean	4.28	3.55	3.50	3.78

Highest oil contents were obtained in 2002/03 at the two heavier land sites, but in 2003/04 on the lighter soil in the South West (Table 3.1.2). No single location consistently gave the highest oil contents.

Table 3.1.2 Effect of location and season on oil content of Royal

Year	Oil Content (% oil at 9% moisture)			
	North	East	South-West	Mean
2002/03	44.2	45.2	41.6	43.7
2003/04	42.6	(39.6)	43.2	41.8
2004/05	43.0	41.5	41.4	42.0
Mean	43.3	42.1	42.1	42.5

The oil yields obtained were very similar between 2002/03 and 2004/05, at all locations (Table 3.1.3). In 2003/04 oil yields were lower, especially in the East (note however that this was a different site).

Table 3.1.3 Effect of location and season on oil yield of Royal

Year	Oil Yield (t/ha at 9% moisture)			
	North	East	South-West	Mean
2002/03	1.87	1.63	1.50	1.67
2003/04	1.78	(1.21)	1.42	1.47
2004/05	1.90	1.65	1.50	1.68
Mean	1.85	1.50	1.47	1.61

Although the relative seed yields of the two varieties differed between locations in 2002/03, Elan consistently gave higher oil contents than Royal (Table 3.1.4). The size of the difference in oil content between the two varieties also differed between locations, although the mean difference was comparable with that on the 2006 HGCA Recommended List.

Table 3.1.4 Effect of variety on seed yield, oil content and oil yield in 2002/03

Location	Seed Yield (t/ha)		Oil Content (%)		Oil Yield (t/ha)	
	Royal	Elan	Royal	Elan	Royal	Elan
North	4.31	3.86	43.9	47.2	1.89	1.82
East	3.63	4.37	45.2	47.0	1.64	2.05
South-West	3.70	3.63	41.3	45.2	1.53	1.64
Mean	3.88	3.95	43.5	46.4	1.69	1.84
RL 2006	-	-	42.3	44.9	-	-

In 2004/05 Royal consistently gave higher seed yields and lower oil contents than Lioness, and the differences in both were similar at all locations (Table 3.1.5). The mean difference in oil content was smaller than that on the 2006 HGCA RL (with a lower than expected value for Lioness).

Table 3.1.5 Effect of variety on seed yield, oil content and oil yield in 2004/05

Location	Seed Yield (t/ha)		Oil Content (%)		Oil Yield (t/ha)	
	Royal	Lioness	Royal	Lioness	Royal	Lioness
North	4.42	3.90	43.0	44.5	1.90	1.73
East	3.98	3.29	41.5	42.9	1.65	1.41
South-West	3.63	3.02	41.4	43.4	1.50	1.31
Mean	4.01	3.41	42.0	43.6	1.68	1.49
RL 2006	-	-	42.3	46.1	-	-

3.2 The Effects of Nitrogen and Sulphur Fertiliser Doses

The effects on seed yield, oil content and oil yield, of spring nitrogen doses of 190 and 240 kg N/ha, and sulphur doses of 30 (or 44) and 60 (or 84) kg S/ha, were compared on Royal over three years. In the second and third years, a third nitrogen dose (150 kg/ha) and a nil sulphur treatment were included.

In 2002/03 in the South-West on Royal, increasing the nitrogen dose from 190 to 240 kg/ha gave small increases in seed yield, but significant reductions in % oil content (Table 3.2.1). The combined effect of these was no increase in oil yield as a result of applying the higher nitrogen dose. Increasing the sulphur dose had little or no effect on seed yield or % oil content, and therefore oil yield.

Table 3.2.1 Effect of nitrogen and sulphur dose on seed yield and oil content (South-West, 2002/03)

Fertiliser Doses		Seed Yield	Oil Content	Oil Yield
N kg/ha	S kg/ha	(t/ha)	(%)	(t/ha)
190	44	3.81	41.6	1.59
240	44	3.92	40.7	1.62
190	84	3.80	41.7	1.58
240	84	3.92	40.3	1.58
LSD		0.28	1.05	0.14
190	mean	3.81	41.7	1.59
240	mean	3.92	40.5	1.60
mean	44	3.87	41.2	1.61
mean	84	3.86	41.0	1.60

In the East in 2003/04, increasing the nitrogen dose from 190 to 240 kg/ha did not give a consistent increase in seed yield, and reduced oil content, with no improvement in oil yield as a result (Table 3.2.2). A higher oil content also meant little reduction in oil yield with a nitrogen dose of only 150 kg/ha. Increasing the sulphur dose from 30 to 60 kg/ha did not benefit seed yield or oil content.

Table 3.2.2 Effect of nitrogen and sulphur dose on seed yield and oil content (East, 2003/04)

N Dose (kg N/ha)	S Dose (kg S/ha)	Seed Yield (t/ha)	Oil Content (%)	Oil Yield (t/ha)
190	0	3.08	41.6	1.29
150	30	3.29	41.8	1.37
190	30	3.44	41.4	1.42
240	30	3.19	40.5	1.29
190	60	3.09	41.1	1.27
240	60	3.15	40.3	1.27
LSD		0.40	1.00	ns
190	mean	3.27	41.3	1.35
240	mean	3.17	40.4	1.28
mean	30	3.32	41.0	1.36
mean	60	3.12	40.7	1.27

Increasing the nitrogen dose from 150 to 190 kg/ha had very little effect on seed yield, but reduced oil content in the South-West in 2003/04 (Table 3.2.3). There was little or no improvement in oil yield when the nitrogen dose was increased to 240 kg/ha. Omitting sulphur significantly reduced seed yield and oil content (and therefore oil yield). This was associated with a significant reduction in the canopy green area index (GAI). Increasing the sulphur dose from 30 to 60 kg/ha improved seed yield without reducing oil content, and therefore benefited oil yield.

Table 3.2.3 Effect of nitrogen and sulphur dose on seed yield and oil content (South-West, 2003/04)

N Dose (kg N/ha)	S Dose (kg S/ha)	Seed Yield (t/ha)	Oil Content (%)	Oil Yield (t/ha)	Canopy Size (GAI)	Crop Height (cm)
190	0	1.72	42.7	0.73	3.00	148
150	30	2.78	44.6	1.24	3.50	148
190	30	2.82	43.6	1.23	3.67	152
240	30	2.92	43.5	1.27	3.83	153
190	60	3.20	43.5	1.39	3.67	152
240	60	3.19	43.4	1.38	3.67	154
LSD		0.41	0.73	0.18	0.36	2.8
190	mean	3.01	43.6	1.31	3.67	152
240	mean	3.06	43.5	1.33	3.75	154
mean	30	2.87	43.6	1.25	3.75	153
mean	60	3.20	43.5	1.39	3.67	153

In the East in 2004/05, increasing the nitrogen dose from 150 to 240 kg/ha did not consistently increase seed yield, but led to a significant reduction in oil content, with no improvement in oil yield (Table 3.2.4). Increasing the sulphur dose from 30 to 60 kg/ha appeared to benefit seed yield and oil content, but it should be noted that there was no reduction in either where no sulphur was applied.

Table 3.2.4 Effect of nitrogen and sulphur dose on seed yield and oil content (East, 2004/05)

N Dose (kg N/ha)	S Dose (kg S/ha)	Seed Yield (t/ha)	Oil Content (%)	Oil Yield (t/ha)	Canopy Size (1-5)	Crop Height (cm)
190	0	3.57	42.0	1.50	2.7	150
150	30	3.22	42.7	1.38	2.3	147
190	30	3.30	41.4	1.36	3.7	152
240	30	3.53	41.4	1.46	4.0	154
150	60	3.71	43.3	1.61	2.3	145
190	60	3.33	42.3	1.41	2.3	149
240	60	3.61	41.2	1.48	3.0	146
LSD		ns	0.73	ns	1.41	6.0
150	mean	3.47	43.0	1.50	2.3	146
190	mean	3.32	41.9	1.39	3.0	151
240	mean	3.57	41.3	1.47	3.5	150
mean	30	3.35	41.8	1.40	3.9	153
mean	60	3.55	42.3	1.50	2.7	148

Overall, five out of six trials in 2003/04 or 2004/05 showed an improvement in seed yield with a nitrogen dose of 190 compared to 150 kg/ha, but none of the increases were statistically significant (Table 3.2.5). There were no consistent benefits from increasing the nitrogen dose to 240 kg/ha, but a small improvement was recorded in the majority of the eight trials over the three years (Table 3.2.6).

Most of the trials showed evidence of yield penalties from not applying sulphur, but these were only significant on the lighter soil in the South-West (Table 3.2.5).

Table 3.2.5 Effect of nitrogen and sulphur dose on seed yield (2 year / 6 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	2003/04			2004/05			Mean
		N	E	SW	N	E	SW	
		Seed Yield (t/ha)						
150	30	4.10	3.29	2.78	4.49	3.22	3.24	3.52
190	30	4.41	3.44	2.82	4.72	3.30	3.70	3.73
240	30	4.42	3.19	2.92	4.88	3.53	3.48	3.74
190	0	4.11	3.08	1.72	4.68	3.57	3.04	3.37
190	30	4.41	3.44	2.82	4.72	3.30	3.70	3.73
190	60	4.24	3.09	3.20	4.96	3.33	3.51	3.72
LSD		ns	ns	0.41	0.40	ns	0.48	

Table 3.2.6 Effect of nitrogen and sulphur dose on seed yield (3 year / 8 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	2002/03		2003/04			2004/05			Mean
		E	SW	N	E	SW	N	E	SW	
		Seed Yield (t/ha)								
190	30 (44*)	3.66	3.81	4.41	3.44	2.82	4.72	3.30	3.70	3.73
190	60 (84*)	3.52	3.80	4.24	3.09	3.20	4.96	3.33	3.51	3.71
190	mean	3.59	3.81	4.33	3.27	3.01	4.84	3.32	3.61	3.72
240	30 (44*)	3.64	3.92	4.42	3.19	2.92	4.88	3.53	3.48	3.75
240	60 (84*)	3.82	3.92	4.51	3.15	3.19	4.99	3.61	3.50	3.84
240	mean	3.73	3.92	4.47	3.17	3.06	4.94	3.57	3.49	3.79

* Doses used in South-West in 2002/03 only

With the exception of the South-West trial in 2004/05, there was a reduction in oil content between nitrogen doses of 150 and 240 kg N/ha. The mean reduction over the six trials from 2003/04 and 2004/05 was 1.1% (Table 3.2.7). Omitting the sulphur application reduced oil content, but only in the two South-West trials. Over the three years, increasing the nitrogen dose from 190 to 240 kg/ha reduced oil content by an average of 0.4% across the eight trials (Table 3.2.8).

Table 3.2.7 Effect of nitrogen and sulphur dose on oil content (2 year / 6 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	2003/04			2004/05			Mean
		N	E	SW	N	E	SW	
		Oil Content (% oil)						
150	30	45.2	41.8	44.6	43.0	42.7	41.2	43.1
190	30	44.3	41.4	43.6	42.3	41.4	41.4	42.4
240	30	43.8	40.5	43.5	41.8	41.4	41.2	42.0
190	0	44.0	41.6	42.7	42.2	42.0	40.3	42.1
190	30	44.3	41.4	43.6	42.3	41.4	41.4	42.4
190	60	44.0	41.1	43.5	42.5	42.3	41.0	42.4
LSD		0.89	1.00	0.73	ns	0.73	ns	

Table 3.2.8 Effect of nitrogen and sulphur dose on oil content (3 year / 8 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	2002/03		2003/04			2004/05			Mean
		E	SW	N	E	SW	N	E	SW	
		Oil Content (% oil)								
190	30 (44*)	45.0	41.6	44.3	41.4	43.6	42.3	41.4	41.4	42.6
190	60 (84*)	45.7	41.7	44.0	41.1	43.5	42.5	42.3	41.0	42.7
190	mean	45.4	41.7	44.2	41.3	43.6	42.4	41.9	41.2	42.7
240	30 (44*)	44.8	40.7	43.8	40.5	43.5	41.8	41.4	41.2	42.2
240	60 (84*)	44.7	40.3	44.4	40.3	43.4	43.1	41.2	40.7	42.3
240	mean	44.8	40.5	44.1	40.4	43.5	42.5	41.3	41.0	42.3

In three out of six trials from 2003/04 and 2004/05, highest oil yields were obtained at a nitrogen dose of 190 kg/ha and a sulphur dose of 30 kg/ha (Table 3.2.9). In two of the trials from 2003/04 and 2004/05, oil yields improved with the 240 kg/ha nitrogen dose and/or the 60 kg/ha sulphur dose. The remaining trial, and the two from 2002/03, showed no clear response to nitrogen or sulphur dose.

Table 3.2.9 Effect of nitrogen and sulphur dose on oil yield (2 year / 6 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	2003/04			2004/05			Mean
		N	E	SW	N	E	SW	
		Oil Yield (t/ha)						
150	30	1.85	1.37	1.24	1.93	1.38	1.33	1.52
190	30	1.95	1.42	1.23	2.00	1.36	1.53	1.58
240	30	1.94	1.29	1.27	2.05	1.46	1.44	1.58
190	0	1.81	1.29	0.73	1.98	1.50	1.23	1.42
190	30	1.95	1.42	1.23	2.00	1.36	1.53	1.58
190	60	1.87	1.27	1.39	2.11	1.41	1.34	1.57
LSD		ns	ns	0.18	ns	ns	ns	

Raising the nitrogen dose from 150 to 190 kg/ha increased output value by an average of £24/ha. There was no consistent improvement in output value as a result of increasing the dose to 240 kg/ha (Table 3.2.10). Applying 30 kg/ha sulphur increased output value in all but one of the trials, and by an average of £53/ha. There was no consistent benefit in applying double the sulphur dose.

Table 3.2.10 Effect of nitrogen and sulphur dose on output value (2 year / 6 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	2003/04			2004/05			Mean
		N	E	SW	N	E	SW	
		Output Value (£/ha)						
150	30	597	456	401	634	452	445	498
190	30	634	474	401	659	455	510	522
240	30	631	434	415	676	487	478	520
190	0	588	426	242	652	496	412	469
190	30	634	474	401	659	455	510	522
190	60	607	424	455	695	465	481	521

Increasing the nitrogen dose from 150 to 190 kg/ha was cost-effective, but increasing to 240 kg/ha was not (Table 3.2.11). Applying 30 kg/ha sulphur was very cost-effective, but increasing to 60 kg/ha did not improve profitability.

Table 3.2.11 Effect of nitrogen and sulphur dose on margin (2 year / 6 trial mean)

Nitrogen Dose (kg N/ha)	Sulphur Dose (kg S/ha)	2003/04			2004/05			Mean
		N	E	SW	N	E	SW	
		Margin (£/ha)						
150	30	534	393	339	571	390	383	435
190	30	555	395	323	581	376	431	443
240	30	532	335	316	578	388	380	421
190	0	512	350	166	576	420	336	393
190	30	555	395	323	581	376	431	443
190	60	525	343	373	613	384	400	440

3.3 The Effects of Nitrogen Fertiliser Timing

The effects on seed yield, oil content and oil yield, of delaying part of the nitrogen dose until timing 3 in April (typically green or yellow bud), or applying a larger proportion in the first timing at the end of February (typically 8 leaves or rosette stage) were compared on Royal over two years.

In the South-West in 2003/04, nitrogen timing had a significant effect on seed yield. Delaying some of the nitrogen until April, or applying more at the first timing, gave similar yield increases, suggesting that applications at timing 2 (late March) were simply less effective in this trial. Nitrogen timing had no effect on oil content; therefore oil yield followed the same trend as seed yield (Table 3.3.1).

Table 3.3.1 Effect of nitrogen timing on seed yield and oil content (South-West, 2003/04)

Nitrogen Fertiliser Dose (kg N/ha)			Seed Yield (t/ha)	Oil Content (%)	Oil Yield (t/ha)
Timing 1	Timing 2	Timing 3			
90	100	0	2.82	43.6	1.23
90	0	100	3.29	43.7	1.44
90	100	50	3.26	43.7	1.42
90	150	0	2.92	43.5	1.27
140	100	0	3.36	43.5	1.46
LSD			0.41	0.73	0.18

Across the six trials in 2003/04 and 2004/05, there were some differences in seed yield between the nitrogen timings, but with the exception of the South-West in 2003/04 these were not significant and there were no consistent trends (Table 3.2.2).

Table 3.3.2 Effect of nitrogen fertiliser timing on seed yield (2 year / 6 trial mean)

Nitrogen Fertiliser Dose (kg N/ha)			2003/04			2004/05			Mean
Timing 1	Timing 2	Timing 3	N	E	SW	N	E	SW	
20-25 Feb	15-20 Mar	1-5 April	Seed Yield (t/ha)						
90	100	0	4.41	3.44	2.82	4.72	3.30	3.70	3.73
90	0	100	4.30	2.99	3.29	4.91	3.63	3.71	3.81
90	100	50	4.16	3.23	3.26	4.89	3.68	3.65	3.81
90	150	0	4.42	3.19	2.92	4.88	3.53	3.48	3.74
140	100	0	4.19	2.97	3.36	-	-	3.38	-
LSD			ns	ns	0.41	0.40	ns	ns	

Nitrogen fertiliser timing had no meaningful effect on oil content in any of the six trials (Table 3.3.3) and therefore, apart from the South-West in 2003/04, no significant effects on oil yield.

Table 3.3.3 Effect of nitrogen fertiliser timing on oil content (2 year / 6 trial mean)

Nitrogen Fertiliser Dose (kg N/ha)			2003/04			2004/05			Mean
Timing 1	Timing 2	Timing 3	N	E	SW	N	E	SW	
20-25 Feb	15-20 Mar	1-5 April	Oil Content (% oil)						
90	100	0	44.3	41.4	43.6	42.3	41.4	41.4	42.4
90	0	100	44.2	40.9	43.7	42.3	41.8	41.4	42.4
90	100	50	43.3	41.0	43.7	42.2	41.3	40.9	42.1
90	150	0	43.8	40.5	43.5	41.8	41.4	41.2	42.0
140	100	0	43.5	40.3	43.5	-	-	41.8	-
LSD			0.89	1.00	0.73	ns	0.73	ns	

3.4 The Impact of Fungicide Strategy and its Interaction with Nitrogen Timing

The effects on seed yield, oil content and oil yield, of autumn, spring or mid flower fungicide sprays were compared on Royal over two years. The fungicide treatments were evaluated with two nitrogen regimes, applying different proportions of the total dose at the two timings.

In the absence of an autumn fungicide treatment, which was omitted, a two-spray fungicide sequence with applications at stem extension and mid flowering significantly increased seed yield in the North in 2003/04 (Table 3.4.1). A single application at green bud also improved seed yield. Both fungicide strategies gave increases in oil content despite higher seed yields, resulting in higher oil yields. Disease assessments did not show clear differences between treatments, but fungicide use led to an obvious reduction in crop leaning.

Table 3.4.1 Effect of fungicide strategy on seed yield and oil content (North, 2003/04)

N Dose (kg N/ha)		Fungicide Strategy	Seed Yield (t/ha)	Oil Content (%)	Oil Yield (t/ha)	Leaning (%)
Timing 1	Timing 2					
70	120	none	4.09	44.3	1.81	57
70	120	green bud	4.41	45.2	1.99	0
70	120	stem ext + mid flower	4.65	45.0	2.09	10
120	70	none	4.22	44.6	1.88	47
120	70	green bud	4.38	45.0	1.97	0
120	70	stem ext + mid flower	4.64	45.3	2.10	0
LSD			0.28	0.68	0.12	41
mean		none	4.16	44.5	1.85	52
mean		green bud	4.40	45.1	1.98	0
mean		stem ext + mid flower	4.65	45.2	2.10	5

In the East in 2004/05, all fungicide strategies significantly increased seed yield compared to the untreated. However, there was no consistent benefit from applying more than the autumn treatment (Table 3.4.2). Despite higher seed yields, there were no reductions in oil content, resulting in higher oil yields where fungicides were applied. Assessments indicated that phoma leaf spot was present, but levels of stem canker were low, with no treatment differences recorded. However, there was evidence that the canopy had remained greener during pod fill where spring or mid flower fungicides had been applied, and the green bud sprays led to a consistent reduction in lodging.

Table 3.4.2 Effect of fungicide strategy on seed yield and oil content (East, 2004/05)

N Dose (kg N/ha)		Fungicide	Seed Yield	Oil Content	Oil Yield	Canopy
Timing 1	Timing 2	Strategy	(t/ha)	(%)	(t/ha)	Green (1-5)
70	120	none	2.77	41.8	1.16	3.3
70	120	autumn	3.50	42.0	1.47	2.7
70	120	aut + gn bud	3.60	41.7	1.50	3.7
70	120	aut + stem ext + mid flower	3.63	41.5	1.51	4.3
120	70	autumn	3.76	41.9	1.59	2.7
120	70	aut + gn bud	3.29	42.0	1.38	3.3
120	70	aut + stem ext + mid flower	3.82	43.0	1.65	4.0
LSD			0.50	ns	0.24	0.95
mean		autumn	3.63	41.9	1.53	2.7
mean		aut + gn bud	3.45	42.0	1.44	3.5
mean		aut + stem ext + mid flower	3.73	42.4	1.58	4.2

Although fungicide treatment had no consistent effect on seed yield, a two-spray stem extension + mid flower sequence gave the most benefit, either compared to an autumn spray alone over five trials in 2003/04 and 2004/05 (Table 3.4.3), or compared to no fungicides at all in 2003/04 in the North.

Table 3.4.3 Effect of fungicide strategy on seed yield (2 year / 5 trial mean)

N Dose (kg N/ha)		Fungicide	2003/04		2004/05			
Timing 1	Timing 2	Strategy	E	SW	N	E	SW	Mean
			Seed Yield (t/ha)					
70	120	none	-	-	4.30	2.77	-	-
70	120	autumn	3.68	2.59	4.12	3.50	3.63	3.50
70	120	aut + gn bud	3.67	2.87	4.35	3.60	3.53	3.60
70	120	aut + stem ext + mid flower	3.48	3.08	4.79	3.63	3.78	3.75
120	70	autumn	3.67	2.64	4.23	3.76	3.46	3.55
120	70	aut + gn bud	3.42	2.85	4.02	3.29	3.58	3.43
120	70	aut + stem ext + mid flower	3.60	2.95	4.41	3.82	3.90	3.74
LSD			0.40	ns	ns	0.50	0.45	

With the exception of the North trial in 2003/04, fungicide strategy had no significant effects on oil content. Three out of six trials (including North 2003/04 not shown) showed a significant effect of fungicide treatment on oil yield (Table 3.4.4), but responses were not always consistent between the two nitrogen regimes. Overall, the two-spray stem extension + mid flower sequence was the most beneficial to oil yield.

Table 3.4.4 Effect of fungicide strategy on oil yield (2 year / 5 trial mean)

N Dose (kg N/ha)		Fungicide	2003/04		2004/05			
Timing 1	Timing 2	Strategy	E	SW	N	E	SW	Mean
			Oil Yield (t/ha)					
70	120	none	-	-	1.86	1.16	-	-
70	120	autumn	1.54	1.17	1.78	1.47	1.51	1.49
70	120	aut + gn bud	1.56	1.30	1.89	1.50	1.47	1.54
70	120	aut + stem ext + mid flower	1.48	1.39	2.08	1.51	1.56	1.60
120	70	autumn	1.56	1.20	1.84	1.59	1.41	1.52
120	70	aut + gn bud	1.44	1.27	1.73	1.38	1.48	1.46
120	70	aut + stem ext + mid flower	1.53	1.35	1.91	1.65	1.62	1.61
LSD			0.18	ns	ns	0.24	0.21	

The most consistent increases in output value (compared to an autumn spray alone) were obtained with the stem extension + mid flower spring sequence. The additional fungicides gave a benefit in eight out ten comparisons, with an average increase in output value of £32/ha (Table 3.4.5). Allowing for the cost of the extra fungicides (but not their application), the average improvement in margin was reduced to £1.50/ha, and they were only profitable in four out of ten comparisons (Table 3.4.6).

Table 3.4.5 Effect of fungicide strategy on output value (2 year / 5 trial mean)

N Dose (kg N/ha)		Fungicide	2003/04		2004/05			
Timing 1	Timing 2	Strategy	E	SW	N	E	SW	Mean
			Output Value (£/ha)					
70	120	none	-	-	609	384	-	-
70	120	autumn	512	376	583	487	501	492
70	120	aut + gn bud	515	419	618	498	488	507
70	120	aut + stem ext + mid flower	487	449	680	501	521	528
120	70	autumn	513	385	601	522	471	499
120	70	aut + gn bud	477	412	568	457	493	481
120	70	aut + stem ext + mid flower	504	432	625	539	538	527

Table 3.4.6 Effect of fungicide strategy on margin (2 year / 5 trial mean)

N Dose (kg N/ha)		Fungicide	2003/04		2004/05			
Timing 1	Timing 2	Strategy	E	SW	N	E	SW	Mean
			Margin (£/ha)					
70	120	none	-	-	609	384	-	-
70	120	autumn	502	367	574	477	492	482
70	120	aut + gn bud	487	391	590	471	460	480
70	120	aut + stem ext + mid flower	453	414	645	466	486	487
120	70	autumn	504	375	592	512	462	489
120	70	aut + gn bud	449	384	540	430	465	454
120	70	aut + stem ext + mid flower	469	398	590	504	503	487

3.5 The Effects of Plant Density

The effects on seed yield, oil content and oil yield, of reducing the plant density were evaluated on Royal over two years. Plant density treatments were evaluated with two nitrogen regimes, applying different proportions of the total dose at the two timings. Although there were no significant effects, reducing the plant density gave small improvements in seed yield, oil content and therefore oil yield in the North in 2003/04 (Table 3.5.1). There were also associated reductions in crop leaning.

Table 3.5.1 Effect of plant density on seed yield and oil content (North, 2003/04)

N Dose (kg N/ha)		Plant	Seed Yield	Oil Content	Oil Yield	Leaning
Timing 1	Timing 2	Density	(t/ha)	(%)	(t/ha)	(%)
70	120	standard	4.09	44.3	1.81	57
70	120	half	4.19	44.6	1.87	3
120	70	standard	4.22	44.6	1.88	47
120	70	half	4.32	45.2	1.95	25
LSD			0.28	0.68	0.12	41

In three out of six trials from 2003/04 and 2004/05, halving the crop density led to significant reductions in seed yield. There were no significant increases in seed yield (Table 3.5.2).

Table 3.5.2 Effect of plant density on seed yield (2 year / 6 trial mean)

N Dose (kg N/ha)		Plant	2003/04			2004/05			
Timing 1	Timing 2	Density	N	E	SW	N	E	SW	Mean
			Seed Yield (t/ha)						
70	120	standard	4.09	3.68	2.59	4.12	3.50	3.63	3.60
70	120	half	4.19	3.05	2.66	4.43	3.16	3.01	3.42
120	70	standard	4.22	3.67	2.64	4.23	3.76	3.46	3.66
120	70	half	4.32	3.09	2.49	4.03	3.08	2.74	3.29
LSD			0.28	0.40	ns	ns	0.50	0.45	

Plant density had no consistent effects on oil content, and oil yields therefore reflected seed yields (Table 3.5.3).

Table 3.5.3 Effect of plant density on oil yield (2 year / 6 trial mean)

N Dose (kg N/ha)		Plant	2003/04			2004/05			
Timing 1	Timing 2	Density	N	E	SW	N	E	SW	Mean
			Oil Yield (t/ha)						
70	120	standard	1.81	1.54	1.17	1.78	1.47	1.51	1.55
70	120	half	1.87	1.29	1.20	1.92	1.31	1.19	1.47
120	70	standard	1.88	1.56	1.20	1.84	1.59	1.41	1.58
120	70	half	1.95	1.32	1.14	1.76	1.28	1.12	1.43
LSD			0.12	0.18	ns	ns	0.24	0.21	

3.6 The Effects of Pre-Harvest Treatment and Timing

The effects on seed yield, oil content and oil yield, of pre-harvest treatment method (swathing, or desiccation with glyphosate) and timing (earlier than the ideal stage, or slightly later) were evaluated on Royal and one other variety over three years.

In the East in 2003/04, swathing resulted in lower seed yields than desiccation, and swathing or desiccation earlier than the ideal stage gave lower seeds yields than swathing or desiccation later (Table 3.6.1). Although harvest was delayed by a week due to wet weather, the detrimental effects on seed yield were mainly the result of smaller seeds rather than greater seed losses at harvest. Swathing early also reduced oil content compared to swathing later, or desiccation early, with a significant reduction in oil yields from swathing early as a result.

Table 3.6.1 Effect of pre-harvest treatment and timing on seed yield and oil content (East, 2003/04)

Variety	Pre-harvest Treatment	Timing	Yield (t/ha)	Oil (%)	Oil Yield (t/ha)	TSW (g)	Losses 000 seeds/m2
Royal	glyphosate	early	3.07	40.1	1.23	4.0	2.8
Royal	glyphosate	late	3.34	40.1	1.34	4.2	2.8
Royal	swathed	early	2.74	38.5	1.05	3.7	3.2
Royal	swathed	late	3.08	39.6	1.22	4.2	2.7
Winner	glyphosate	early	3.30	41.7	1.38	4.5	2.5
Winner	glyphosate	late	3.47	42.2	1.46	4.8	3.0
Winner	swathed	early	2.86	41.0	1.17	4.2	2.8
Winner	swathed	late	3.17	42.3	1.34	4.6	2.4
LSD			0.36	1.59	0.16	0.20	ns
mean	glyphosate	early	3.19	40.9	1.31	4.3	2.7
mean	glyphosate	late	3.41	41.2	1.40	4.5	2.9
mean	swathed	early	2.80	39.8	1.11	4.0	3.0
mean	swathed	late	3.12	40.9	1.28	4.4	2.5
LSD			0.25	1.10	0.11	0.10	ns

In 2004/05, earlier swathing consistently resulted in lower oil contents for Lioness, whereas timing of desiccation had little effect (Table 3.6.2). Differences were generally not significant though.

Table 3.6.2 Effect of pre-harvest treatment on % oil content of Lioness (2004/05)

Pre-harvest Treatment	Timing	Oil Content (% oil)			
		North	East	South-West	Mean
glyphosate	early	44.6	43.1	43.7	43.8
glyphosate	late	44.5	43.2	43.5	43.7
swathed	early	44.2	42.4	42.8	43.1
swathed	late	44.7	42.8	43.6	43.7
no pre-harvest (direct)		44.3	42.9	43.4	43.5
LSD		0.80	0.61	1.00	

In six out of eight trials over the three years, swathing resulted in lower harvested seed yields than desiccation with glyphosate (Table 3.6.3). In most cases the penalty was where treatments were compared at the earlier timing. The average seed yield reduction with swathing compared to desiccation was 0.30 t/ha at the early timing, and 0.19 t/ha at the late timing.

Table 3.6.3 Effect of pre-harvest treatment and timing on seed yield of Royal (3 year / 8 trial mean)

Pre-harvest Treatment	Timing	2002/03		2003/04			2004/05			Mean
		E	SW	N	E	SW	N	E	SW	
		Seed Yield (t/ha)								
glyphosate	early	3.66	3.81	4.42	3.07	3.33	4.61	3.99	3.68	3.82
glyphosate	late	3.94	3.68	4.35	3.34	3.22	4.60	4.02	3.72	3.86
swathed	early	3.62	3.28	3.88	2.74	3.19	3.91	3.98	3.58	3.52
swathed	late	3.24	3.62	4.08	3.08	3.39	4.58	3.75	3.58	3.67
LSD		0.34	0.28	0.40	0.36	0.50	0.48	0.25	0.42	

Time of swathing or desiccation had no consistent effect on oil content. However, swathing had a slight tendency to give lower oil contents than desiccation, especially at the earlier of the two timings (Table 3.6.4).

Table 3.6.4 Effect of pre-harvest treatment and timing on oil content of Royal (3 year / 8 trial mean)

Pre-harvest Treatment	Timing	2002/03		2003/04			2004/05			Mean
		E	SW	N	E	SW	N	E	SW	
		Oil Content (% oil)								
glyphosate	early	45.0	41.6	43.3	40.1	43.5	43.0	42.0	41.5	42.5
glyphosate	late	45.6	42.0	42.7	40.1	43.1	43.1	41.4	41.0	42.4
swathed	early	45.0	41.1	42.5	38.5	43.0	43.4	41.1	41.3	42.0
swathed	late	45.3	41.8	41.9	39.6	43.3	43.0	41.6	41.4	42.2
LSD		1.69	1.05	0.72	1.59	0.94	0.80	0.61	1.00	

Over the eight trials, swathing result in lower harvested oil yields than desiccation with glyphosate (Table 3.6.5). The largest differences were at the earlier timing, due to swathing suffering a greater early penalty than desiccation.

Table 3.6.5 Effect of pre-harvest treatment and timing on oil yield of Royal (3 year / 8 trial mean)

Pre-harvest Treatment	Timing	2002/03		2003/04			2004/05			Mean
		E	SW	N	E	SW	N	E	SW	
		Oil Yield (t/ha)								
glyphosate	early	1.65	1.59	1.92	1.23	1.45	1.98	1.68	1.53	1.63
glyphosate	late	1.80	1.54	1.86	1.34	1.39	1.98	1.67	1.52	1.64
swathed	early	1.63	1.35	1.65	1.05	1.37	1.69	1.63	1.48	1.48
swathed	late	1.47	1.51	1.71	1.22	1.46	1.97	1.56	1.48	1.55
LSD		0.18	0.14	0.18	0.16	0.23	0.21	0.11	0.19	

Output values followed a similar trend to oil yields. Swathing resulted in lower output values than desiccation, with the differences being greater at the early timing (Table 3.6.6). Over the three years, swathing early reduced output value in five out of eight trials, and by an average of £20/ha, compared to swathing late. At the same time, however, swathing early reduced output value in all eight trials compared to desiccation early, and by an average of £45/ha. Only two trials showed a meaningful reduction in output value from desiccation early rather than late.

Table 3.6.6 Effect of pre-harvest treatment and timing on output value of Royal (3 year / 8 trial mean)

Pre-harvest Treatment	Timing	2002/03		2003/04			2004/05			Mean
		E	SW	N	E	SW	N	E	SW	
		Output Value (£/ha)								
glyphosate	early	531	527	626	415	473	650	555	508	536
glyphosate	late	577	512	611	452	455	650	554	510	540
swathed	early	525	450	543	362	450	555	546	493	491
swathed	late	472	502	567	413	480	646	518	493	511

4. Discussion

As expected, both seed yields and seed oil contents varied with location and season. The North site always gave the highest seed yields for Royal, and gave the highest oil yields in all three years, indicating greater oil production at the more northerly location. Cooler temperatures during seed development, associated with higher latitudes, are known to increase the oil content of some oilseeds. The similarity in Royal oil yields between 2002/03 and 2004/05 at all sites is remarkable, but possibly just a coincidence. In the South-West this occurred because very similar seed yields and % oil contents were obtained in the two seasons. However, in the North and East higher seed yields in 2004/05 were balanced by lower oil contents, suggesting a degree of 'compensation'. Oil yields were lower in 2003, but the unusually dry autumn which resulted in slow establishment (and necessitated the re-location of the East site) might partly explain this.

The comparative performance of the two varieties, Royal and Elan, in 2002/03 is interesting. Seed yields for Elan ranged from 10% below Royal in the North to 20% above Royal in the East, with seed yields about equal in the South-West. Despite this big range, Elan always had a higher oil content than Royal, and the largest difference in oil content between the two varieties was in the South-West where their seed yields were very similar. In contrast in 2004/05, Lioness consistently produced a lower seed yield but a higher oil content than Royal.

Applying a higher dose of nitrogen fertiliser usually resulted in higher seed yields but lower % oil contents. The most likely explanation for this is that the extra nitrogen benefited the production of seed protein more than oil. When the nitrogen dose was raised from 150 to 190 kg/ha, the increase in seed yield usually outweighed the decrease in % oil content, with a small net increase in the yield of oil. However, raising the dose from 190 to 240 kg/ha generally resulted in no increase in oil yield.

Although the rape seed pricing formula means that there can be slight differences in the output value (per hectare) of rape seed, for the same oil yield, output value did follow a similar trend to oil yield. Taking into account the cost of the additional fertiliser, increasing the nitrogen dose to 240 kg/ha was generally less profitable than applying 150 kg/ha, even though there may have been improvements in seed yield. The 190 kg/ha nitrogen dose was invariably the most cost-effective.

It had been suggested that the higher nitrogen doses might contribute more productively to oil yield where the supply of sulphur was not limiting. There was a slight indication in some trials that, where the dose of sulphur applied was also increased to reduce the ratio of N:S applied, seed yield was more responsive to the 240 kg/ha nitrogen. The reduction in oil content between the 190 and 240 kg/ha nitrogen doses was the same regardless of the sulphur dose. As a result there was a very slight improvement in oil yield where a higher nitrogen dose was combined with a higher sulphur dose, but this was still not cost-effective.

Not applying any sulphur at all was detrimental to seed yield in most of the trials, and in particular on the known-deficient soil in the South-West. However, in this case the additional seed yield was not associated with a reduction in oil content. In fact, oil content was increased at the same time as seed yield in the South-West, suggesting that oil production might have benefited more than seed protein production from the sulphur. In addition, the two trials that gave a further improvement in seed yield as a result of applying a higher sulphur dose again did not suffer a reduction in oil content, indicating that the extra sulphur was contributing equally to oil production.

In previous trials seed yields of oilseed rape have tended not to show a consistent nitrogen fertiliser timing effect, within the normal range of practical application dates (mid February to early April). This was also the case here, albeit that only split doses were examined, but it was apparent from these trials that oil content was affected even less by timing. This implies that manipulating the nitrogen timing is unlikely to mean that higher nitrogen doses can be made to contribute more to oil production.

Improving light interception by the crop canopy, through the use of fungicides to prolong green leaf retention, or by altering the canopy structure, was one of the husbandry factors originally identified as being likely to influence oil content. Seed yield responses to fungicide treatment have again tended to be inconsistent, especially in the absence of light leaf spot, sclerotinia or high levels of stem canker. Here, two out of six trials showed significant increases in seed yield with fungicides, even though the variety used, Royal, is moderately susceptible to light leaf spot and very susceptible to stem canker.

Responses in the first trial were obtained with spring applied treatments in the absence on any autumn fungicide. Although there were no clear disease differences, some light leaf spot was observed at this site, and the reduction in leaning where fungicides were applied may also have contributed to the yield benefit. It has previously been observed that the control of light leaf spot can increase oil content, and this was supported by the results from this trial. As with sulphur, this led to a double improvement in oil yield through increases in seed yield and oil content, implying increased oil production.

In the second trial, there was a large increase in seed yield as a result of applying an autumn fungicide, but little or no further improvement from the spring applied treatments. Again, no clear differences in disease were observed, but phoma leaf spot was present on the site and the crop established relatively late, which might have increased the associated yield penalty. There was also evidence of better retention of green leaf, although this was only apparent with the spring applied treatments. Although fungicide use did not consistently increase oil content in this case, it was not reduced either, indicating that production of oil benefited.

Although only two trials showed significant benefits, there was an overall improvement in both oil yield and output value across the trials, with the two-spray spring sequence compared to an autumn fungicide alone. This bordered on being cost-effective, but only if little or no cost is attached to their application.

Reducing the plant density to create a more open canopy generally reduced seed yields, although the method of achieving this in these trials (removing alternate rows after harvest) intentionally had a more drastic effect on the density than might occur through slight reductions in the seed rate used. With no consistent increases in oil content to compensate, oil yields were also reduced. Only one trial showed a slight improvement in oil content with the lower plant density, and this was obtained with no reduction in seed yield so represented an increase in oil production.

The results from the trials that compared the pre-harvest treatments and their timing require careful interpretation. This is particularly true of seed yields (and therefore oil yields), as it is necessary to determine whether any differences that are recorded are the result of the weight of seed produced, or the amount of seed that is recovered. For example, swathing too early could curtail seed fill, or could lead to loss of seed in the swath if combining is delayed. Swathing too late is most likely to lead to seed losses through shatter caused by the swathing operation. Desiccation with glyphosate is perhaps less likely to cause losses, but going much too early could limit seed fill, and desiccating later could interfere with separation of seeds from the pods if they have not fully dried out. All trials were examined carefully to identify situations where significant seed losses were evident at harvest, and treatments were assessed to quantify any differences. A loss of 2000 seeds per m2 with a TSW of 5g is equivalent to 0.1 t/ha, and most of the trials and treatments did not exceed this.

In the majority of comparisons, swathing resulted in lower harvested seed yields than desiccation. In 2003/04, all three locations experienced wet weather between swathing or desiccation, and combining. Seed losses were recorded at the North and East sites, but only in the North was swathing substantially worse than desiccation. The largest penalties were with early swathing in the South-West in 2002/03, where seed losses were observed but not recorded as there were no apparent treatment differences, and also in the North in 2004/05, where no significant losses were reported.

The most compelling evidence of an effect of pre-harvest treatment or timing on oil content was at the East location in 2003/04. Swathing early reduced oil content, despite the fact that a lower seed yield was recorded. Even if the lower harvested seed yield was solely due to greater losses (and the results suggest that this was not the case) the actual seed yield would not have been higher, so the lower oil content would not have been due to greater dilution. A similar logic applies to the 2002/03 South-West trial, where both seed yield and oil content were numerically lower with early swathing.

To summarise, the trials here suggest a fairly consistent reduction in oil yield and output value from swathing compared to desiccation with glyphosate, and greater timing flexibility for desiccation. However, the extent to which this might be the case in practice may well have been exaggerated by the necessary limitations within these trials, which meant that time of combining had to be a compromise based on the readiness of all treatments. Nevertheless, swathing too early clearly has the potential to reduce oil content, oil yield and output value.

5. Conclusions and Implications

Variety choice is clearly the main method by which growers can improve the % oil content of their rape seed, without necessarily reducing yield. In these trials, differences due to crop husbandry were typically only 1-2%, compared to the 4% that can be achieved through varietal selection. However, even if a high oil content variety is chosen, both location and season will have an impact on oil content as well as seed yield. Seasonal variation in oil content may result more from differences in seed yield (and therefore dilution) rather than differences in oil production.

The only husbandry factor that consistently affected oil content was nitrogen fertiliser dose, with % oil decreasing as nitrogen dose was increased. This is most likely to have resulted from dilution of the oil by a higher seed protein yield. As nitrogen dose is generally the only way of consistently increasing seed yields (assuming that other nutrient deficiencies or specific weed, pest or disease problems have been eliminated), the right balance must be struck between seed yield and oil content.

These trials have shown that applying nitrogen doses in excess of 190 kg N/ha, which is the current RB209 recommendation for crops growing in the majority of situations (SNS Index 1, mineral soils), may reduce oil content and may not increase oil yield or output value, resulting in a lower margin. Altering application timings within the practical window for solid fertilisers gave no advantage.

Applying sulphur fertiliser is important to maximise oil content, as well as seed yield, especially on known deficient sites and soil types. In these trials, doses in excess of 30 kg S/ha (the current RB209 recommendation) did not consistently improve oil yield or output value. Where seed yields benefited from a higher sulphur dose this did not result in lower oil content (in contrast to increases in nitrogen dose).

Fungicide applications in the autumn or spring that give significant increases in seed yield are also likely to maintain or increase oil content, and should therefore benefit both oil yield and output value. There may be a more general improvement in oil yield and output value in response to fungicides applied in the spring (in these trials a two-spray sequence at stem extension and mid flowering), but these are unlikely to be cost-effective.

Swathing too early (as little as 5 days before the ideal stage according to pod and seed colour) has the potential to reduce oil content as well as seed yield, compared to later swathing or desiccation with glyphosate. However, this risk must be balanced against the risk of increased seed losses as a result of swathing too late. Timing of desiccation with glyphosate was less critical for seed yield and oil content in these trials.

6.1 Acknowledgements

The author would like to thank colleagues within The Arable Group for conducting the field trials, and collecting and analysing the data; the three host farmers for accommodating the trials, and finally the HGCA for their funding and guidance over the three years of the project.

6.2 References

HGCA Recommended List 2006/07 for cereals and oilseeds

Part B

Factors that Influence the Chlorophyll Concentration of Rape Seed

Overall aim

To investigate the effects of crop husbandry and, in particular, harvest method and timing, on the seed chlorophyll concentration at harvest, and its relationship to other seed quality factors.

1. Introduction

Chlorophyll pigments remaining in oilseed rape seed at harvest are extracted with the oil during the crushing process. This leads to several problems during refining; discolouration of the oil, promotion of oxidation reactions and rancidity, and interference with the nickel catalyst used for hydrogenation. As such, chlorophyll and related pigments must be removed during refining, and high chlorophyll concentrations increase refining costs and oil losses.

Chlorophyll concentrations in crude oil extracted from UK produced seed vary widely from season to season. In a low chlorophyll year such as 2001 concentrations are typically around 30-40 mg per kg oil. This is higher than those usually found in oil extracted from French seed (17-20 mg per kg). Moreover, in some years (e.g. 1999), concentrations from UK seed can exceed 60 mg per kg (Bingham et al. 2003).

The high and inconsistent concentrations compared with imported French seed places UK growers and crushers at a competitive disadvantage, as refiners are becoming increasingly concerned about the additional costs incurred.

Results from a one year pilot study showed that UK varieties differ in seed chlorophyll concentration, and that seasonal variations in weather pattern at harvest may have a significant impact (Bingham et al. 2003). Analysis of seed collected from RL trials in Aberdeen over several years suggests that high concentrations may be associated with particularly dry weather between swathing and harvesting. However, this is not an exclusive cause. In the year 2000, high concentrations were found in seed from commercial crops when the weather during the harvest period was unsettled (Bingham et al. 2003).

Chlorophyll is present in the seed as it develops. Once the embryo has fully expanded and the seed is at physiological maturity, the chlorophyll begins to degrade. There has been little research on chlorophyll degradation in ripening oilseed rape seed under UK conditions. Much of what is known about the process has come from work in Canada on spring rape (*Brassica napus* and *B. rapa*) varieties (Cenkowski et al. 1989, Ward et al. 1992). Chlorophyll degradation occurs more rapidly during warm weather, but its rate is restricted by low seed moisture content. It is possible that rapid drying of swathed crops during warm dry weather reduces the extent to which chlorophyll is degraded in the ripening seed (Brown et al. 1999).

It is also possible that premature harvesting during unsettled weather might contribute to high seed chlorophyll concentrations. A large proportion of immature seed in the crop could lead to high concentrations in the sample if there has been insufficient time allowed for the chlorophyll to clear. Although swathing can, under favourable conditions, accelerate the rate of chlorophyll degradation, swathing early will mean that it takes place at a higher initial chlorophyll concentration.

At present there is little information available on the effects of crop husbandry and harvest practice on the seed chlorophyll concentration of UK grown rapeseed, or on its relationship to other seed quality factors including oil concentration. As such, it is not known what the consequences will be for seed chlorophyll concentrations of changing management practices to maximise oil yield. Nor is it known whether there is scope for minimising chlorophyll concentrations through changes in husbandry and harvest practice.

Experiments were conducted at three sites and over three years to investigate the effects of husbandry practice on seed oil concentrations. In this part of the project, samples from the same experiments were analysed for chlorophyll.

2. Materials and Methods

Seed samples were collected from the trials described in Part A - Factors that Influence the % Oil Content of Rape Seed and dispatched to SAC for analysis of chlorophyll concentration. On arrival at SAC, the samples were stored dry at 4^{o}C prior to analysis.

Chlorophyll and related pigments were extracted and determined using a modification of the method developed by Bingham et al. (2003). The modification involved agitation of the homogenised sample to ensure a more complete extraction of chlorophyll and a second centrifugation step to improve the optical clarity of the extract. Full details are given below.

Seed samples were mixed thoroughly and approximately 2g sub-sample taken from each and weighed to the nearest 0.1mg. The sub-samples were then transferred to 50ml centrifuge tubes and 10 ml ice-cold solvent (n-heptane : ethanol 3 : 1[v/v]) added to each. The tubes were then placed in an ice bucket and seeds ground with an Ultraturrax homoginiser (IKA, Germany) for 60 sec. After homogenising, the tubes were stoppered and gently shaken for 1 h at 4°C. The samples were centrifuged for 10 min in a pre-chilled (4°C) centrifuge (Sorval) at 3000 rpm. A 1.5 ml sample of supernatant was transferred into an eppendorff tube and centrifuged at 13000 rpm for 1 min. The optically clear supernatant was then transferred by pipette to a cuvette with 1 cm path length and its absorbance measured at wavelengths of 630, 665 and 710 nm in a UV/visible spectrophotometer with a bandwidth < 2 nm. The extraction solvent (n-heptane:ethanol 3 : 1[v/v]) was used as the blank.

The chlorophyll concentration of the seed was calculated as:

$$\text{Chlorophyll, mg kg}^{-1} = k \times \frac{A\,corr \times V}{m \times l}$$

Acorr (the corrected absorbance) = A665 – [(A710-A630)/2]
k = 13 mg l^{-1} cm
l = path length in cm
m = weight of seed as received (i.e. at storage moisture content) in g.
V = volume of solute in ml

The method expresses the content of chlorophyll-related pigments in the seed as chlorophyll *a*. A665 is the absorbance of the sample at the wavelength of maximum absorbance for chlorophyll *a*. Absorbance at 630 and 710 nm are used to correct for background. The absorbance coefficient k is taken from the American Oil Chemists Society (AOCS) official method AK 2-92 (Firestone, 1998).

Seed samples of known chlorophyll concentration were included in each batch to serve as an internal standard, enabling variations in extraction efficiency between batches to be corrected for. Statistical analysis of the results was carried in Genstat (Lawes Agricultural Trust).

3. Results

3.1 Effects of site and year

The average seed chlorophyll concentrations differed significantly between sites and years. Concentrations ranged from around 5 mg/kg at Bainton (north) in 2005 to 9 mg/kg at the same site in 2003 (Fig. 1). There was no pattern of concentration with geographical region that was consistent between years. Thus, the highest concentration was found in the north in 2003, but in the east in 2004 and 2005. When averaged across sites, the chlorophyll concentrations were very similar, ranging from 7.78 in 2004 to 6.09 in 2005.

There was no significant linear association between the chlorophyll concentration and the amount of rainfall in June (P = 0.16) and July (P = 91) (Fig. 2). Daily rainfall data were available for two of the three sites. Analysis of these data revealed no significant association between the amount of rain falling in the period from swathing to final harvesting and seed chlorophyll concentration (Fig. 3).

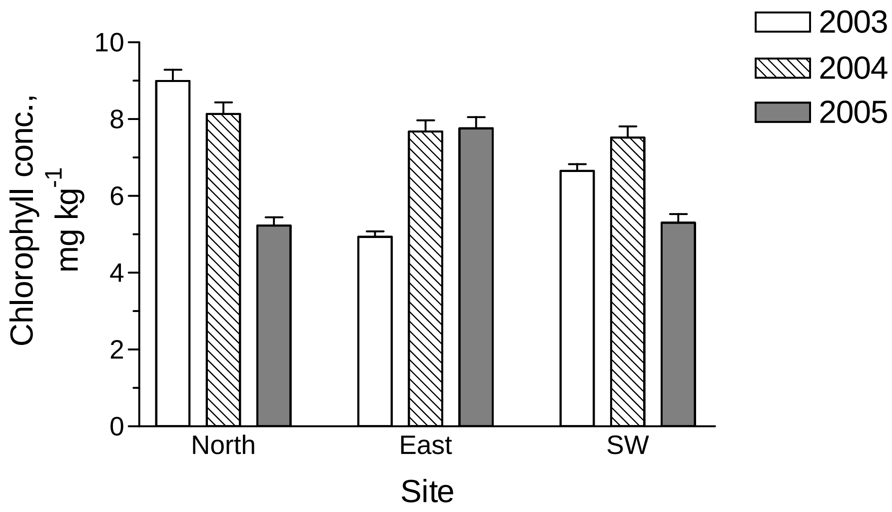


Fig. 1. Variation in seed chlorophyll concentrations between sites and years. Values are means across all treatments and trial series at a particular site. Error bars of SE of mean. The year refers to the harvest year.

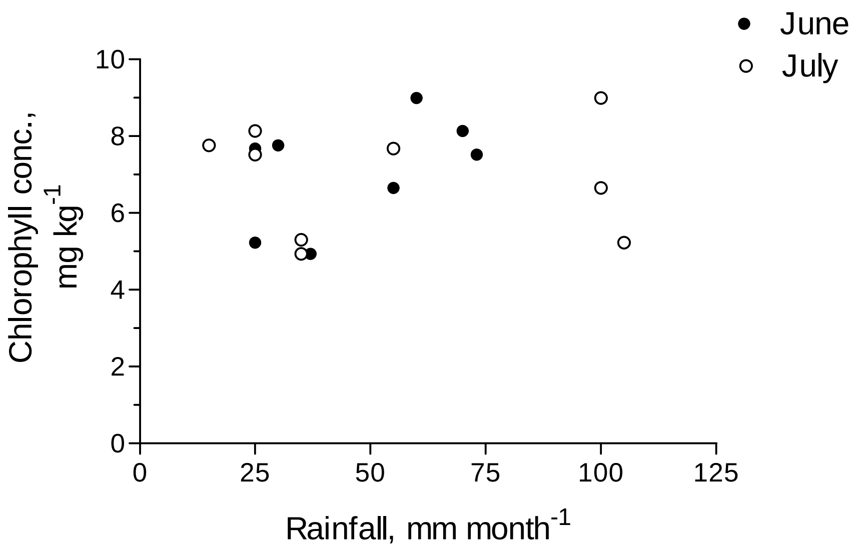


Fig. 2. Relationship between seed chlorophyll concentration and rainfall for the months of June and July. Each point is the mean for a single site/year.

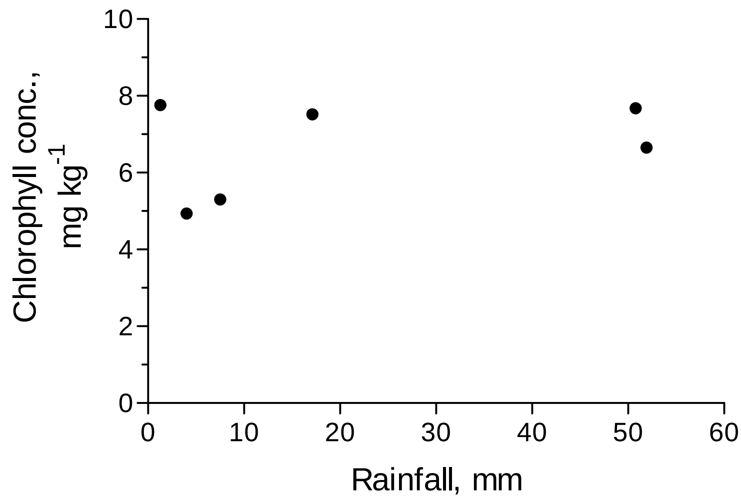


Fig. 3. Relationship between the amount of rain falling from swathing to harvesting and seed chlorophyll concentrations for two sites (east and SW) and over three harvest years 2003, 2004, 2005. Each point is the mean of all trial series for a particular site/year combination.

3.2 Harvest method and timing

In order to determine the effects of pre-harvest method and timing on seed chlorophyll concentration, data for each of the harvest years 2003, 2004 and 2005 have been analysed separately. In 2003, the early desiccation treatment was missed at the northern site (Bainton). Consequently, data for this site were omitted from the analysis of variance so that a balanced design could be adopted to explore interactions between site and pre-harvest method and timing. The data were analysed according to a multi-factorial design with site, variety, harvest method, and timing as the factors. In 2003, the variety Royal was used at each site as an example of a low oil content variety, and Elan as a high content variety. In 2004, Royal was again used at each site, whilst Caracas was the high oil content variety in the north and SW sites and Winner in the East. For the purpose of analysis, Caracas and Winner have been classed as a single variety type (i.e. high oil content) rather than as separate varieties. In 2005, an additional direct harvesting treatment was included in the experiment. Timing was not varied with this treatment, unlike swathing and desiccation. Thus, in order to keep the analysis balanced, timing has been excluded as a main factor, and late desiccation, early desiccation, late swathing, early swathing and direct combining have been considered as five individual harvest treatments. Results of the statistical analyses are given in Appendix 8.

When averaged across the different sites and varieties, there was no significant effect of pre-harvest method on seed chlorophyll concentrations in 2003 and 2004 (Tables 8.1.2 & 8.1.4). This indicates that swathing and desiccation resulted in comparable seed chlorophyll concentrations. Similarly, in

2005, there was no significant effect of harvest treatment, including direct combining, on seed chlorophyll concentrations (Table 8.1.6).

No significant interaction was found between pre-harvest method and either site or variety in 2003 and 2004 which implies that the overall response of seed chlorophyll to swathing and desiccation was similar in each variety and at each site. However, there was a significant effect of the timing of pre-harvest treatment in 2004 (though not 2003), and highly significant interactions between pre-harvest method, timing and site in both 2003 and 2004. These effects are examined in more detail in Figs. 4 and 5.

In 2003, the timing of swathing had no significant effect on the chlorophyll concentration at both the east and SW sites. Similarly, the timing of desiccation had no effect in the east, but early desiccation resulted in a slightly lower (17 %) concentration compared with late desiccation (Fig. 4). A different pattern emerged in 2004. Here, there was no significant effect of varying the timing of desiccation at any site, but varying the time of swathing did influence chlorophyll concentrations. Early swathing reduced the concentration compared to late swathing at the northern site, but increased it in the east and SW by 66% and 39% respectively (Fig. 5). By and large these effects were consistent between varieties as there was no interaction between variety-type, pre-harvest method and timing.

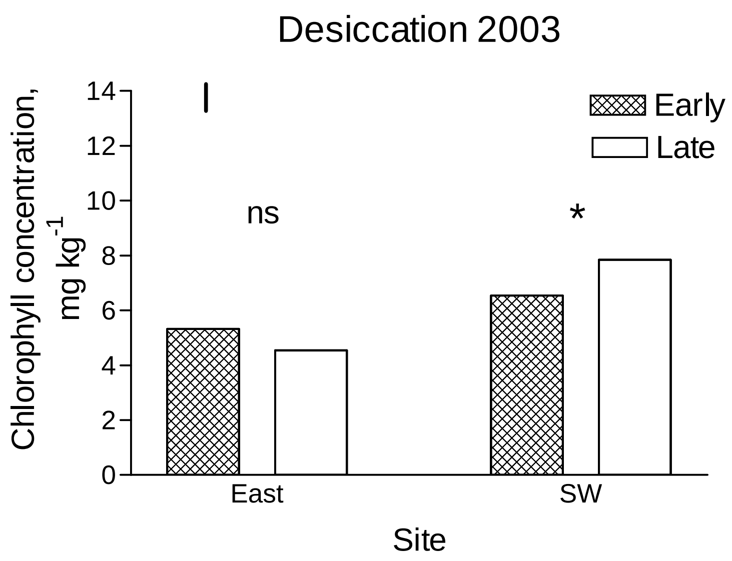


Fig. 4a. Effects of the timing of desiccation with glyphosate on seed chlorophyll concentrations in 2003. Values are means averaged over two varieties (Royal and Elan). Vertical bar shows LSD P = 0.05; * significantly different at P = 0.05; ns, not significantly different.

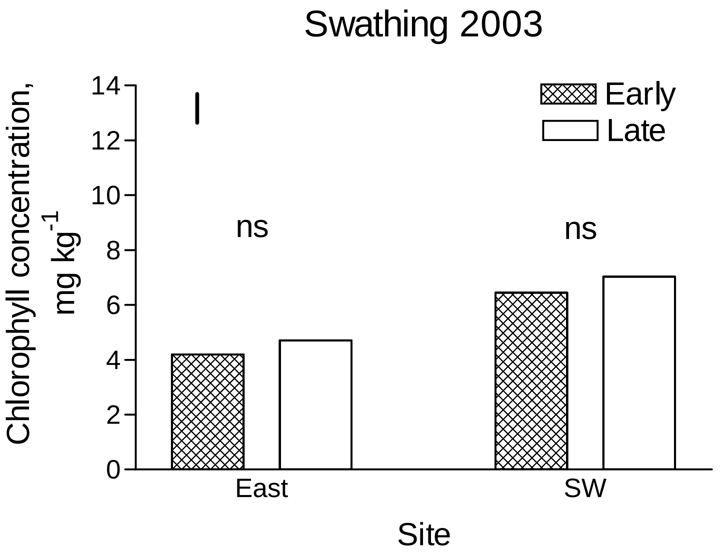


Fig. 4b. Effects of the timing of swathing on seed chlorophyll concentrations in 2003. Values are means averaged over two varieties (Royal and Elan). Vertical bar shows LSD P = 0.05; ns, not significantly different at P = 0.05.

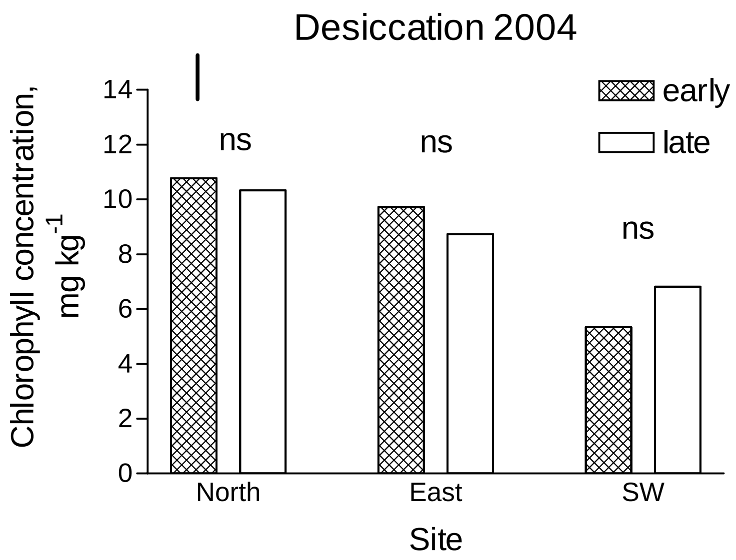


Fig. 5a. Effects of the timing of desiccation with glyphosate on seed chlorophyll concentrations in 2004. Values are means averaged over two variety types (Royal, low oil content; Caracas or Winner, high oil content). Vertical bar shows LSD P = 0.05; ns, not significantly different at P = 0.05.

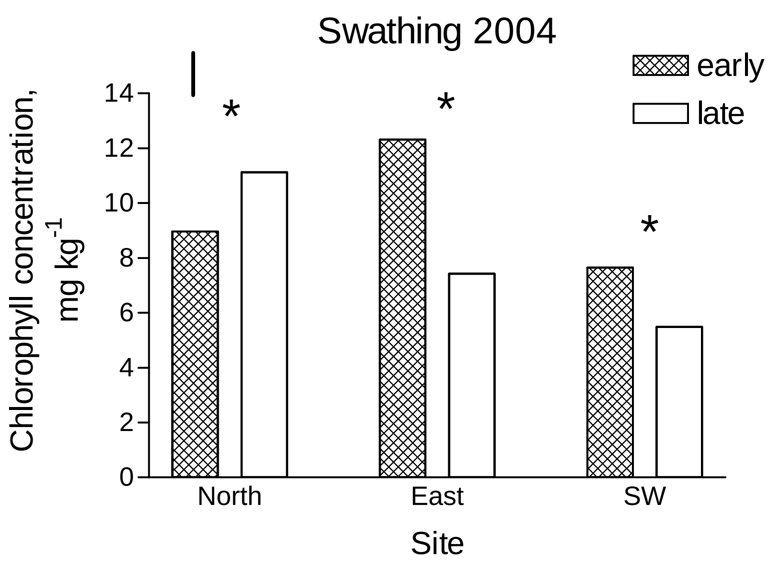


Fig. 5b. Effects of the timing of swathing on seed chlorophyll concentrations in 2004. Values are means averaged over two variety types (Royal, low oil content; Caracas or Winner, high oil content). Vertical bar shows LSD P = 0.05. * significantly different at P = 0.05; ns, not significantly different.

3.3 Fertiliser regime

In 2002/2003, the fertiliser regime applied had no significant effect on the seed chlorophyll concentration of variety Royal (Table 8.2.2). However, only a narrow range of treatments was applied (190 and 240 kg/ha N and 30 and 60 kg/ha S). In 2003/2004 the range was extended. A zero S treatment was included, the lowest dose of N was reduced from 190 to 150 kg/ha, and different N timings were examined. With this combination, highly significant effects of fertiliser regime on seed chlorophyll concentrations were found and a significant interaction between fertiliser regime and site (Table 8.2.4). The latter implied that the response of seed chlorophyll to fertiliser regime differed between sites.

When the effects of S fertiliser were compared at the same dose of N, failure to apply S resulted in significantly higher chlorophyll concentrations (Fig. 6). When averaged over all 3 sites, there was no effect of increasing the dose of S further from 30 to 60 kg/ha, which is consistent with the results of 2002/2003. The greatest response of seed chlorophyll to S fertiliser was found at the north and SW sites (Table 8.2.1).

At a given S dose (30 kg/ha), chlorophyll concentrations increased when N fertiliser was increased from 150 to 240 kg/ha (Fig. 6). There was no significant effect of timing of N on seed chlorophyll (Table 8.2.1).

The fertiliser regime had smaller effects on chlorophyll concentrations in 2004/2005. The results were more variable than in the previous year and thus no significant effect of fertiliser regime was found (Table 8.2.6). However, the pattern of response was the same as that observed in 2003/05. Thus, there was a greater concentration when no S fertiliser was applied, and a small increase in concentration when N was increased from 150 to 240 kg/ha (Fig. 7).

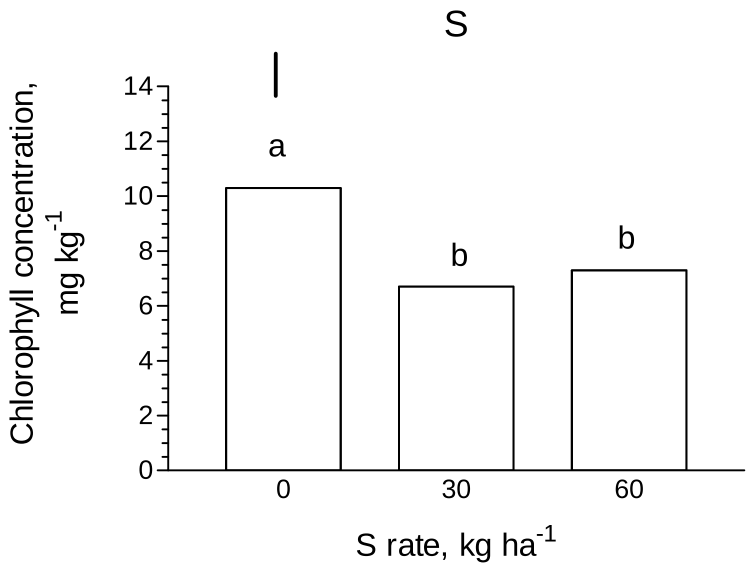


Fig. 6a. Effects of S fertiliser regime on seed chlorophyll concentrations in 2004. Data have been averaged across sites. Response to S is with 190 kg/ha N applied as 90 and 100 kg at the first and second application dates respectively. Columns followed by a different letter are significantly different. Vertical bar represents LSD at P = 0.05.

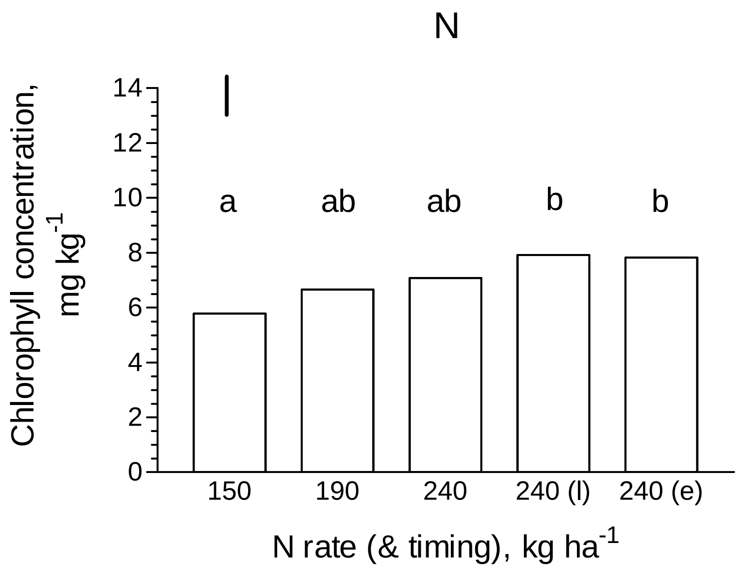


Fig. 6b. Effects of N fertiliser regime on seed chlorophyll concentrations in 2004. Data have been averaged across sites. Response to N is with 30 kg/ha S For doses of 150, 190 and 240 kg N, crops received 90 kg at the first timing and the remainder at the second. For the treatment 240 (l) the split was 90, 100 & 50 kg and for 240 (e) it was 140, 100 & 0 kg at the first, second and third application dates respectively. Columns followed by a different letter are significantly different. Vertical bar represents LSD at P = 0.05.

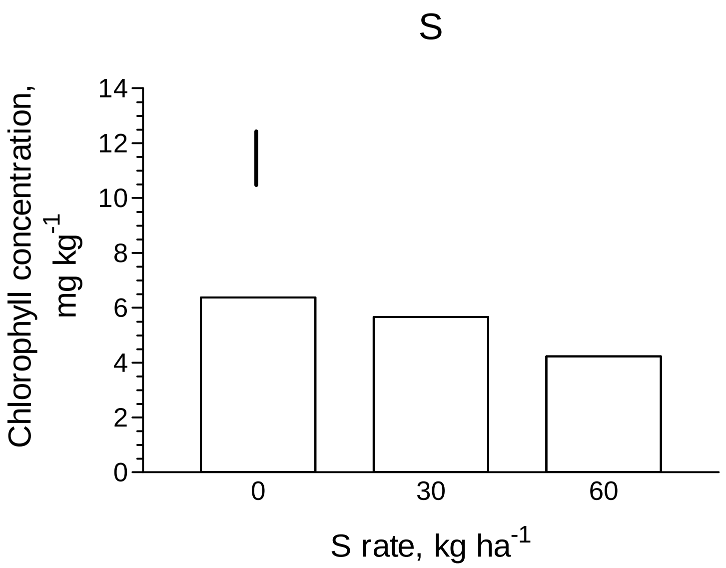


Fig. 7a. Effects of S fertiliser regime on seed chlorophyll concentrations in 2005. Data have been averaged across sites. Response to S is with 190 kg/ha N applied as 90 and 100 kg at the first and second application dates respectively. Vertical bar represents LSD at P = 0.05.

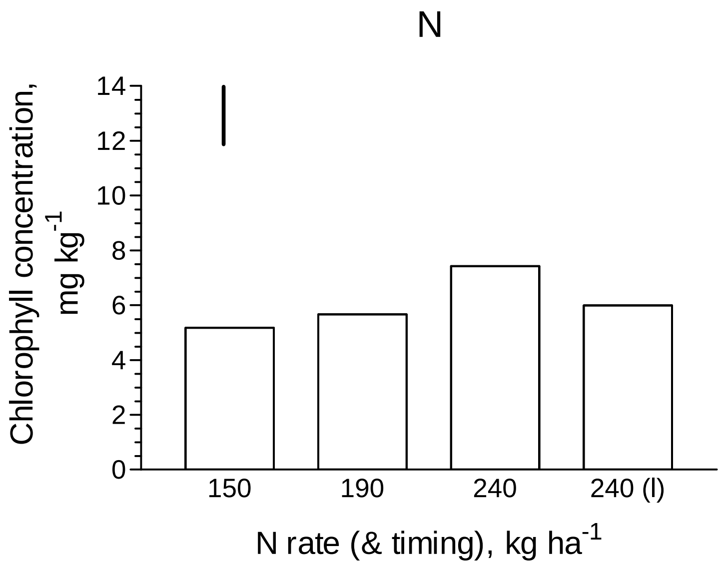


Fig. 7b. Effects of N fertiliser regime on seed chlorophyll concentrations in 2005. Data have been averaged across sites. Response to N is with 30 kg/ha S For doses of 150, 190 and 240 kg N, crops received 90 kg at the first timing and the remainder at the second. For the treatment 240 (l) the split was 90, 100 & 50 kg at the first, second and third application dates respectively. An early N treatment (equivalent to 240 (e) in Fig. 6b) was applied at the SW site only and is therefore not presented here. Vertical bar represents LSD at P = 0.05.

3.4 Canopy management factors

The effects of several factors that influence canopy growth and longevity on seed chlorophyll were investigated in 2004 using the variety Royal. The factors were N timing, fungicide programme and plant density operating in various combinations (Table 8.3.1). Analysis of variance revealed no significant effect of any of the treatments on chlorophyll concentrations, although there were highly significant differences between sites (Table 8.3.2). In 2005 seed from only selected treatments (N timing and crop density) and two sites were analysed. Here too, there was no significant effect of N timing or crop density on chlorophyll concentrations. Nor was there any significant interaction between N and plant density treatments (Table 8.3.4).

3.5 Relationship between seed oil concentration and chlorophyll

The relationship between chlorophyll concentration and oil concentration is shown in Fig. 8. At the north and SW sites, the fertiliser regime influenced both oil and chlorophyll concentrations. In particular, low S and high N tended to reduce oil concentration and increase chlorophyll. By contrast, in the east, the fertiliser regime modified oil concentrations over the range 40-42%, but had relatively little effect on the chlorophyll concentration.

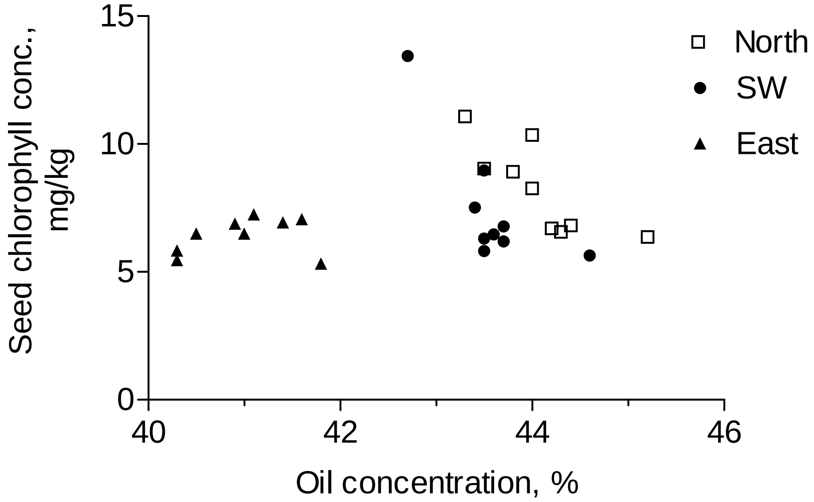


Fig. 8. The relationship between oil concentration and seed chlorophyll concentration for seed samples in 2004. Data are from crops of variety Royal given different fertiliser regimes. Each point is the mean of 3 replicate plots.

4. Discussion

In 2000 and 2001, crushers were reporting chlorophyll concentrations in crude oil from UK rapeseed of 55-60 mg kg^{-1} (Bingham et al. 2003). These were unacceptably high and, after correcting for extraction efficiency, equated to concentrations measured in the seed of 14-16 mg kg^{-1} (Bingham et al. 2003). In a more typical year, concentrations in crude oil from UK grown rape tend to be in the region of 30 mg kg^{-1} (seed concentrations of 6-7 mg kg^{-1}). When averaged over experimental treatments and sites, seed concentrations found in the present study varied between 6 and 8 mg kg^{-1}. Thus, over the three years of the study, chlorophyll concentrations were on average in the range acceptable to the crushers, although higher than those often found in seed imported from France (Bingham et al. 2003). Nevertheless, with some site and treatment combinations, concentrations exceeded 11 mg kg^{-1} and thus approached levels that would begin to concern the crushers (e.g. Fig. 5).

The rate and extent of chlorophyll degradation is dependent on several factors, including the prevailing climate. The rate of chlorophyll degradation is temperature dependent and occurs more rapidly at warmer temperatures. Low temperatures coinciding with ripening of late-sown crops in Canada can result in high seed chlorophyll concentrations at harvest (Ward et al. 1992). However, if the seed dries rapidly during ripening, chlorophyll degradation can be restricted by low seed moisture content leading to high residual concentrations at harvest. However, there is no consensus as to the critical value at which this restriction occurs. Some reports indicate little or no loss of chlorophyll below 35% seed moisture, whilst others have found that in standing crops some, albeit slow, degradation can occur below 20% (Ward et al. 1995). Seed moisture content declines more rapidly in swathed than standing crops (Cenkowski et al. 1993). Thus, swathing in hot dry climates such as northern Idaho, USA, can increase seed chlorophyll concentrations compared to direct combining (Brown et al. 1999). The effects of swathing can be exacerbated if crops are swathed early because chlorophyll concentrations at the time of swathing are higher. Re-wetting of the seed can prolong the chlorophyll degradation process resulting in lower final concentrations (Cenkowski et al. 1993). Although swathing might lead to high chlorophyll retention in dry conditions, under favourable conditions it can accelerate the rate of chlorophyll degradation compared to that in standing crops (Cenkowski et al. 1993).

The variation in chlorophyll concentration from site to site observed in the current study is likely to result from the complex interplay between the initial seed chlorophyll concentration, the time of final harvest, and factors that govern the rate of chlorophyll degradation and loss of seed moisture (i.e. temperature, rainfall and relative humidity). In an analysis of seed saved from several years of RL trials in Aberdeen, high concentrations appeared to be associated with those years where no rain fell between swathing and harvesting. This supports the idea that even in UK conditions, chlorophyll may become trapped if rapid drying occurs following swathing (Bingham et al. 2003). However, in the present study, no relationship was found between the amount of rain falling between swathing and harvesting for two sites and over three years (Fig. 3).

When averaged over sites and timing of operation, there was no significant difference between swathing and desiccation with glyphosate on seed chlorophyll retention. This was observed in each of three years. In 2004, the time of swathing influenced the chlorophyll concentration, but the effects differed between sites. In the north, early swathing reduced the concentration, whereas in the east and SW, it increased retention (Fig. 5). At present, the reasons underlying the different responses are not known but it probably relates to the interplay between initial seed moisture content, temperature and rate of seed moisture loss discussed above. In conclusion, within the range examined in the present study, the effects of the timing of swathing are too inconsistent and unpredictable to justify any change to recommended harvest practice. The timing of desiccation had minor and largely non-significant effects on chlorophyll concentrations.

High rates of N fertiliser tended to increase chlorophyll retention. This effect was observed in 2004 and to a lesser extent in 2005. This may be the result of a greater number of immature branches at harvest with high N supply, containing seed whose chlorophyll had only partially cleared. There might also be effects of N supply in terms of delaying the chlorophyll degradation process. This may be functionally equivalent to the widely observed delay in leaf senescence with high application rates of N. In addition, high chlorophyll concentrations occurred when no sulphur was applied. No effect of S regime was found in 2003, but the lowest application was 30 kg/ha in 2003. The benefits of S fertiliser for reducing seed chlorophyll concentrations were found in 2004 and 2005 when a zero S treatment was included.

There is evidence that chlorophyll concentrations of seed from branches are greater than seed from the main stem (Ward et al. 1992). Buds on branches flower and set seed later than those on the main stem, and consequently, their seeds ripen later and are less mature at harvest. It has been suggested that high seed rates which favour even stand establishment can be used to reduce branching and possibly reduce chlorophyll concentrations at harvest (Ward et al. 1992). However, in the present study, halving the plant population by removing alternate rows of plants after seedling establishment had no significant effect on seed chlorophyll concentrations. Thus, under the conditions prevailing at the experimental sites, seed chlorophyll concentrations appeared to be relatively insensitive to variation in plant density over the approximate range 35-70 plants per m^2.

When the chlorophyll concentration was varied through N treatments, there appeared to be a negative association with the seed oil concentration in the north and SW, but not the east. There is no mechanistic link between oil deposition and chlorophyll degradation, and thus where an association is found it reflects the independent response of both oil and chlorophyll concentrations to the same experimental treatment. A lack of correlation between oil and chlorophyll concentrations has been reported elsewhere (Ward et al. 1995).

5. Conclusions and recommendations

A large proportion of immature seed in a sample, or conditions restricting the natural breakdown of chlorophyll during ripening can lead to high seed chlorophyll concentrations at harvest. Whilst a red seed coat can indicate immaturity, it is not a reliable indicator of seed quality, because the colour of the seed coat can also differ between varieties. A better test of potential problems with high chlorophyll concentrations in a sample is to crush the seed and examine the cotyledons inside. In a good sample, the cotyledons should be yellow; poor samples have a proportion of seeds with cotyledons that are distinctly green. Crushers in the UK may be unwilling to accept seed lots with more than about 5% of green seed.

Results from the current and previous project (Bingham et al. 2003) indicate that chlorophyll retention in seed differs between varieties. The variety Apex seems to be particularly susceptible to retaining high chlorophyll concentrations under UK conditions. Apex was the variety grown most extensively during the years when crushers reported problems with high chlorophyll concentrations in crude oil. Since the decline in popularity of Apex amongst growers, fewer problems have been encountered, although occasional seed lots are found with unacceptable levels of green seed. Harvest method and timing, over the range examined in the current work, had no consistent effect on the chlorophyll concentration, but high N and inadequate S fertiliser tended to increase the concentration. Concentrations differed between sites, and the differences are likely to result from interactions between the physiological state of the crop at the onset of seed ripening and the prevailing climatic conditions.

Recommendations to minimise seed chlorophyll concentrations:

i. With the passing of Apex, fewer problems are likely to be encountered than in previous years. However, it is recommended that a watching brief be kept on new varieties entering the market for their susceptibility to chlorophyll retention.
ii. Avoid applications of high rates of N fertiliser (above the current RB209 recommendation of 190 kg/ha on SNS index 1 soils).
iii. Apply sulphur, especially on S deficient sites.

These recommendations are similar to those made for maximising seed oil content, and thus management for these two independent aspects of seed quality (oil and chlorophyll concentration) are compatible.

6.1 Acknowledgements

SAC received financial assistance from the Scottish Executive Environment and Rural Affairs Department. We are grateful to Linda Paterson and Brian Pool (SAC) for conducting the chlorophyll analyses and to colleagues at TAG for supplying the samples.

6.2 References:

Bingham IJ, Kightley SPJ and Walker K. 2003. Identifying the factors determining the chlorophyll content of UK rapeseed. Project Report No. OS61, Home-Grown Cereals Authority, London.

Brown J, Davis JB, Erickson DA, and Brown AP. 1999. Effects of swathing on yield and quality of spring canola in northern Idaho. *Journal of Production Agriculture* 12: 33-37.

Cenkowski S, Jayas DS and Daun JK. 1993. Potential of in-field and low temperature drying for reducing chlorophyll contents in canola (*Brassica napus* L*). Journal of the Science of Food and Agriculture* 63: 377-383.

Cenkowski S, Sokhansznj A and Sosulski FW. 1989. Effects of harvest date and swathing on moisture content and chlorophyll content of canola seed. *Canadian Journal of Plant Science* 69: 925-928.

Firestone D. 1998. Official Methods and Recommended Practices of the American Oil Chemists' Society, 5th Edition, AOCS Press, Champaign. Method Ak 2-92.

Ward K, Scarth R, Daun J and McVetty PBE. 1992. Effects of genotype and environment on seed chlorophyll degradation during ripening in four cultivars of oilseed rape (*Brassica napus*). *Canadian Journal of Plant Science* 72: 643-649.

Ward K, Scarth R, Daun JK, and Vessey JK. 1995. Chlorophyll degradation in summer oilseed rape and summer turnip rape during seed ripening. *Canadian Journal of Plant Science* 75: 413-420.

7. Appendices – Oil content

7.1 Key Results by Season and Site

2002/03

Table 7.1.1 North

Variety	Fertiliser Doses		Pre-harvest Treat and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)
	S kg/ha	N kg/ha				
Royal	30	190	glyphosate early	-	-	-
Royal	30	240	glyphosate early	4.45	43.5	1.94
Royal	60	190	glyphosate early	4.04	43.9	1.77
Royal	60	240	glyphosate early	4.48	43.3	1.94
Royal	30	190	glyphosate late	4.37	44.2	1.93
Royal	30	190	swathed early	4.25	44.1	1.87
Royal	30	190	swathed late	4.28	44.6	1.91
			LSD (P = 0.05)	0.29	0.77	0.14
			Prob.	ns	0.0426	ns
			CV (%)	3.75	0.97	3.96
Elan	30	190	glyphosate early	-	-	-
Elan	30	240	glyphosate early	3.87	47.0	1.82
Elan	60	190	glyphosate early	3.66	47.1	1.72
Elan	60	240	glyphosate early	3.95	46.2	1.83
Elan	30	190	glyphosate late	3.70	47.6	1.76
Elan	30	190	swathed early	4.05	47.4	1.92
Elan	30	190	swathed late	3.93	47.6	1.87
			LSD (P = 0.05)	0.44	0.78	0.19
			Prob.	ns	0.0220	ns
			CV (%)	6.30	0.91	5.86

Table 7.1.2 East

Variety	Fertiliser Doses		Pre-harvest Treat and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)
	S kg/ha	N kg/ha				
Royal	30	190	glyphosate early	3.66	45.0	1.65
Royal	30	240	glyphosate early	3.64	44.8	1.63
Royal	60	190	glyphosate early	3.52	45.7	1.61
Royal	60	240	glyphosate early	3.82	44.7	1.71
Royal	30	190	glyphosate late	3.94	45.6	1.80
Royal	30	190	swathed early	3.62	45.0	1.63
Royal	30	190	swathed late	3.24	45.3	1.47
Elan	30	190	glyphosate early	4.17	47.2	1.97
Elan	30	240	glyphosate early	4.59	46.4	2.13
Elan	60	190	glyphosate early	4.51	46.6	2.10
Elan	60	240	glyphosate early	4.57	47.8	2.19
Elan	30	190	glyphosate late	4.56	45.9	2.10
Elan	30	190	swathed early	4.10	47.9	1.99
Elan	30	190	swathed late	3.86	47.3	1.82
			LSD (P = 0.05)	0.34	1.69	0.18
			Prob.	0.0001	0.0019	0.0001
			CV (%)	5.06	2.18	5.67

Table 7.1.3 South-West

Variety	Fertiliser Doses		Pre-harvest Treat and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)
	S kg/ha	N kg/ha				
Royal	44	190	glyphosate early	3.81	41.6	1.59
Royal	44	240	glyphosate early	3.92	40.7	1.62
Royal	84	190	glyphosate early	3.80	41.7	1.58
Royal	84	240	glyphosate early	3.92	40.3	1.58
Royal	44	190	glyphosate late	3.68	42.0	1.54
Royal	44	190	swathed early	3.28	41.1	1.35
Royal	44	190	swathed late	3.62	41.8	1.51
Elan	44	190	glyphosate early	3.97	46.0	1.81
Elan	44	240	glyphosate early	4.01	44.8	1.80
Elan	84	190	glyphosate early	3.86	45.6	1.76
Elan	84	240	glyphosate early	4.00	44.2	1.74
Elan	44	190	glyphosate late	3.86	46.2	1.78
Elan	44	190	swathed early	2.70	45.1	1.22
Elan	44	190	swathed late	3.37	45.3	1.51
			LSD (P = 0.05)	0.28	1.05	0.14
			Prob.	0.0001	0.0001	0.0001
			CV (%)	4.51	1.40	4.94

2003/04 Trial Series 1

Table 7.1.4 North

1st Fertiliser Dose		2nd Dose	3rd Dose	Yield	Oil	Oil Yld	TSW	Canopy Green	Pod shatter
S kg/ha	N kg/ha	N kg/ha	N kg/ha	(t/ha)	(%)	(t/ha)	(g)	(1-5)	(%)
30	90	60	0	4.10	45.2	1.85	4.5	3.0	12
30	90	100	0	4.41	44.3	1.95	4.9	3.3	10
30	90	150	0	4.42	43.8	1.94	4.7	4.7	15
30	90	0	100	4.30	44.2	1.90	4.8	3.3	17
30	90	100	50	4.16	43.3	1.80	4.7	3.3	17
30	140	100	0	4.19	43.5	1.82	4.5	3.7	12
60	90	100	0	4.24	44.0	1.87	4.7	3.0	10
60	90	150	0	4.51	44.4	2.02	4.8	3.3	15
0	90	100	0	4.11	44.0	1.81	4.4	1.7	10
LSD (P = 0.05)				0.323	0.89	0.16	0.60	1.13	5.4
Prob.				ns	0.0151	ns	ns	0.0066	0.0525
CV (%)				4.36	1.15	4.80			

Table 7.1.5 East

1st Fertiliser Dose		2nd Dose	3rd Dose	Yield	Oil	Oil Yld	TSW
S kg/ha	N kg/ha	N kg/ha	N kg/ha	(t/ha)	(%)	(t/ha)	(g)
30	90	60	0	3.29	41.8	1.37	4.5
30	90	100	0	3.44	41.4	1.42	4.3
30	90	150	0	3.19	40.5	1.29	4.2
30	90	0	100	2.99	40.9	1.23	4.2
30	90	100	50	3.23	41.0	1.33	4.2
30	140	100	0	2.97	40.3	1.20	4.2
60	90	100	0	3.09	41.1	1.27	4.0
60	90	150	0	3.15	40.3	1.27	4.1
0	90	100	0	3.08	41.6	1.29	3.8
LSD (P = 0.05)				0.403	1.00	0.19	0.26
Prob.				ns	1.41	ns	0.0024
CV (%)				7.37	0.0385	8.35	

Table 7.1.6 South-West

1st Fertiliser Dose		2nd Dose	3rd Dose	Yield	Oil	Oil Yld	TSW	Canopy	Height
S kg/ha	N kg/ha	N kg/ha	N kg/ha	(t/ha)	(%)	(t/ha)	(g)	(GAI)	(cm)
30	90	60	0	2.78	44.6	1.24	4.7	3.50	148
30	90	100	0	2.82	43.6	1.23	4.7	3.67	152
30	90	150	0	2.92	43.5	1.27	4.5	3.83	153
30	90	0	100	3.29	43.7	1.44	4.9	3.50	148
30	90	100	50	3.26	43.7	1.42	4.7	3.83	154
30	140	100	0	3.36	43.5	1.46	4.9	3.67	152
60	90	100	0	3.20	43.5	1.39	5.0	3.67	152
60	90	150	0	3.19	43.4	1.38	4.5	3.67	154
0	90	100	0	1.72	42.7	0.73	5.1	3.00	148
LSD (P = 0.05)				0.413	0.73	0.18	0.58	0.363	2.8
Prob.				0.0001	0.0089	0.0001	ns	0.0062	0.0004
CV (%)				8.09	0.97	8.16			

2003/04 Trial Series 2

Table 7.1.7 North

Crop	N Dose kg/ha		Fungicide	Yield	Oil	Oil Yld	TSW	Leaning	(%) Pod
Density	1st	2nd	Strategy	(t/ha)	(%)	(t/ha)	(g)	(%)	Shatter
standard	70	120	none	4.09	44.3	1.81	4.5	57	13
standard	120	70	none	4.22	44.6	1.88	4.7	47	12
standard	70	120	GB	4.41	45.2	1.99	5.6	0	12
standard	120	70	GB	4.38	45.0	1.97	5.1	0	12
standard	70	120	SE + MF	4.65	45.0	2.09	4.8	10	13
standard	120	70	SE + MF	4.64	45.3	2.10	4.8	0	10
half	70	120	none	4.19	44.6	1.87	4.4	3	12
half	120	70	none	4.32	45.2	1.95	4.9	25	20
LSD (P = 0.05)				0.278	0.68	0.12	0.61	41	9.3
Prob.				0.0057	0.0538	0.0010	0.0254	0.0449	ns
CV (%)				3.64	0.87	3.48			

Table 7.1.8 East

Crop	N Dose kg/ha		Fungicide	Yield	Oil	Oil Yld	TSW	Height
Density	1st	2nd	Strategy	(t/ha)	(%)	(t/ha)	(g)	(cm)
standard	70	120	A	3.68	42.0	1.54	4.8	173
standard	120	70	A	3.67	42.4	1.56	4.4	163
standard	70	120	A + GB	3.67	42.6	1.56	4.7	167
standard	120	70	A + GB	3.42	42.2	1.44	4.5	168
standard	70	120	A + SE + MF	3.48	42.5	1.48	4.5	172
standard	120	70	A + SE + MF	3.60	42.4	1.53	4.6	168
half	70	120	A	3.05	42.3	1.29	4.6	168
half	120	70	A	3.09	42.6	1.32	4.7	167
LSD (P = 0.05)				0.403	0.94	0.18	0.32	6.9
Prob.				0.0174	ns	0.0331	ns	ns
CV (%)				6.66	1.27	7.19		

Table 7.1.9 South-West

Crop	N Dose kg/ha		Fungicide	Yield	Oil	Oil Yld	TSW	Height
Density	1st	2nd	Strategy	(t/ha)	(%)	(t/ha)	(g)	(cm)
standard	70	120	A	2.59	45.1	1.17	5.1	117
standard	120	70	A	2.64	45.3	1.20	5.0	115
standard	70	120	A + GB	2.87	45.4	1.30	5.3	109
standard	120	70	A + GB	2.85	44.7	1.27	5.5	110
standard	70	120	A + SE + MF	3.08	45.3	1.39	5.3	116
standard	120	70	A + SE + MF	2.95	45.7	1.35	5.4	114
half	70	120	A	2.66	45.1	1.20	4.9	109
half	120	70	A	2.49	45.7	1.14	4.6	107
LSD (P = 0.05)				0.567	1.06	0.26	0.53	6.2
Prob.				ns	ns	ns	0.0581	0.0245
CV (%)				11.70	1.33	11.61	5.91	3.15

2003/04 Trial Series 3

Table 7.1.10 North

Variety	Pre-harvest Treat. and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)	Pod Shatter (%)
Royal	glyphosate late	4.35	42.7	1.86	4.8	25
Royal	glyphosate early	4.42	43.3	1.92	5.1	12
Royal	swathed late	4.08	41.9	1.71	4.7	47
Royal	swathed early	3.88	42.5	1.65	4.8	48
Caracas	glyphosate late	4.45	44.1	1.96	5.9	10
Caracas	glyphosate early	4.13	43.9	1.81	5.6	9
Caracas	swathed late	3.78	43.5	1.65	5.5	43
Caracas	swathed early	3.77	43.7	1.65	4.9	63
	LSD (P = 0.05)	0.40	0.72	0.18	0.66	26.2
	Prob.	0.0072	0.0002	0.0059	0.0119	0.0025
	CV (%)	5.50	0.96	5.71		

Table 7.1.11 East

Variety	Pre-harvest Treat. and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)	Losses 000 seeds/m2
Royal	glyphosate late	3.34	40.1	1.34	4.2	2.8
Royal	glyphosate early	3.07	40.1	1.23	4.0	2.8
Royal	swathed late	3.08	39.6	1.22	4.2	3.2
Royal	swathed early	2.74	38.5	1.05	3.7	2.7
Winner	glyphosate late	3.47	42.2	1.46	4.8	2.5
Winner	glyphosate early	3.30	41.7	1.38	4.5	3.0
Winner	swathed late	3.17	42.3	1.34	4.6	2.8
Winner	swathed early	2.86	41.0	1.17	4.2	2.4
	LSD (P = 0.05)	0.36	1.59	0.16	0.20	1.2
	Prob.	0.0094	0.0016	0.0021	0.0001	ns
	CV (%)	6.54	2.24	7.19		

Table 7.1.12 South-West

Variety	Pre-harvest Treat. and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)
Royal	glyphosate late	3.22	43.1	1.39	4.7
Royal	glyphosate early	3.33	43.5	1.45	5.0
Royal	swathed late	3.39	43.3	1.46	5.3
Royal	swathed early	3.19	43.0	1.37	5.0
Caracas	glyphosate late	2.63	44.4	1.17	5.3
Caracas	glyphosate early	2.39	44.2	1.06	5.2
Caracas	swathed late	2.39	44.2	1.06	5.3
Caracas	swathed early	2.49	44.1	1.10	5.5
	LSD (P = 0.05)	0.502	0.94	0.23	0.85
	Prob.	0.0010	0.0264	0.0029	ns
	CV (%)	9.96	1.23		

2004/05 Trial Series 1

Table 7.1.13 North

1st Fertiliser Dose		2nd Dose	3rd Dose	Yield	Oil	Oil Yld	TSW
S kg/ha	N kg/ha	N kg/ha	N kg/ha	(t/ha)	(%)	(t/ha)	(g)
30	90	60	0	4.49	43.0	1.93	5.2
30	90	100	0	4.72	42.3	2.00	4.8
30	90	150	0	4.88	41.8	2.05	5.2
30	90	0	100	4.91	42.3	2.08	5.0
30	90	100	50	4.89	42.2	2.06	5.4
60	90	60	0	5.34	42.4	2.27	5.4
60	90	100	0	4.96	42.5	2.11	5.2
60	90	150	0	4.99	43.1	2.12	5.1
0	90	100	0	4.68	42.2	1.98	5.3
LSD (P = 0.05)				0.396	0.92	0.21	0.81
Prob.				0.0294	ns	ns	ns
CV (%)				4.52	1.25	5.53	

Table 7.1.14 East

1st Fertiliser Dose		2nd Dose	3rd Dose	Yield	Oil	Oil Yld	TSW	Canopy	Height
S kg/ha	N kg/ha	N kg/ha	N kg/ha	(t/ha)	(%)	(t/ha)	(g)	Size (1-5)	(cm)
30	90	60	0	3.22	42.7	1.38	4.0	2.3	147
30	90	100	0	3.30	41.4	1.36	4.0	3.7	152
30	90	150	0	3.53	41.4	1.46	4.0	4.0	154
30	90	0	100	3.63	41.8	1.52	4.1	3.7	142
30	90	100	50	3.68	41.3	1.52	4.2	4.7	152
60	90	60	0	3.71	43.3	1.61	4.1	2.3	145
60	90	100	0	3.33	42.3	1.41	4.0	2.3	149
60	90	150	0	3.61	41.2	1.48	4.0	3.0	146
0	90	100	0	3.57	42.0	1.50	4.1	2.7	150
LSD (P = 0.05)				0.519	0.73	0.23	0.21	1.41	6.0
Prob.				ns	0.0001	ns	ns	0.0204	0.0088
CV (%)				8.45	1.01	8.86			

Table 7.1.15 South-West

1st Fertiliser Dose		2nd Dose	3rd Dose	Yield	Oil	Oil Yld	TSW
S kg/ha	N kg/ha	N kg/ha	N kg/ha	(t/ha)	(%)	(t/ha)	(g)
30	90	60	0	3.24	41.2	1.33	4.1
30	90	100	0	3.70	41.4	1.53	4.1
30	90	150	0	3.48	41.2	1.44	4.3
30	90	0	100	3.71	41.4	1.54	4.1
30	90	100	50	3.65	40.9	1.49	3.9
30	140	100	0	3.38	41.8	1.41	4.3
60	90	100	0	3.51	41.0	1.34	4.2
60	90	150	0	3.50	40.7	1.42	4.2
0	90	100	0	3.04	40.3	1.23	4.3
LSD (P = 0.05)				0.483	0.88	0.25	0.37
Prob.				ns	ns	ns	ns
CV (%)				8.04	1.23	10.11	

2004/05 Trial Series 2

Table 7.1.16 North

Crop Density	N Dose kg/ha 1st	2nd	Fungicide Strategy	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)	Lodging (%)
Standard	70	120	A	4.12	43.2	1.78	6.8	1
Standard	120	70	A	4.23	43.5	1.84	5.2	20
Standard	70	120	A + GB	4.35	43.5	1.89	6.4	1
Standard	120	70	A + GB	4.02	43.1	1.73	5.6	1
Standard	70	120	A + SE + MF	4.79	43.4	2.08	5.1	17
Standard	120	70	A + SE + MF	4.41	43.3	1.91	4.9	20
half	70	120	A	4.43	43.3	1.92	6.6	2
half	120	70	A	4.03	43.7	1.76	5.3	2
Standard	70	120	none	4.30	43.3	1.86	5.5	25
LSD (P = 0.05)				0.510	0.58	0.23	1.94	37.3
Prob.				ns	ns	ns	ns	ns
CV (%)				6.85	0.77	7.27		

Table 7.1.17 East

Crop Density	N Dose kg/ha 1st	2nd	Fungicide Strategy	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)	Canopy Green (1-5)	Lodging (%)
Standard	70	120	A	3.50	42.0	1.47	4.0	2.7	12
standard	120	70	A	3.76	41.9	1.59	4.2	2.7	23
standard	70	120	A + GB	3.60	41.7	1.50	4.3	3.7	2
standard	120	70	A + GB	3.29	42.0	1.38	4.0	3.3	7
standard	70	120	A + SE + MF	3.63	41.5	1.51	4.1	4.3	17
standard	120	70	A + SE + MF	3.82	43.0	1.65	4.2	4.0	0
half	70	120	A	3.16	41.6	1.31	3.9	3.3	0
half	120	70	A	3.08	41.4	1.28	3.9	4.3	0
Standard	70	120	none	2.77	41.8	1.16	4.4	3.3	8
LSD (P = 0.05)				0.497	1.21	0.24	0.43	0.95	23
Prob.				0.0059	ns	0.0103	ns	0.0098	ns
CV (%)				8.40	1.66	9.58			

Table 7.1.18 South-West

Crop Density	N Dose kg/ha 1st	2nd	Fungicide Strategy	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)	Canopy (GAI)	Height (cm)
standard	70	120	A	3.63	41.5	1.51	4.1	4.08	147
standard	120	70	A	3.46	40.6	1.41	4.1	3.67	141
standard	70	120	A + GB	3.53	41.6	1.47	4.1	3.75	140
standard	120	70	A + GB	3.58	41.3	1.48	4.2	3.58	146
standard	70	120	A + SE + MF	3.78	41.4	1.56	4.1	3.83	145
standard	120	70	A + SE + MF	3.90	41.4	1.62	4.2	3.83	146
half	70	120	A	3.01	41.2	1.19	4.1	3.42	140
half	120	70	A	2.74	40.8	1.12	3.9	3.17	136
standard	70	120	none	3.53	40.9	1.44	4.2	3.50	142
LSD (P = 0.05)				0.449	1.33	0.21	0.21	0.61	5.21
Prob.				0.0013	ns	0.0020	ns	ns	0.0080
CV (%)				7.49	1.85	8.42			

2004/05 Trial Series 3

Table 7.1.19 North

Variety	Pre-harvest Treat. and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)
Royal	glyphosate late	4.60	43.1	1.98	5.1
Royal	glyphosate early	4.61	43.0	1.98	5.8
Royal	swathed late	4.58	43.0	1.97	5.1
Royal	swathed early	3.91	43.4	1.69	5.8
Royal	direct combined	4.41	42.8	1.89	5.3
Lioness	glyphosate late	3.95	44.5	1.77	5.0
Lioness	glyphosate early	4.01	44.6	1.78	5.6
Lioness	swathed late	3.93	44.7	1.76	5.2
Lioness	swathed early	3.62	44.3	1.60	4.7
Lioness	direct combined	3.98	44.3	1.76	5.3
	LSD (P = 0.05)	0.484	0.80	0.21	0.77
	Prob.	0.0033	0.0001	0.0162	ns
	CV (%)	6.69	1.06	6.68	

Table 7.1.20 East

Variety	Pre-harvest Treat. and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)	Seed Loss (000s/m2)
Royal	glyphosate late	4.02	41.4	1.67	4.3	2.6
Royal	glyphosate early	3.99	42.0	1.68	4.4	2.6
Royal	swathed late	3.75	41.6	1.56	4.4	2.9
Royal	swathed early	3.98	41.1	1.63	4.1	3.7
Royal	direct combined	4.16	41.3	1.72	4.0	3.5
Lioness	glyphosate late	3.12	43.2	1.35	4.4	3.5
Lioness	glyphosate early	3.30	43.1	1.42	4.3	3.4
Lioness	swathed late	3.29	42.8	1.41	4.3	3.1
Lioness	swathed early	3.43	42.4	1.46	3.7	2.7
Lioness	direct combined	-	42.9	1.21	4.4	2.8
	LSD (P = 0.05)	0.247	0.61	0.11	0.44	1.50
	Prob.	0.0001	0.0001	0.0001	0.0218	ns
	CV (%)	4.01	0.84	4.21		

Table 7.1.21 South-West

Variety	Pre-harvest Treat. and Timing	Yield (t/ha)	Oil (%)	Oil Yld (t/ha)	TSW (g)
Royal	glyphosate late	3.72	41.0	1.52	4.1
Royal	glyphosate early	3.68	41.5	1.53	4.1
Royal	swathed late	3.58	41.4	1.48	4.3
Royal	swathed early	3.58	41.3	1.48	3.8
Royal	direct combined	3.58	41.8	1.49	4.0
Lioness	glyphosate late	3.03	43.5	1.32	3.9
Lioness	glyphosate early	3.03	43.7	1.32	4.1
Lioness	swathed late	3.13	43.6	1.37	4.1
Lioness	swathed early	2.83	42.8	1.21	3.9
Lioness	direct combined	3.10	43.4	1.34	4.1
	LSD (P = 0.05)	0.416	0.997	0.19	0.35
	Prob.	0.0010	0.0001	0.0241	ns
	CV (%)	7.29	1.37	7.73	

7.2 Application Dates and Growth Stages

2002/03

Table 7.2.1 North

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	20 Feb 03	7 leaves
2nd fertiliser dose (N)	20-25 Mar	26 Mar 03	early stem extension
early glyphosate / swath	5 days pre ideal	04 July 03	10% pods ripe / seeds black
late glyphosate / swath	3-5 days post ideal	10 July 03	30% pods ripe / seeds black

Table 7.2.2 East

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	27 Feb 03	8 leaves
2nd fertiliser dose (N)	20-25 Mar	20 Mar 03	stem extension
early glyphosate / swath	5 days pre ideal	26 June 03	most seeds green / green-brown
late glyphosate / swath	3-5 days post ideal	04 July 03	most seeds brown-black

Table 7.2.3 South-West

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	5 Mar 03	9 leaves
2nd fertiliser dose (N)	20-25 Mar	01 Apr 03	green bud
early glyphosate / swath	5 days pre ideal	03 July 03	most seeds green-brown
late glyphosate / swath	3-5 days post ideal	10 July 03	70-90% seeds brown-black

2003/04 Trial Series 1

Table 7.2.4 North

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	2 Mar 04	8 leaves
2nd fertiliser dose (N)	15-20 Mar	16 Mar 04	9 leaves
3rd fertiliser dose (N)	1-5 April	29 Mar 04	early stem extension

Table 7.2.5 East

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	03 Mar 04	start of stem extension
2nd fertiliser dose (N)	15-20 Mar	30 Mar 04	early green bud
3rd fertiliser dose (N)	1-5 April	06 Apr 04	green bud

Table 7.2.6 South-West

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	26 Feb 04	6 leaves
2nd fertiliser dose (N)	15-20 Mar	17 Mar 04	rosette stage
3rd fertiliser dose (N)	1-5 April	5 Apr 04	mid stem extension

2003/04 Trial Series 2

Table 7.2.7 North

Application	Target Timing	Actual Date	Actual Crop Growth Stage
Punch C 0.4	autumn	not applied	-
1st fertiliser dose (N + S)	20-25 Feb	1 Mar 04	8 leaves
2nd fertiliser dose (N)	15-20 Mar	16 Mar 04	9 leaves
Folicur 0.5	stem extension	26 Mar 04	early stem extension
Folicur 1.0	late green bud	6 Apr 04	green bud
Filan 0.5kg	mid flowering	22 Apr 04	mid flowering

Table 7.2.8 East

Application	Target Timing	Actual Date	Actual Crop Growth Stage
Punch C 0.4	autumn	15 Dec 03	6 leaves
1st fertiliser dose (N + S)	20-25 Feb	02 Mar 04	start of stem extension
2nd fertiliser dose (N)	15-20 Mar	26 Mar 04	mid stem extension
Folicur 0.5	stem extension	17 Mar 04	early stem extension
Folicur 1.0	late green bud	9 Apr 04	late green / early yellow bud
Filan 0.5kg	mid flowering	2 May 04	mid flowering

Table 7.2.9 South-West

Application	Target Timing	Actual Date	Actual Crop Growth Stage
Punch C 0.4	autumn	21 Nov 03	4 leaf
1st fertiliser dose (N + S)	20-25 Feb	26 Feb 04	6 leaf
2nd fertiliser dose (N)	15-20 Mar	26 Mar 04	early stem extension
Folicur 0.5	stem extension	26 Mar 04	early stem extension
Folicur 1.0	late green bud	8 Apr 04	late green bud
Filan 0.5kg	mid flowering	2 May 04	early-mid flowering

2003/04 Trial Series 3

Table 7.2.10 North

Application	Target Timing	Actual Date	Actual Crop Growth Stage
early glyphosate / swath	5 days pre ideal	6 July 04	most seeds green
late glyphosate / swath	3-5 days post ideal	16 July 04	most seeds brown-black but soft

Table 7.2.11 East

Application	Target Timing	Actual Date	Actual Crop Growth Stage
early glyphosate / swath	5 days pre ideal	25 June 04	most seeds green, a few brown
late glyphosate / swath	3-5 days post ideal	07 July 04	60-70% seeds brown-black

Table 7.2.12 South-West

Application	Target Timing	Actual Date	Actual Crop Growth Stage
early glyphosate / swath	5 days pre ideal	5 July 04	most seeds green
late glyphosate / swath	3-5 days post ideal	13 July 04	most seeds brown-black

2004/05 Trial Series 1

Table 7.2.13 North

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	9 Mar 05	early stem extension
2nd fertiliser dose (N)	15-20 Mar	23 Mar 05	early green bud
3rd fertiliser dose (N)	1-5 April	5 Apr 05	yellow bud

Table 7.2.14 East

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	7 Mar 05	8 leaves
2nd fertiliser dose (N)	15-20 Mar	22 Mar 05	mid stem extension
3rd fertiliser dose (N)	1-5 April	8 April 05	late green bud

Table 7.2.15 South-West

Application	Target Timing	Actual Date	Actual Crop Growth Stage
1st fertiliser dose (N + S)	20-25 Feb	25 Feb 05	rosette
2nd fertiliser dose (N)	15-20 Mar	21 Mar 05	stem extension
3rd fertiliser dose (N)	1-5 April	8 Apr 0.5	early yellow bud

2004/05 Trial Series 2

Table 7.2.16 North

Application	Target Timing	Actual Date	Actual Crop Growth Stage
Punch C 0.4	autumn	5 Nov 04	6 leaves
1st fertiliser dose (N + S)	20-25 Feb	4 Mar 05	early stem extension
2nd fertiliser dose (N)	15-20 Mar	23 Mar 05	green bud
Folicur 0.5	stem extension	10 Mar 05	early stem extension
Folicur 1.0	late green bud	29 Mar 05	late green bud
Filan 0.5kg	mid flowering	19 Apr 05	mid flowering

Table 7.2.17 East

Application	Target Timing	Actual Date	Actual Crop Growth Stage
Punch C 0.4	autumn	23 Nov 04	4 leaves
1st fertiliser dose (N + S)	20-25 Feb	17 Feb 05	7 leaves
2nd fertiliser dose (N)	15-20 Mar	18 Mar 05	early stem extension
Folicur 0.5	stem extension	14 Mar 05	early stem extension
Folicur 1.0	late green bud	1 April 05	late green bud
Filan 0.5kg	mid flowering	22 April 05	mid flowering

Table 7.2.18 South-West

Application	Target Timing	Actual Date	Actual Crop Growth Stage
Punch C 0.4	autumn	19 Nov 04	8 leaves
1st fertiliser dose (N + S)	20-25 Feb	25 Feb 05	up to rosette
2nd fertiliser dose (N)	15-20 Mar	21 Mar 05	stem extension
Folicur 0.5	stem extension	05 Apr 05	early green bud
Folicur 1.0	late green bud	11 Apr 05	early yellow bud
Filan 0.5kg	mid flowering	29 Apr 05	mid – full flower

2004/05 Trial Series 3

Table 7.2.19 North

Application	Target Timing	Actual Date	Actual Crop Growth Stage
early glyphosate / swath	5 days pre ideal	11 July 05	most seeds green
late glyphosate / swath	3-5 days post ideal	18 July 05	most seeds brown-black but soft

Table 7.2.20 East

Application	Target Timing	Actual Date	Actual Crop Growth Stage
early glyphosate / swath	5 days pre ideal	4 July 05	60-80% seeds green or red
late glyphosate / swath	3-5 days post ideal	12 July 05	70-90% seeds brown-black

Table 7.2.21 South-West

Application	Target Timing	Actual Date	Actual Crop Growth Stage
early glyphosate / swath	5 days pre ideal	1 July 05	most seeds green / green-brown
late glyphosate / swath	3-5 days post ideal	11 July 05	most seeds brown-black but soft

7.3 Soil and Tissue Analysis Results

Table 7.3.1 Available soil N and S, and malate:sulphate ratio test results (Trials Series 1)

Year	**Location**	**Available Soil N** (kg N/ha)	**Available Soil S** (mg S/kg)	**Malate Test** (malate:sulphate ratio)
2003/04	North	63	11 (ppm)	1.5 (Stem ext.)
	East	107	30.5	1.7 (Stem ext.)
	South-West	108	260 (mg/l)	5.0 (Stem ext.)
2004/05	North	84	7.2	1.9 (Stem ext.)
	East	68	38.7	4.7 (Stem ext.) 0.9 (Flowering)
	South-West	28	28.3	2.0 (Stem ext.)

7.4 Site Details and Overall Inputs

North 2002/03

Location:	Bainton, East Yorkshire
Soil Type:	Panholes, sandy clay loam
Soil Analysis (ppm):	P-22, K-178, Mg-64, Mn-589, S-4, B-2.07, Cu-5, pH-7.8, OM-3.6 %
Previous Crop:	Winter Barley
Drill Date:	01/09/02
Harvest Date:	28/07/03
Seed Rate:	70 seeds/m2 (Royal and Elan)

Input Type	**Product**	**Rate**	**Date**
Herbicide:	Fusilade 250EW	0.57 l/ha	15/02/03
Fertiliser:	Double Top (27% N, 12% S)	86 kg/ha N	20/02/03
(Trial Series 3)		38 kg/ha S	
	46 % N Urea	82 kg/ha N	20/03/03
	46 % N Urea	60 kg/ha N	31/03/03
Fungicides:	Folicur	0.5 l/ha	24/03/03
(Trial Series 1 and 3)			
Insecticides:	Cypermethrin	0.25 l/ha	13/09/02
	Hallmark Zeon	0.05 l/ha	24/03/02
Adjuvant:	Partna	1.1 l/ha	15/02/03
Molluscicide:	Mini Slug Pellets	12.8 kg/ha	10/09/02

East 2002/03

Location:	Biggleswade, Bedfordshire
Soil Type:	Cannamore, (deep calcareous clay loam)
Soil Analysis (ppm):	P-29, K-271, Mg-100, Mn-348, S-13, pH-8.1, OM 3.8%
Previous Crop:	Winter Wheat
Drill Date:	06/09/02
Harvest Date:	14-15/07/03
Seed Rate:	70 seeds per m2 (Royal and Elan)

Input Type	**Product**	**Rate**	**Date**
Nitrogen:	AN 34.5%	50 kg N/ha	21/09/02
(Trial Series 3)	Double Top	70 kg N/ha	26/02/03
		31 kg S/ha	
	AN 34.5%	100 hg N/ha	20/03/03
Herbicides:	Falcon	0.35 l/ha	25/09/02
	Katamaran	2.0 l/ha	30/09/02
	Aramo	1.0 l/ha	28/10/02
Fungicides:	Punch C	0.4 l/ha	01/11/02
(Trial series 1 and 3)	Punch C	0.4 l/ha	19/03/03
Insecticides:	Hallmark Zeon	0.05 l/ha	01/11/02
	Hallmark Zeon	0.075 l/ha	27/03/03
Molluscicides:	Mini-pellets	10.0 kg/ha	06/09/02
	Mini-pellets	8.0 kg/ha	18/09/02

South-West 2002/03

Location:	Cirencester, Gloucestershire
Soil Type:	Elmton 1, Cotswold brash (shallow calcareous clay loam over rock)
Soil Analysis (ppm):	P-25, K-294, Mg-86, Mn-685, S-5, pH-7.9, OM-6.8%
Previous Crop:	Winter Barley
Drill Date:	06/09/02
Harvest Date:	27/07/03
Seed Rate:	70 seeds per m2 (Royal and Elan)

Input Type	**Product**	**Rate**	**Date**
Herbicides:	Butisan S	1.5 l/ha	07/09/02
	Trifluralin	2.0 l/ha	07/09/02
	Falcon	0.25 l/ha	18/09/02
	Laser	1.0 l/ha	07/04/03
Fertiliser:	Double Top (27% N, 12% S)	100 kg/ha N	05/03/03
(Trial Series 3)		44 kg/ha S	
	AN 34.5%	100 kg/ha N	01/04/03
Fungicides:	Punch C	0.4 l/ha	16/11/02
(Trial Series 1 and 3)			
Insecticides:	Hallmark Zeon	0.075 l/ha	18/09/02
	Hallmark Zeon	0.05 l/ha	16/11/02
Adjuvants:	Enhance	0.06 l/ha	18/09/02
	Enhance	0.06 l/ha	16/11/02
	Sprayprover	1.6 l/ha	07/04/03

North 2003/04

Location:	Bainton, East Yorkshire
Soil Type:	Panholes, sandy clay loam
Soil Analysis (ppm):	P-14, K-196, Mg-82, Mn-579, S-6, pH-7.9, OM-3.9, B-1.96
Previous Crop:	Winter Barley
Drill Date:	01/09/03
Seed Rate:	70 seeds per m2 (Royal)
	100 seeds per m2 (Caracas)
Harvest Date:	

Input Type	**Product**	**Rate**	**Date**
Herbicides:	Trifluralin	2.3 l/ha	30/08/03
	Fusilade Max	0.22 l/ha	18/10/03
Fertiliser:	0-26-26	345 kg/ha	08/08/03
(Trial Series 3)	Double Top	86 kg N/ha	26/02/04
		38 kg S/ha	
	Urea 46%	71 kg N/ha	18/03/04
	Urea 46%	75 kg N/ha	30/03/04
Fungicides:	none		
(Trial Series 1 and 3)			
Insecticides:	Cypermethrin	0.25 l/ha	18/10/03

East 2003/04

Location:	Camsix Farm, Hartford End, Chelmsford
Soil Type:	Hanslope series chalky boulder clay
Soil Analysis (ppm):	P-22 , K-93, Mg-49, Mn-307, S-2, pH-7.9, OM-2.4%
Previous Crop:	Winter Wheat
Drill Date:	29/08/03
Seed Rate:	70 seeds per m2 (Royal)
	100 seeds per m2 (Winner)
Harvest Date:	22/07/04

Input Type	**Product**	**Rate**	**Date**
Herbicides:	Katamaran	2.0 l/ha	29/08/03
	Fusilade 250EW	0.5 l/ha	10/11/03
Fertiliser:	AN 34.5%	50 kg/ha N	19/11/03
(Trial Series 3)	Double Top (27% N, 12% S)	80 kg/ha N	02/03/04
		35 kg/ha S	
	AN 34.5 %	100 kg/ha N	26/03/04
	0:24:24	60 kg/ha P+K	26/03/04
Fungicide:	Plover	0.25 l/ha	15/12/03
(Trial Series 1 and 3)			
Insecticides:	Hallmark Zeon	0.075 l/ha	17/09/03
	Hallmark Zeon	0.075 l/ha	10/11/03
Adjuvant:	Partna	1.0 l/ha	10/11/03

South-West 2003/04

Location:	Cirencester, Gloucestershire
Soil Type:	Elmton 1, Cotswold brash (shallow calcareous clay loam over rock)
Soil Analysis (ppm):	P-23, K-285, Mg-85, S-7, pH-7.8
Previous Crop:	Winter Wheat
Drill Date:	04/09/03
Seed Rate:	70 seeds per m^2 (Royal)
	100 seeds per m^2 (Caracas)
Harvest Date:	28/07/04

Input Type	**Product**	**Rate**	**Date**
Fertiliser:	AN 34.5%	100 kg N/ha	08/03/04
(Trial Series 3)	Kieserite	30 kg S/ha	16/03/04
Herbicides:	Katamaran	2.0 l/ha	04/09/03
	Fusilade Max	0.3 l/ha	16/09/04
	Fusilade Max	0.6 l/ha	14/10/03
	Kerb Flo	1.75 l/ha	21/11/03
Insecticide:	Hallmark Zeon	0.05 l/ha	02/05/04
Fungicides:	Punch C	0.4 l/ha	21/11/03
(Trial Series 1 and 3)			

North 2004/05

Location:	Bainton, East Yorkshire
Soil type:	Panholes, sandy clay loam
Soil analysis (ppm):	P-156, K-16, Mg-86, Mn-541, B-1.77, S-5, Cu-6.8, pH-7.8, OM 4.3%
Previous crop:	Winter barley
Drill date:	01/09/04
Seed rate:	70 seeds per m2 (Royal) 100 seeds per m2 (Lioness)
Harvest date:	03/08/05

Input type	**Product**	**Rate**	**Date**
Herbicides:	Trifluralin	2.3 l/ha	03/09/04
	Fusilade Max	0.35 l/ha	23/11/04
Fertiliser:	Double Top (27% N, 12% S)	91 kg/ha N 40 kg/ha S	09/03/05
(Trial Series 3)	AN 34.5%	132 kg/ha N	31/03/05
Fungicides: (Trial Series 1 and 3)	Caramba	0.6 l/ha	03/04/05
Insecticides:	Cypermethrin	0.25 l/ha	27/09/04
	Cypermethrin	0.25 l/ha	23/11/04
Molluscicide:	Mini slug pellets	11.7 kg/ha	13/09/04

East 2004/05

Location:	Biggleswade, Bedfordshire
Soil Type:	Cannamore, deep calcareous clay loam
Soil Analysis: (ppm)	P-17 , K-350, Mg-207, Mn-157, S-5, pH-7.8, OM-3.5%
Previous Crop:	Winter Wheat
Drill Date:	15/09/04
Seed Rate:	70 seeds per m2 (Royal) 100 seeds per m2 (Lioness)
Harvest Date:	18/07/05

Input Type	**Product**	**Rate**	**Date**
Herbicides:	Katamaran	2.0 l/ha	26/10/04
	Falcon	0.7 l/ha	03/11/04
Fertiliser:	AN 34.5%	40 kg/ha N	19/10/04
(Trial series 3)	Double Top (27% N, 12% S)	80 kg/ha N 35 kg/ha S	16/02/05
	AN 34.5 %	100 kg/ha N	22/03/05
Fungicides: (Trial series 1 and 3)	Punch C	0.4 l/ha	16/11/04
Insecticides:	Hallmark Zeon	0.05 l/ha	26/10/04
	Hallmark Zeon	0.075 l/ha	12/04/05
Molluscicides:	metaldehyde mini-pellets	15 kg/ha	05/10/04
	metaldehyde mini-pellets	15 kg/ha	11/11/04

South-West 2004/05

Location:	Cirencester, Gloucestershire
Soil type:	Elmton 1, Cotswold brash (shallow calcareous clay loam over rock)
Soil analysis (ppm):	P-8, K-264, Mg-51, S-7, pH-8.0
Previous crop:	Winter Wheat
Drill date:	07/09/04
Seed rate:	70 seeds per m2 (Royal) 100 seeds per m2 (Lioness)
Harvest date:	19/07/05 – 04/08/05

Input Type	**Product**	**Rate**	**Date**
Herbicides:	Katamaran	2.0 l/ha	10/09/04
	Treflan	2.0 l/ha	10/09/04
	Falcon	1.0 l/ha	01/10/04
	Laser	1.0 l/ha	19/11/04
	Laser	1.0 l/ha	17/02/05
Fertiliser:	AN 34.5%	30 kg/ha N	01/12/04
(Trial Series 3)	Double Top (27% N, 12% S)	90 kg/ha N 30 kg/ha S	25/02/05
	AN 34.5%	100 kg/ha N	21/03/05
Fungicides: (Trial Series 1 and 3)	Punch C	0.4 l/ha	19/11/04
Insecticide:	Hallmark Zeon	0.05 l/ha	19/11/04
Molluscicide:	New Draza	5 kg/ha	04/11/04
Adjuvants:	Output	0.75 l/ha	19/11/04
	Toil	1.0 l/ha	17/02/05

Monthly Rainfall Data

Figure 7.1 Monthly rainfall (mm) for Bainton, East Yorkshire (2002/03 season)

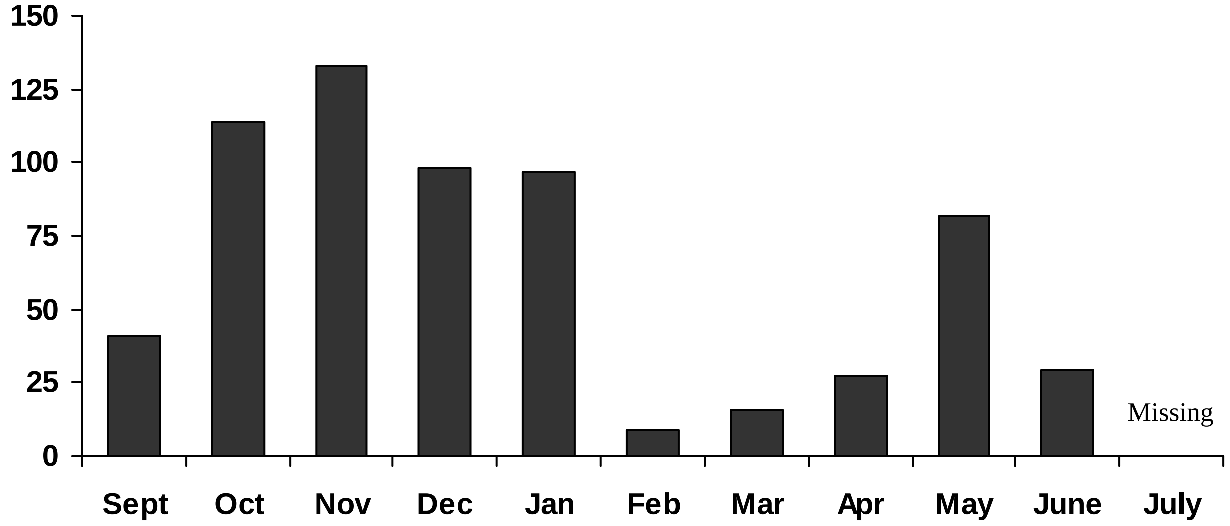


Figure 7.2 Monthly rainfall (mm) for Bainton, East Yorkshire (2003/04 season)

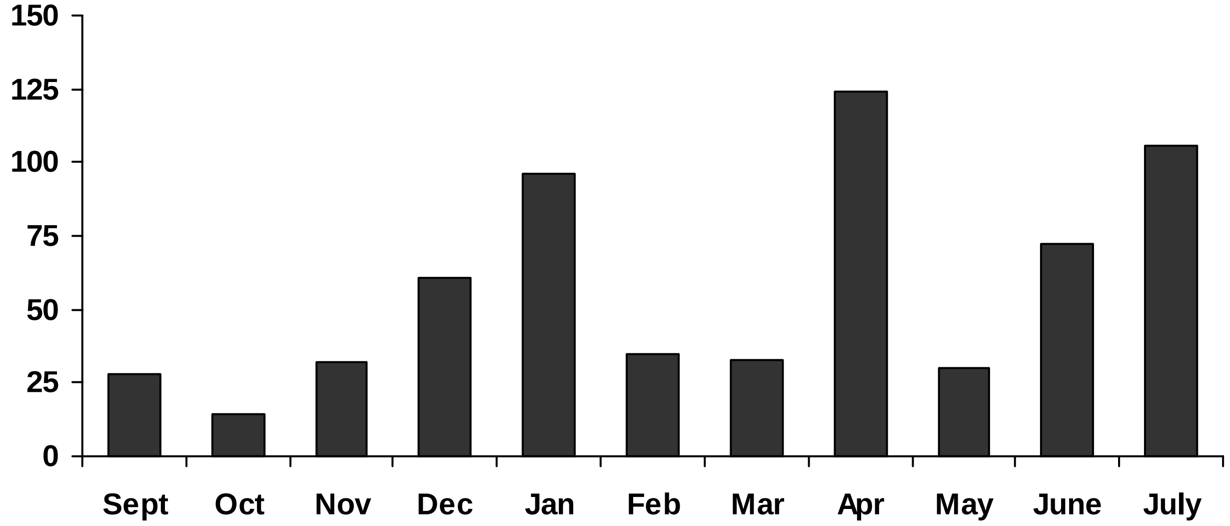


Figure 7.4 Monthly (mm) rainfall for Bainton, East Yorkshire (2004/05 season)

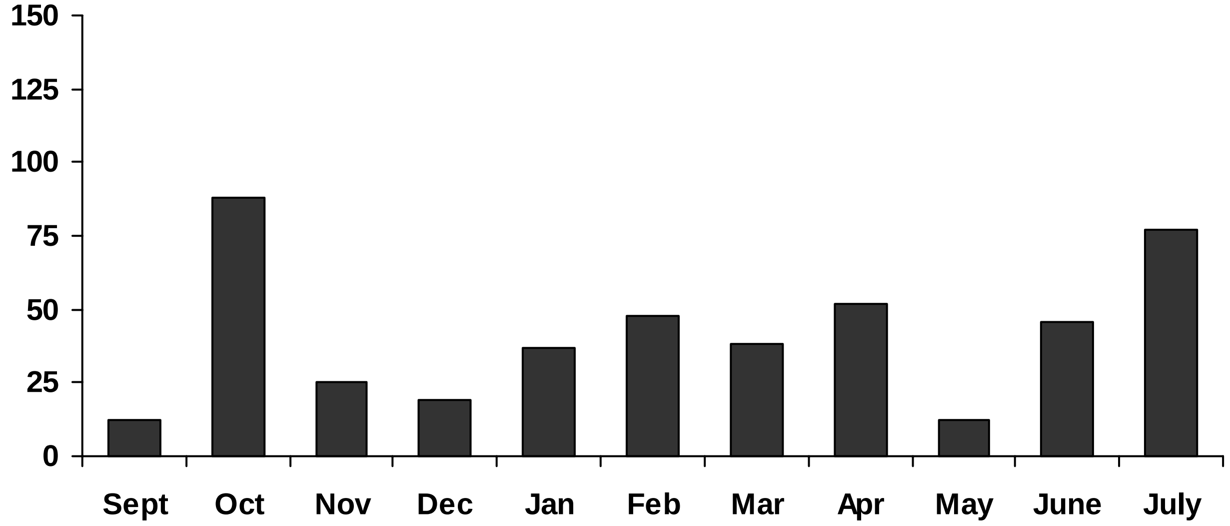


Figure 7.4 Monthly rainfall (mm) for Biggleswade, Bedfordshire (2002/03 season)

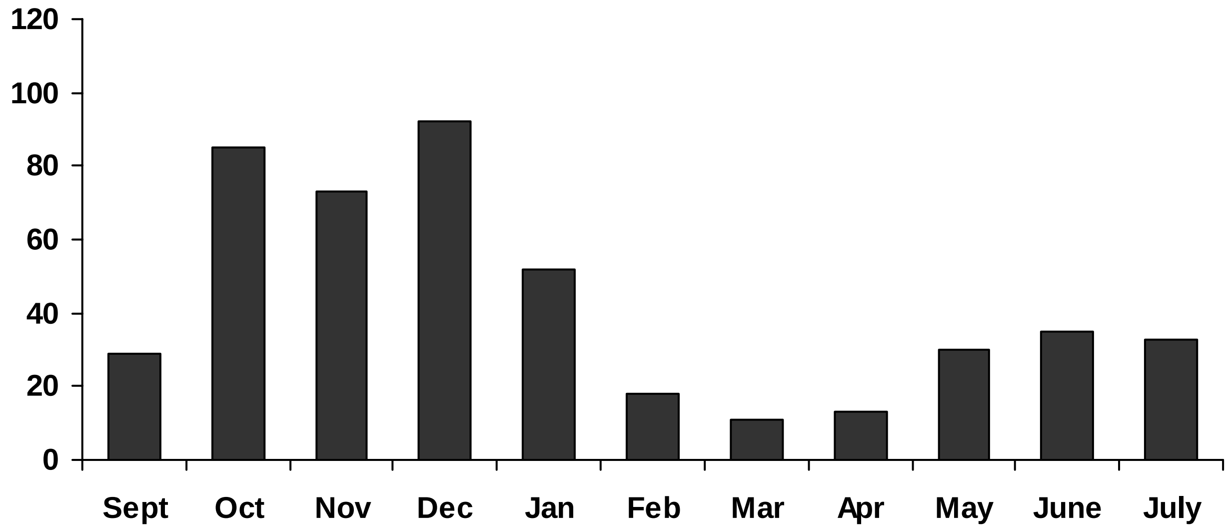


Figure 7.5 Monthly rainfall (mm) for Chelmsford, Essex (2003/04 season, nearest available data**)**

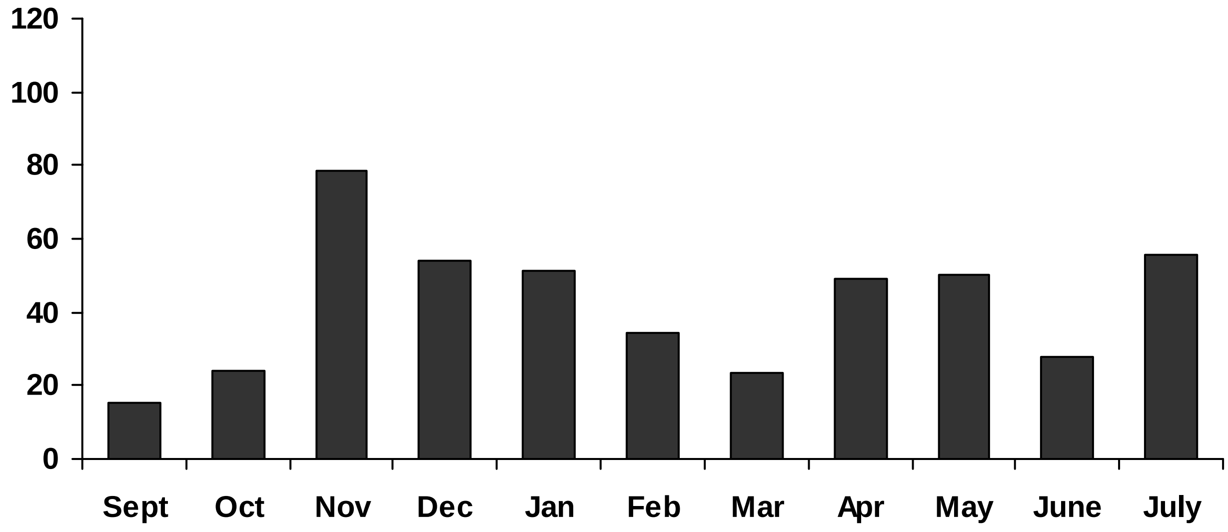


Figure 7.6 Monthly (mm) rainfall for Biggleswade, Bedfordshire (2004/05 season)

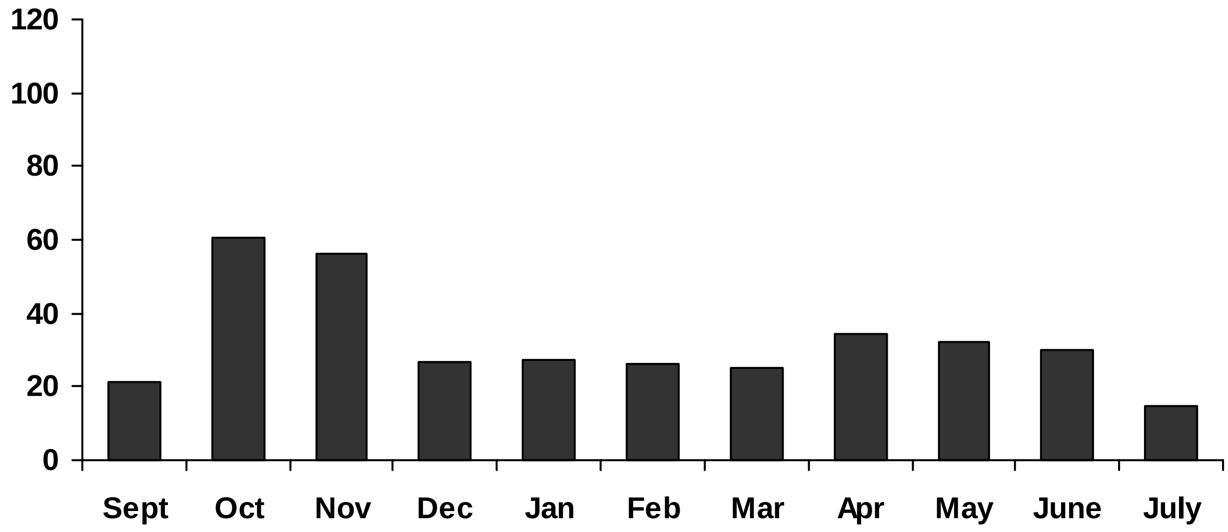


Figure 7.7 Monthly rainfall (mm) for Cirencester, Gloucestershire (2002/03 season)

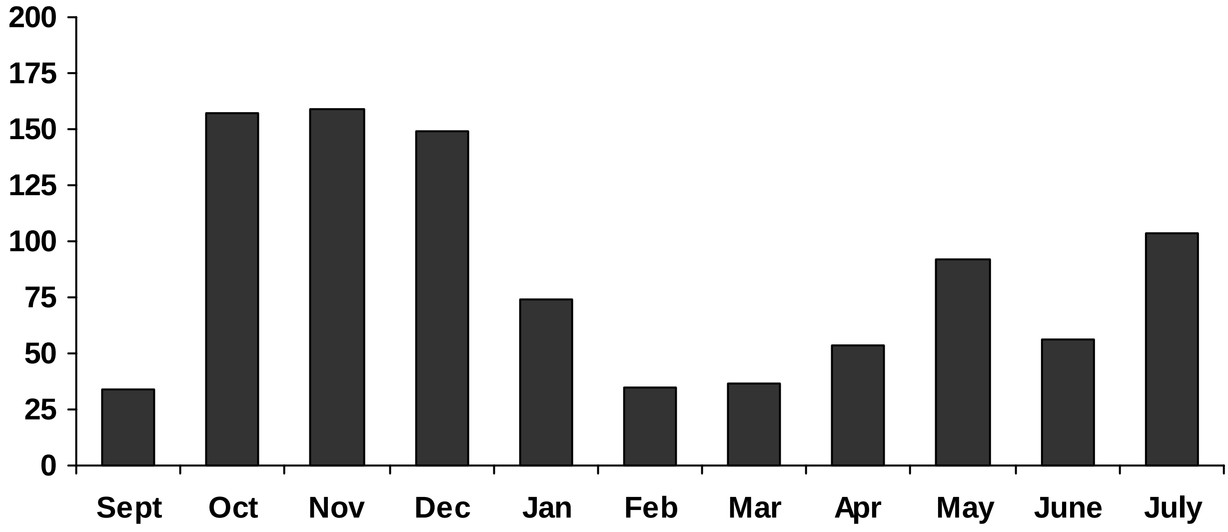


Figure 7.8 Monthly rainfall (mm) for Cirencester, Gloucestershire (2003/04 season)

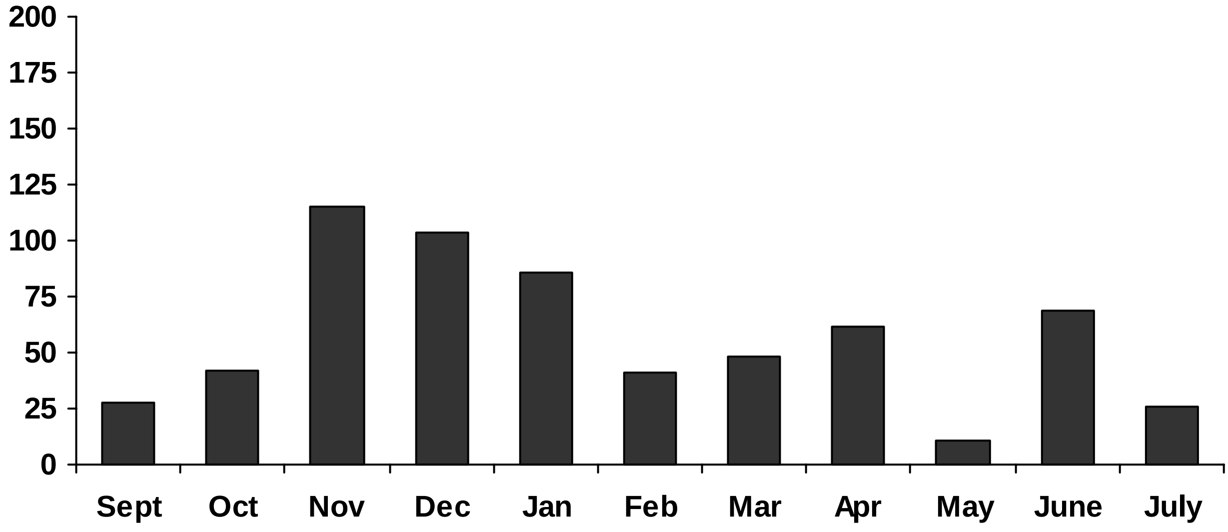
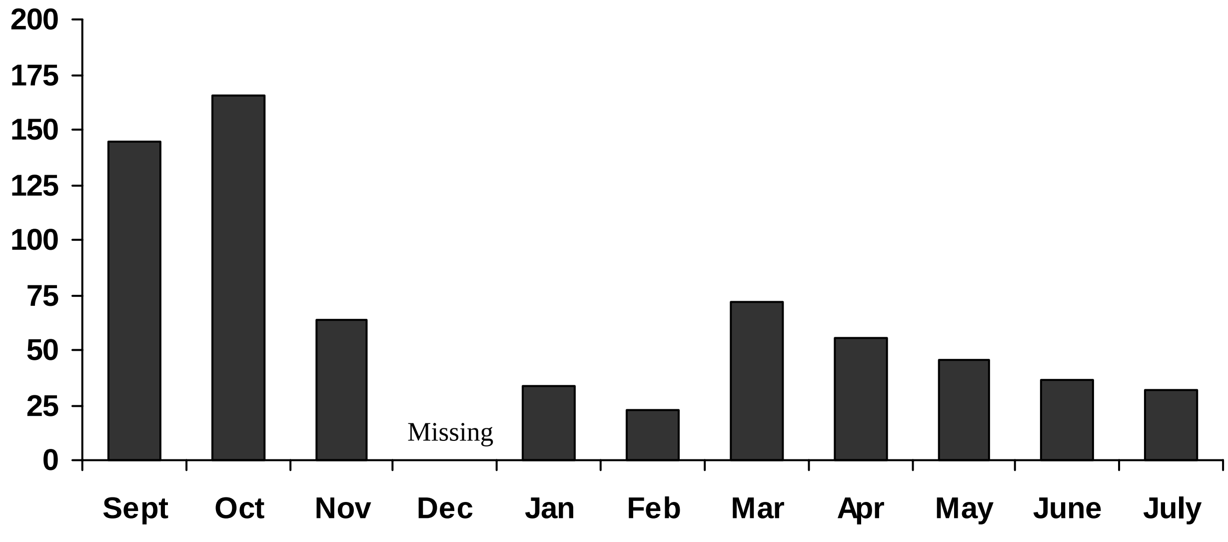


Figure 7.9 Monthly (mm) rainfall for Cirencester, Gloucestershire (2004/05 season)



8. Appendices – Chlorophyll concentrations

8.1 Effects of pre-harvest method and timing on seed chlorophyll concentrations

2002/03

Table 8.1.1 Site means. Values are means of 3 replicates. *at Cirencester (the SW site), the S fertiliser dose was 44 kg/ha

Variety	Fertiliser Doses		Pre-harvest Treat	Chlorophyll mg/kg		
	S kg/ha*	N kg/ha	and Timing	North	East	SW
Royal	30	190	glyphosate early	-	5.75	6.54
Royal	30	190	glyphosate late	7.37	4.52	7.45
Royal	30	190	swathed early	8.12	3.95	5.71
Royal	30	190	swathed late	10.02	5.25	6.67
Elan	30	190	glyphosate early	-	4.88	6.55
Elan	30	190	glyphosate late	7.27	4.57	8.25
Elan	30	190	swathed early	6.49	4.44	7.16
Elan	30	190	swathed late	8.54	4.18	7.38

Table 8.1.2 Analysis of variance on data from the East and SW sites. SEDs are given for 30 df.

	F pr	Significance	SED
Pre-harv method (Harv)	0.063	ns	0.24
Timing	0.103	ns	0.24
Variety	0.425	ns	0.24
Site	<0.001	***	0.24
Harv*Timing	0.557	ns	0.35
Harv*Variety	0.420	ns	0.35
Timing*Variety	0.760	ns	0.35
Harv*Site	0.977	ns	0.35
Timing*Site	0.036	*	0.35
Variety*Site	0.033	*	0.35
Harv*Timing*Variety	0.049	*	0.49
Harv*Timing*Site	0.049	*	0.49
Harv*Variety*Site	0.575	ns	0.49
Timing*Variety*Site	0.720	ns	0.49
Harv*Timing*Variety*Site	0.635	ns	0.69

2003/04

Table 8.1.3. Site means. Varieties have been grouped according to potential oil concentration. The 'low' concentration variety at each site was Royal; the 'high' concentration variety in the North and SW was Caraccas, whilst in the East it was Winner. Values are means of 3 replicates.

Variety type	Pre-harvest Treat and Timing	Chlorophyll mg/kg		
		North	East	SW
Low	glyphosate early	13.22	11.47	5.66
Low	glyphosate late	12.60	9.72	7.30
Low	swathed early	9.72	15.45	7.14
Low	swathed late	11.94	7.93	5.82
High	glyphosate early	8.32	7.96	5.01
High	glyphosate late	8.01	7.73	6.34
High	swathed early	8.19	9.18	8.15
High	swathed late	10.30	6.90	5.16

Table 8.1.4. Analysis of variance of data from N, E and SW sites. SEDs are for 46 df

Variety refers to variety type as outlined above.

	F pr	Significance	SED
Pre-harv method (Harv)	0.569	ns	0.37
Timing	0.033	*	0.37
Variety	<0.001	***	0.37
Site	<0.001	***	0.45
Harv*Timing	0.032	*	0.52
Harv*Variety	0.151	ns	0.52
Timing*Variety	0.266	ns	0.52
Harv*Site	0.401	ns	0.64
Timing*Site	<0.001	***	0.64
Variety*Site	0.003	**	0.64
Harv*Timing*Variety	0.667	ns	0.74
Harv*Timing*Site	<0.001	***	0.91
Harv*Variety*Site	0.094	ns	0.91
Timing*Variety*Site	0.053	ns	0.91
Harv*Timing*Variety*Site	0.339	ns	1.28

2004/05

Table 8.1.5. Site means. Values are means of 3 replicates.

Variety	Pre-harvest Treat and Timing	Chlorophyll mg/kg North	East	SW
Lioness	glyphosate early	4.67	10.81	5.27
Lioness	glyphosate late	5.61	7.54	4.11
Lioness	swathed early	7.70	8.65	5.08
Lioness	swathed late	5.69	11.19	6.06
Lioness	Direct combined	4.90	8.99	4.57
Royal	glyphosate early	5.34	7.71	5.14
Royal	glyphosate late	5.92	8.75	5.01
Royal	swathed early	5.30	7.10	7.24
Royal	swathed late	4.06	6.88	4.94
Royal	Direct combined	6.93	7.61	4.15

Table 8.1.6. Analysis of variance of data from N, E and SW sites. An additional harvest method (direct combining) was included in 2005. The design with regard to timing of harvest treatments was therefore unbalanced, with timing applying only to swathed and desiccated plots. The data were therefore analysed as a 2 x 2 x 5 factorial design (site x variety x harvest treatment). SEDs are for 60 df

Factor	F pr	Significance	SED
Site	<0.001	***	0.36
Treatment	0.592	ns	0.47
Variety	0.054	ns	0.30
Site*Treatment	0.121	***	0.81
Site*Variety	0.014	**	0.51
Treatment*Variety	0.019	*	0.66
Site*Treatment*Variety	0.076	ns	1.15

8.2 Fertiliser regime

2002/2003

Table 8.2.1. Effects of N and S fertiliser regime on seed chlorophyll concentrations of variety Royal at 3 sites (North, East and SW). Values are means of 3 replicate plots. *At the SW site, S doses were 44 and 84 kg/ha instead of the 30 and 60 kg/ha respectively applied at the other two sites.

Variety	Fertiliser Doses		Pre-harvest Treat and Timing	Chlorophyll, mg/kg		
	S kg/ha*	N kg/ha		North	East	SW
Royal	30	190	glyphosate early	-	5.75	6.54
Royal	30	240	glyphosate early	10.00	5.89	5.64
Royal	60	190	glyphosate early	9.80	5.67	5.74
Royal	60	240	glyphosate early	11.41	5.78	6.29
Elan	30	190	glyphosate early	-	4.88	6.55
Elan	30	240	glyphosate early	9.83	5.26	6.41
Elan	60	190	glyphosate early	8.45	4.46	7.43
Elan	60	240	glyphosate early	9.82	4.66	5.94

Table 8.2.2. Analysis of variance. Data for the north site have been excluded to enable a balanced design to be used to explore fertiliser regime, site and variety interactions. SED is given with 27 df.

Factor	F pr	Signif	SED
Fertiliser regime	0.933	ns	0.411
Site	0.001	***	0.291
Variety	0.466	ns	0.291
Fertiliser*Site	0.599	ns	0.582
Fertiliser* Variety	0.619	ns	0.582
Site*Variety	0.016	*	0.411
Fertiliser*Site*Variety	0.555	ns	0.823

2003/2004

Table 8.2.3. Effects of N and S fertiliser regime on seed chlorophyll concentrations of variety Royal at 3 sites (North, East and SW). Values are means of 3 replicate plots.

1st Fertiliser Dose		2nd Dose	3rd Dose	Chlorophyll, mg/kg			Fert
S kg/ha	N kg/ha	N kg/ha	N kg/ha	North	East	SW	mean
30	90	60	0	6.37	5.32	5.65	5.78
30	90	100	0	6.57	6.94	6.47	6.66
30	90	150	0	8.91	6.49	5.81	7.07
30	90	0	100	6.71	6.88	6.78	6.79
30	90	100	50	11.08	6.49	6.19	7.92
30	140	100	0	9.04	5.46	8.97	7.82
0	90	100	0	10.36	7.06	13.44	10.29
60	90	100	0	8.26	7.25	6.30	7.27
60	90	150	0	6.82	5.84	7.52	6.72
Site mean				8.23	6.41	7.46	

Table 8.2.4. Analysis of variance of data in Table 8.2.3. SED is given with 54 df.

Factor	F pr	Significance	SED
Fertiliser regime	<0.001	***	0.81
Site	0.001	***	0.27
Fertiliser*Site	0.009	**	1.41

2004/2005

Table 8.2.5. Effects of N and S fertiliser regime on seed chlorophyll concentrations of variety Royal at 3 sites (North, East and SW). Values are means of 3 replicate plots. * In one treatment combination marked * the fertiliser regime for the North and East sites (given in parentheses) differed from the SW site.

1st Fertiliser Dose		2nd Dose	3rd Dose	Chlorophyll, mg/kg			Fert
S kg/ha	N kg/ha	N kg/ha	N kg/ha	North	East	SW	mean
30	90	60	0	2.97	6.11	6.42	5.17
30	90	100	0	3.94	6.28	6.75	5.66
30	90	150	0	7.27	8.61	6.41	7.43
30	90	0	100	6.11	5.84	3.91	5.29
30	90	100	50	3.97	7.24	6.75	5.99
30 (60)*	140 (90)	100 (60)	0 (0)	5.89	5.36	7.28	
0	90	100	0	7.52	7.90	3.74	6.38
60	90	100	0	2.62	5.66	4.41	4.23
60	90	150	0	4.85	9.28	5.70	6.61
Site mean				5.01	6.92	5.71	

Table. 8.2.6. Analysis of variance of data in Table 8.2.5. SED is given with 48 df.

Factor	F pr	Significance	SED
Fertiliser regime	<0.008	**	1.03
Site	0.138	ns	0.59
Fertiliser*Site	0.192	ns	1.78

8.3 Canopy management (Trial Series 2)

2003/2004

Table 8.3.1. Effects of fungicide regime, N timing and crop density on seed chlorophyll concentrations.

Crop Density	N Dose kg/ha		Fungicide Strategy	Chlorophyll, mg/kg			Treat mean
	1st	2nd		North	East	SW	
Standard	70	120	A	7.18	7.71	9.04	7.98
Standard	120	70	A	6.99	6.16	6.85	6.66
Standard	70	120	A + GB	5.49	6.93	8.45	6.96
Standard	120	70	A + GB	5.43	8.27	11.08	8.26
Standard	70	120	A + SE + MF	5.93	7.25	8.78	7.32
Standard	120	70	A + SE + MF	4.92	6.61	7.80	6.45
half	70	120	A	4.99	7.86	8.90	7.25
half	120	70	A	6.12	7.11	9.50	7.58
Site mean				5.88	7.24	8.80	

Table 8.3.2. Analysis of variance of data in Table 8.3.1. SED are given with 48 df

Factor	F pr	Significance	SED
Treatment	0.237	ns	0.75
Site	<0.001	***	0.46
Treatment*Site	0.542	ns	1.30

2004/2005

Table 8.3.3. Effects of crop density and N timing on the seed chlorophyll concentrations for two sites.

Crop	N Dose kg/ha		Fungicide	Chlorophyll, mg/kg		Treat
Density	1st	2nd	Strategy	North	SW	mean
Standard	70	120	A	3.64	5.24	4.44
Standard	120	70	A	4.43	4.04	4.24
half	70	120	A	4.74	4.00	4.34
half	120	70	A	4.30	5.28	4.79
Site mean				4.28	4.64	

Table 8.3.4. Analysis of variance of data in Table 8.3.3. SED are given with 15 df

Factor	F pr	Signif	SED
N timing	0.86	ns	0.58
Density	0.68	ns	0.58
Site	0.54	ns	0.58
N*Density	0.60	ns	0.82
N*Site	0.91	ns	0.82
Density*Site	0.68	ns	0.82
N*Density*Site	0.13	ns	1.15