Project Report No. 442

November 2008

£4.50

Growing 'high oleic low linolenic' (HOLL) oilseed rape for specialised markets

by

Jim Orson[1], Elaine Booth[2], Colin Merritt[3], Cliff Lea[4]

[1]TAG, The Old Rectory, Morley St. Botolph, Wymondham, Norfolk, NR18 9DB
[2]SAC Aberdeen, Craibstone Farm, Bucksburn, Aberdeen, AB21 9TQ
[3]Monsanto UK Ltd., PO Box 663, Cambourne, Cambridge, CB1 0LD
[4]FUCHS Lubricants plc, New Century Street, Hanley, Stoke-on-Trent, Staffs., ST1 5HU

This is the final report of an HGCA project that ran for forty-four months from August 2004. It was funded by a contract from HGCA (Project No. 3039, £146,819) supported by in-kind contributions from Monsanto plc of £30,000 and from Fuchs Lubricants of £15,000 making a total of £191,819.

Contents

ABSTRACT

The rapeseed oils from HOLL (high oleic and low linolenic) varieties are more suited to some food uses, notably frying oil, and also possibly for biolubricants.

Splendor, the first commercial winter HOLL oilseed rape variety, was sown on six sites in major arable areas in England and Scotland over three years.

Site and season were the most likely causes of variation in fatty acid profiles. The lowest content of the key fatty acid, oleic acid, was consistently found at the Scottish site. Input management had no or little impact on fatty acid profiles. Harvesting a crop before it was completely ripe may result in lower oleic acid content. Commercially, delaying harvest results in a less desirable fatty acid profile.

Oil from Splendor was not directly suitable for the key range of biolubricants and further increases in oleic acid content are required. The desired scale of these increases may only be possible with genetic modification.

Volunteers of previous more conventional crops had minimal effect on the fatty acid profile after a three year break from the previous oilseed rape where cultivations were carried out after harvest to minimise the dormancy of shed seed. This, along with the fact that the ingress of pollen from neighbouring fields has little or no impact on the fatty acid profile of the seed, suggests an opportunity for the UK to grow a significant area of HOLL varieties.

The results show that responses to fungicides are not assured and their use needs to be considered on a field-by-field basis. A malate test early in the season did not reliably predict the sulphur requirement of the current crop at the time S needs to be applied.

SUMMARY

INTRODUCTION

All edible oils and fats consist of triglycerides with a variety of fatty acids, which differ in chain-length (number of carbon atoms in molecule), degree of saturation (number of double bonds in carbon chain), position of double bonds within the carbon chain and geometry of each double bond (*cis* and *trans* isomers). Unsaturated fatty acids, which contain one or more double bonds between adjacent carbon atoms, are the primary cause of the development of oxidative fat decomposition during storage and high temperature cooking, because the double bonds are easily attacked by oxygen.

Oleic acid (C18:1) is the most abundant mono-unsaturated fatty acid (one double bond only) in all common edible oils. Compared with polyunsaturated fatty acids (two or more double bonds) oleic acid is more stable towards oxidation both at ambient storage temperatures and at the high temperatures which prevail when used as a biolubricant or during frying of food. Therefore, oils with high amounts of oleic acid are slower in developing oxidative rancidity during shelf-life or oxidative decomposition during frying than those oils that contain high amounts of polyunsaturated fatty acids.

Winter oilseed rape can be produced competitively in the UK. It has a desirable fatty acid profile when compared to other sources of vegetable oils. Plant breeders have been developing new conventionally bred varieties of winter and spring oilseed rape, appropriate for production in North Europe, that more closely meet the demands of both the food and non-food market. These varieties may be more suitable for the biolubricant and food markets, having a significantly increased mono-unsaturated acid profile (oleic acid) and a reduced content of less desirable polyunsaturated fatty acids (linolenic and linoleic) for these uses. Such HOLL (high oleic and low linolenic) varieties should help to expand the market for oilseed rape oil and protect the home market from imports from other countries that may also have access to such improvements.

This project used the first commercially available HOLL cultivar Splendor to test over three years with the overall aim:

To evaluate and promote the production and value of winter oilseed rape varieties that have been conventionally bred to meet as closely as possible the requirements for biolubricants and other specific uses.

The specific objectives were:

1. To establish a series of six trials/year in order to investigate the impact of agronomic practice, soil type and location on the yield, oil content and fatty acid profile of the varieties that more closely meet the requirements of the food and biolubricant markets. This will help to evaluate and ensure consistency of oil quality in the UK.
2. To establish a committee of stakeholders to steer the field trials, to co-ordinate the analysis and testing of samples and resulting oils produced by the field trials and to help to ensure that the potential for these new varieties is fully exploited.
3. To develop approaches, such as demonstration projects, to increase demand for the products of the new varieties.

The project was steered by a small committee established under the auspices of the National Non Food Crops Centre (NNFCC). This comprised producers (*via* the HGCA), plant breeders, research agronomists and major end users.

METHODS

The treatments (all receiving 30 kg/ha sulphur, except those specifically excluding this nutrient) were determined after a review of the possible impact of location and crop management on oil content and fatty acid profile of oilseed rape. They represented extremes of the major crop inputs, with a nitrogen dose of 190 kg/ha being around the recommended optimum nitrogen application. The autumn/winter application of a fungicide was for the control of phoma stem canker and/or light leaf spot. The full fungicide programme was the autumn/winter application followed by to further applications in the spring.

A total of six sites were sown for three years near Aberdeen, Lincolnshire, Bedfordshire, Norfolk, Gloucestershire and Kent or Wiltshire. Yields were recorded and the plot centres sampled by hand at harvest. These samples were analysed by Monsanto Laboratories for their fatty acid profiles.

RESULTS

Overall yields were low, particularly for the low nitrogen application rate and the responses to fungicides and sulphur occurred in only a few trials (Table 1).

N (kg/ha)	Fungicide	S (kg/ha)	2005 yield (t/ha)	2006 yield (t/ha)	2007 Yield (t/ha)
26	None	30	2.07	2.49	2.17
26	Winter	30	2.01	2.59	2.10
26	Full	30	2.15	2.64	2.28
190	None	30	3.07	3.34	2.78
190	Winter	30	3.20	3.38	2.84
190	Full	30	3.23	3.59	3.09
240	None	30	3.22	3.32	2.85
240	Winter	30	3.27	3.40	2.90
240	Full	30	3.34	3.68	3.10
190	None	-	-	3.04	2.39
190	Winter	-	-	3.03	2.55
190	Full	-	3.13	3.39	2.77

Table 1. Mean yield results from six sites, harvests 2005, 2006, 2007 (t/ha at 9% moisture)

Oil content of the samples was reduced by the application of nitrogen when the chosen ‘optimum’ dose of 190 kg/ha was compared to a minimal nitrogen dose sufficient to apply the required amount of sulphur in ammonium sulphate. There was no or very limited impact of input management on the fatty acid profile of Splendor in individual trials or overall (Table 2).

N	Fungicide	S	Oil 9%	C16 Palmitic	C18 Stearic	C18:1 Oleic	C18:2 Linoleic	C18:3 Linolenic
26	None	30	45.17	4.03	2.01	78.29	12.47	3.22
26	Winter	30	45.24	3.99	2.01	78.38	12.38	3.23
26	Full	30	45.64	3.97	2.04	78.62	12.21	3.17
190	None	30	43.25	3.95	1.96	78.25	12.67	3.18
190	Winter	30	43.46	3.97	1.96	78.16	12.66	3.25
190	Full	30	43.45	3.97	1.96	78.12	12.72	3.23
240	None	30	42.94	3.95	1.94	78.04	12.83	3.24
240	Winter	30	42.85	3.99	1.95	77.95	12.82	3.30
240	Full	30	43.15	3.93	2.01	78.12	12.68	3.28
190	Full	-	43.86	4.09	1.97	78.01	12.67	3.28

Table 2. Percentage oil in the seed at 9% dry matter and % fatty acids in oil, harvest 2005 (five sites), harvest 2006 (five sites) and harvest 2007 (six sites)

However, there was an impact of site and season on fatty acid profiles with the Scottish site having the lowest oleic acid content in all three years (Appendix B). In three trials samples were taken a week before harvest to simulate an early harvest. In one of these the oleic acid content was consistently lower than in samples taken on the day of harvest.

DISCUSSION

Within sites the fatty acid profiles were remarkable consistent between input treatments. However, there was more variation between sites with the site in Scotland having low values of oleic acid in all three harvest years. In addition, the linoleic acid levels at the Scottish site sometimes reached the unacceptable levels for frying oils. The likely explanation is that the cooler minimum temperatures during early pod fill at this location which increases the activity of oleate desaturase, the enzyme that catalyzes the conversion of oleic to linoleic acid.

Date of harvest may be an important factor. Three trials were sampled eight to eleven days before harvest and one of the sites had lower oleic acid content and higher levels of the less desirable linoleic and linolenic acid in the ‘early’ harvest samples when compared to the ‘timely’ harvest samples. Commercial experience with Splendor suggests that the oleic acid content also reduces where harvest is delayed.

Tests by Fuchs Lubricants in Appendix C suggest that the oleic acid content of the oil needs to increase to above 90% for it to be used directly in a range of biolubricants. This may not be achieved by conventional breeding and is more possible with genetic modification. However, these levels of oleic acid may make the oil not suitable for frying because of lack of flavour.

All the trials were grown after at least a three year break from oilseed rape. Volunteers of more conventional varieties could reduce the levels of oleic acid in the sample but there was only a suggestion of this in the small hand samples in three of the 528 plots analysed. These were treated as missing plots. This demonstrates that sensible volunteer management after harvest and at least three years break from oilseed rape is sufficient basis to provide HOLL varieties. It is accepted that incoming pollen is unlikely to affect the oil quality but may affect the oil quality of any crop grown from the seed during multiplication.

The trials also tested the main input management options for one variety over three seasons. The results clearly demonstrate that responses to fungicides are not assured for this variety and their use needs to be considered on a field by field basis. The results also demonstrate that early season malate testing is not sufficiently reliable to use as a precise guide to sulphur application to the current crop at a time before it needs to be applied. A more comprehensive assessment of sulphur supply is required that also takes into account soil type, previous experience on the farm, rainfall and recent use of sulphur and manures.

INTRODUCTION

All edible oils and fats consist of triglycerides with a variety of fatty acids, which differ in chain-length (number of carbon atoms in molecule), degree of saturation (number of double bonds in carbon chain), position of double bonds within the carbon chain and geometry of each double bond (*cis* and *trans* isomers). Unsaturated fatty acids, which contain one or more double bonds between adjacent carbon atoms, are the primary cause of the development of oxidative fat decomposition during storage and high temperature cooking, because the double bonds are easily attacked by oxygen.

Oleic acid (C18:1) is the most abundant mono-unsaturated fatty acid (one double bond only) in all common edible oils. Compared with polyunsaturated fatty acids (two or more double bonds) oleic acid is more stable towards oxidation both at ambient storage temperatures and at the high temperatures which prevail when used as a biolubricant or during frying of food. Therefore, oils with high amounts of oleic acid are slower in developing oxidative rancidity during shelf-life or oxidative decomposition during frying than those oils that contain high amounts of polyunsaturated fatty acids.

Winter oilseed rape can be produced competitively in the UK. The oil has a desirable fatty acid profile when compared to other vegetable oils (Figure 1). Plant breeders have been developing new conventionally bred varieties of winter and spring oilseed rape, appropriate for production in North Europe, that more closely meet the demands of both the food and non-food market. These varieties may be more suitable for the biolubricant and food markets, having a significantly increased mono-unsaturated acid profile (oleic acid) and a reduced content of less desirable polyunsaturated fatty acids (linolenic and linoleic) for these uses. Such varieties should help to expand the market for oilseed rape oil and protect the home market from imports from other countries that may also have access to such improvements.

Biolubricants

Lubricants made from vegetable oils offer a number of distinct advantages in some areas over mineral oils. They are biodegradable, have good load carrying ability, extremely low coefficients of friction, low evaporation rates and they are naturally multigrade. They also have improved flash points, low sulphur levels and very low levels of volatility. However, if the oil sump temperatures exceed 70^{o}C their thermal and oxidative stability does not measure up to that from mineral oils. This is due to the total unsaturated content, and particularly of the polyunsaturated content from linolenic and linoleic acid.

Figure 1. Typical fatty acid profile (% weight) of vegetable oils (Source: Monsanto)

Monsanto has conventional lines of winter oilseed rape that are becoming competitive in yield, that have an increased oleic acid content raised to close to 80% and the less desirable linolenic acid content reduced to around than 3%. Discussions with end users suggest that such oils could be more attractive for biolubricants and the cooking oil market and they stress the importance of consistency of supply and also potential value of relatively small changes in the fatty acid profile. The biolubricant market is currently around 1% of UK sales/year in a total lubricant market of 840,000 tonnes/year. The EU15 market exceeds 4 million tonnes/year.

Fuchs Lubricants is the largest lubricant manufacturer in the UK and it suggests that improved fatty acid oil profile could not only be attractive for the market which produces desirable esters from rape oil to produce high grade synthetic lubricants but also that high oleic oils are attractive for the direct production of products such as hydraulic oils. The hydraulic oil market in the UK alone is 120,000 tonnes/year and only approximately 1% is currently supplied by biolubricants. However, the current and future environmental legislation and awareness, together with increasing costs and limitations in supply for the medium future of mineral oil will undoubtedly prompt a trend away from mineral oils.

Food uses

Choosing an oil or fat for food uses has traditionally been dictated by availability and price. In Europe, animal fats such as tallow and lard were widely used for this purpose. However, the recognition of a link between high cholesterol contents in the blood and the incidence of coronary heart disease has led to advice to replace the cholesterol-rich animal fats with vegetable oils, which contain only traces of cholesterol.

Among the vegetable oils, some have been proven to be more suitable for deep-fat frying operations than others. For the evaluation of the suitability of oils for frying, a number of indicators are being used. These indicators are either the results of certain chemical tests of the quality of the oil, or the sensory characteristics of the food immediately after frying/cooking, or after a defined storage period. Usually, only one or two of these indicators are used by an industrial or catering fryer to assess the frying performance of an oil. At the end, the result of such assessment is important for the economy of a frying operation, because the frying performance is an indirect measure for the costs incurred.

Palm oil, palm olein and groundnut oil were soon recognised as having a better stability during deep-fat frying than oils such as soya bean oil, sunflower oil and rapeseed oil. As mentioned above, the stability of an oil towards oxidative deterioration depends greatly on the types of fatty acid present. Palm oil products and groundnut oil contain significantly lower amounts of the more unstable polyunsaturated fatty acids compared with soya bean, sunflower and rapeseed oils. Because of their good stability, in addition to their ready availability, at comparatively low prices, palm oil products are now used widely for deep-fat frying.

To overcome the drawback of the poor stability of traditional soya bean, sunflower and rapeseed oils, ways of reducing the unstable polyunsaturated fatty acids were sought. One way is the partial hydrogenation of these oils during which polyunsaturated fatty acids are transformed into more stable monounsaturated and saturated fatty acids.

These hydrogenated or hardened oils have a greatly improved stability during frying and are therefore often sold as 'high-performance' frying oils. However, there are two downsides of these oils resulting from the hydrogenation process: high amounts of *trans* fatty acids are formed, for which a link to an increased risk of coronary heart disease has been made, and a distinctive hydrogenation flavour profile, not found in natural oils, is formed which can also be tasted in the fried food.

Another way of reducing the polyunsaturated fatty acid content in the above-mentioned vegetable oils is the development of plant varieties which yield oils with significantly increased amounts of the monounsaturated oleic acid and very low levels of polyunsaturated fatty acids. This has resulted in several high-oleic oils being technically viable alternative to palm olein.

High Oleic Low Linolenic (HOLL) varieties

HOLL varieties have been bred conventionally as part of a progression from the original lines that had high levels of erucic acid. Initially down-regulation mutation was used to reduce the enzymes responsible for the production of erucic acid (Figure 2). This resulted in increasing the oleic acid in the oil from 50% to 60% but unfortunately increased linoleic acid from 15% to 20% in double low varieties (Figure 1). The same process has now been used to reduce also the production of linoleic and linolenic acid. The HOLL varieties have further increased the proportion of oleic acid to 80% but with a concomitant reduction in linoleic acid to around 8% and linolenic acid from around 10% to around 3%.

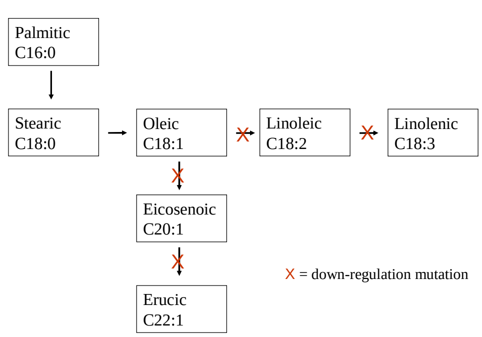


Figure 2. Representation of developments in breeding to reduce the component of erucic acid, linoleic and linolenic acids in oilseed rape oil

The future

No practical implications are foreseen for the co-existence of these high oleic oilseed rape varieties with varieties with ‘conventional’ fatty acid profiles. They have been bred by conventional methods and the current development in traits are desirable for both food and non-food uses. Hence, whilst some limited measures are required to protect their integrity in order to ensure consistency and the maximum content of the desirable fatty acids, there is little concern regarding their contamination of other conventional lines either because of pollen flow, feral or volunteer populations or due to machinery, storage and transport.

It is well known that increasing latitude and decreasing nitrogen improve overall oil content but the impact on fatty acid profile is less clear. Similarly, it has been shown that disease infection can cause significant qualitative and quantitative changes in fatty acid composition but changes differ according to the predominant pathogen (Doughty *et al.*, 1998). No information is available on the impact of various management parameters and location for the novel varietal types used in the proposed study. Such an evaluation is necessary both to exploit fully these new varieties in the UK and also to assess the ability of the UK producer to provide oils with a consistent quality to the consumers both at home and abroad.

It is essential that UK producers are pro-active in meeting more closely quality requirements for new markets in order to maintain and hopefully expand their markets. Sunflower oil with high oleic content is now a reality (despite its typical oleic content indicated in Figure 1) and high oleic rape varieties have been developed in Canada and Australia. This project measures the impact of crop management and location in the UK on the fatty acid profile of the HOLL winter rape variety Splendor, the first to be commercially released in the UK.

The overall aim of the projects was:

To evaluate and promote the production and value of winter oilseed rape varieties that have been conventionally bred to meet as closely as possible the requirements for biolubricants and other specific uses.

The specific objectives were:

1. To establish a series of six trials/year in order to investigate the impact of agronomic practice, soil type and location on the oil yield and fatty acid profile of the varieties that more closely meet the requirements of the food and biolubricant markets. This will help to evaluate and ensure consistency of oil quality in the UK.
2. To establish a committee of stakeholders to steer the field trials, to co-ordinate the analysis and testing of samples and resulting oils produced by the field trials and to help to ensure that the potential for these new varieties is fully exploited.
3. To develop approaches, such as demonstration projects, to increase demand for the products of the new varieties.

The project was steered by a small committee established under the auspices of the National Non Food Crops Centre (NNFCC). This comprised of producers (*via* the HGCA), plant breeders, research agronomists and major end users.

METHODS

Specific objective 1:

a. The steering committee to review the influence of the impact of soil type, location and crop management on the oil content and fatty acid profile of oilseed rape.

b. To establish six sites a year located throughout the UK to evaluate the protocols established by the steering committee.

c. To ensure that the appropriate analysis and testing (as determined by the steering committee) is carried out by co-operating plant breeders and end users.

The six sites were in Kent (harvest year 2005) or Wiltshire (2006, 2007) on clay loam soils, Biggleswade (Beds) on a heavy soil, Cirencester on a shallow loam over limestone, Lincolnshire on clay loam soils, Morley (Norfolk) on a medium soil and in the vicinity of Aberdeen on sandy or clay loam soils (site details in Appendix B). The lead cultivar in development (Splendor) was used with fully randomised treatments with four replicates. The variety yields about 85% of conventional varieties on the CEL/HGCA recommended list with good to moderate stem canker, light leaf spot and lodging resistance.

Sites chosen had a few or no volunteers, which could contaminate the samples of seed. In practice this meant at least three years break from the previous oilseed rape crop. In addition, the soil after the previous rape crop was not cultivated until there had been a significant germination of shed seed. This reduces the dormancy of any surviving viable shed seed (Lutman *et al*., 1998).

In harvest year 2005 the trials were surrounded with two drill widths of guard plots of the same variety in order to reduce cross contamination from the surrounding conventional commercial crop. The standard of isolation was checked by collection of seed from the middle of the plots at harvest and compared to samples from the combined plots in one trial in year 1.

The ten treatments (all receiving 30 kg/ha sulphur, except treatment 10) were determined after a review of the possible impact of location and crop management on oil content and fatty acid profile of oilseed rape (full protocol in Appendix A). They represented extremes of the major crop inputs, with a nitrogen dose of 190 kg/ha being around the recommended optimum nitrogen application. Variations from the protocol are listed in Appendix B.

1. 26 kg/ha applied nitrogen - no fungicide
2. 26 kg/ha nitrogen - autumn fungicide
3. 26 kg/ha nitrogen - autumn and spring fungicide
4. 190 kg/ha N - no fungicide
5. 190 kg/ha N - autumn/winter fungicide
6. 190 kg/ha N – autumn/winter and spring fungicide
7. 240 kg/ha N - no fungicide
8. 240 kg/ha N – autumn/winter fungicide
9. 240 kg/ha N – autumn/winter and spring fungicide
10. 190 kg/ha N – autumn/winter fungicide (no sulphur)

Plot yields were taken and samples analysed for oil content and fatty acid profile by Monsanto. Fuchs Lubricants tested samples of the finally derived and refined oils for their oxidation characteristics that measure the deterioration of the viscosity on oxidation. This test is an important determinant of the suitability of vegetable oils for biolubricants (Appendix C).

The treatments for field trials were changed for years 2 and 3 of the project with 12 treatments replicated four times. The additional treatments investigated more fully the impact of fungicide treatments at optimum nitrogen applications in the absence of applied sulphur. Three drill widths of the same variety surrounded the trial sites. The full protocol is in Appendix A, with site details listed in Appendix B. The treatments were:

1. 26 kg/ha applied nitrogen - no fungicide
2. 26 kg/ha nitrogen - autumn fungicide
3. 26 kg/ha nitrogen - autumn and spring fungicide
4. 190 kg/ha N - no fungicide
5. 190 kg/ha N - autumn/winter fungicide
6. 190 kg/ha N – autumn/winter and spring fungicide

7. 240 kg/ha N - no fungicide
8. 240 kg/ha N – autumn/winter fungicide
9. 240 kg/ha N – autumn/winter and spring fungicide
10. 190 kg/ha N – no fungicide (no sulphur)
11. 190 kg/ha N – autumn/winter fungicide (no sulphur)
12. 190 kg/ha N – autumn/winter and spring fungicide (no sulphur)

The results of each trial are in Appendix B in tabular form. The protocols were followed with only one or two trials where there was variation from the protocols and these are listed under the heading 'Other' in the right hand column of the results table for each trial. Also listed are the dates of drilling and harvest and also the date of the autumn/winter fungicide application, which varied between seasons. In addition, the soil texture of the topsoil is described and the results of the early season malate test (the ratio:1) and soil mineral nitrogen assessment carried out in the early spring (in kg/ha with depth of sampling in brackets)

Specific objective 2:

The steering committee met three times and comprised Ian Law, NNFCC (not present at the third meeting), Cliff Lea of Fuchs, Colin Merritt of Monsanto, Kerr Walker (first meeting) and Elaine Booth of SAC and Jim Orson of TAG.

Specific objective 3:

The results of the trials suggest that the HOLL varieties did not yet provide sufficient quality on their own to be used in an expanded biolubricant market (Appendix C). Their value for the food sector has been recognised through specific contracts and it became clear during the project that input management had little impact on the fatty acid profile of the oil.

RESULTS

Plot samples collected by the combine or through hand harvesting a small sample from the centre of the plot at harvest at the SAC site in 2005 indicated that both methods gave very similar results and errors in terms of fatty acid profiles of the oil. It was decided that hand collection immediately prior to harvest would be the method chosen for all future analysis of oils because it guaranteed no sample contamination from other plots and it opened up the possibility of sampling prior to harvest to investigate the impact of time of harvest on fatty acid profiles. The results of tests by Fuchs Lubricants on the suitability of the oil from Splendor for biolubricants are in Appendix C

Yields

Annual mean yields are provided in Table 1 and the yields of individual trials in Appendix B. Yields were generally low and overall there was limited response to fungicides and sulphur use.

The application of nitrogen generally increased yields and there was no benefit from applying more than 190 kg N/ha except on one occasion when there was an apparent interaction with fungicide use. This was at the SAC site in 2005 when there was only a significant response to the autumn/winter application of a fungicide at the 240 kg/ha dose of nitrogen. In the same year an autumn/winter application increased yields at the Kent site. In the following year at the SAC site there was an additional response to the spring/summer fungicides at the recommended dose and above the recommended dose of nitrogen. Also in 2006, the full fungicide programme increased yields at the Lincolnshire site but only when above the recommended dose of nitrogen was applied. In 2007, the full fungicide programme also increased yields at the Biggleswade site at both the recommended and above the recommended dose of nitrogen.

The mean yields showed that sulphur application resulted in higher yields for all fungicide treatments when comparable means from plots receiving 190 kg N/ha are considered (Table 1). Considering individual sites (Appendix B), the application of sulphur consistently increased yields at the Cirencester site in all years, despite the malate test in 2007 indicating that at the time of testing the plant was sufficient in this nutrient. There were also responses to sulphur at Morley in 2006 and at the

Wiltshire site in 2007. Both these occurred where the malate test indicated a sulphur deficiency at the time of sampling. Otherwise, there was no consistent trend towards higher yields with the application of sulphur despite the malate test indicating a deficiency at the time of application and *vice-versa*.

N (kg/ha)	Fungicide	S (kg/ha)	2005 yield (t/ha)	2006 yield (t/ha)	2007 Yield (t/ha)
26	None	30	2.07	2.49	2.17
26	Winter	30	2.01	2.59	2.10
26	Full	30	2.15	2.64	2.28
190	None	30	3.07	3.34	2.78
190	Winter	30	3.20	3.38	2.84
190	Full	30	3.23	3.59	3.09
240	None	30	3.22	3.32	2.85
240	Winter	30	3.27	3.40	2.90
240	Full	30	3.34	3.68	3.10
190	None	-	-	3.04	2.39
190	Winter	-	-	3.03	2.55
190	Full	-	3.13	3.39	2.77

Table 1. Mean yield results from six sites, harvests 2005, 2006, 2007 (t/ha at 9% moisture)

Oil content

Oil analysis was not carried out on samples taken from Ashford in 2005 and Cirencester in 2006. This was due to transport problems to the laboratory in Paris and/or damage in store.

There was the acknowledged reduction in oil content with the application of the recommended doses of nitrogen, when compared to very low doses of the nutrient (Tables 2, 3 and 4 and Appendix B). The trial at Morley in 2006 indicated a continued fall in the oil content when an above recommended dose of nitrogen was applied. This occurred despite no additional yield from the above recommended dose.

There was some trials, notably SAC 2007, Biggleswade 2006 and 2007, Morley 2007 and Wiltshire 2006 where there was no or a very limited reduction in oil content from the application of the recommended dose of nitrogen. These sites had no or a limited yield response to the application of nitrogen but there was no overall relationship between increase in physical or relative yield and decrease in oil content due to this nutrient.

N	Fungicide	S	Oil 9%	C16 Palmitic	C18 Stearic	C18:1 Oleic	C18:2 Linoleic	C18:3 Linolenic
26	None	30	44.60	4.11	2.16	78.80	12.09	2.86
26	Winter	30	44.99	4.07	2.14	79.03	11.89	2.86
26	Full	30	44.98	4.03	2.17	78.78	12.04	2.98
190	None	30	41.98	3.97	2.05	78.47	12.53	2.98
190	Winter	30	42.40	4.00	2.06	78.30	12.59	3.06
190	Full	30	42.47	4.13	2.07	77.87	12.87	3.09
240	None	30	41.92	4.05	2.04	78.13	12.73	3.06
240	Winter	30	41.99	4.08	2.08	78.41	12.51	2.92
240	Full	30	41.97	3.89	2.06	78.50	12.53	3.02
190	Full	-	42.97	4.21	2.08	78.46	12.29	2.98

Table 2. Percentage oil in the seed at 9% dry matter and % fatty acids in oil, harvest 2005 (five sites)

Fatty acid profiles

Whilst there were variations between sites, the profiles were very consistent within sites across all treatments (Tables 2, 3 and 4 and Appendix B). The coefficient of variations suggested more variation in the levels of linolenic acid than the other fatty acids. This may be an artefact of experimental error on low values but such variation did not occur with palmitic acid which also occurred at similar levels.

N	Fungicide	S	Oil	C16	C18	C18:1	C18:2	C18:3

(kg/ha)		(kg/ha)	9%	Palmitic	Stearic	Oleic	Linoleic	Linolenic
26	None	30	46.02	4.18	2.06	78.12	12.20	3.46
26	Winter	30	46.00	4.12	2.09	78.55	11.92	3.31
26	Full	30	46.49	4.11	2.12	78.97	11.63	3.16
190	None	30	43.73	4.16	2.05	78.31	12.32	3.20
190	Winter	30	44.13	4.20	2.02	78.10	12.35	3.33
190	Full	30	43.77	4.10	2.01	78.45	12.23	3.16
240	None	30	43.36	4.13	1.99	77.93	12.64	3.33
240	Winter	30	43.23	4.18	1.97	77.66	12.70	3.50
240	Full	30	43.62	4.18	2.01	77.87	12.54	3.41
190	None	-	44.40	4.19	2.04	77.85	12.50	3.45
190	Winter	-	44.14	4.23	2.02	77.47	12.75	3.54
190	Full	-	44.46	4.17	2.00	77.67	12.63	3.55

Table 3. Percentage oil in the seed at 9% dry matter and % fatty acids in oil, harvest 2006 (five sites)

N (kg/ha)	Fungicide	S (kg/ha)	Oil 9%	C16 Palmitic	C18 Stearic	C18:1 Oleic	C18:2 Linoleic	C18:3 Linolenic
26	None	30	44.87	3.79	1.80	77.97	13.13	3.33
26	Winter	30	44.74	3.79	1.80	77.57	13.34	3.51
26	Full	30	45.43	3.76	1.83	78.11	12.95	3.35
190	None	30	44.04	3.74	1.77	77.96	13.17	3.37
190	Winter	30	43.84	3.72	1.80	78.08	13.05	3.37
190	Full	30	44.10	3.69	1.78	78.05	13.05	3.44
240	None	30	43.55	3.69	1.78	78.08	13.12	3.34
240	Winter	30	43.34	3.71	1.79	77.78	13.24	3.49
240	Full	30	43.87	3.71	1.95	78.00	12.96	3.41
190	None	-	44.06	3.86	1.79	77.72	13.24	3.41
190	Winter	-	43.94	3.88	1.81	77.69	13.19	3.46
190	Full	-	44.14	3.78	1.82	78.09	12.93	3.39

Table 4. Percentage oil in the seed at 9% dry matter and % fatty acids in oil, harvest 2007 (six sites)

Impact of site

Overall, the site in Scotland consistently produced low oleic acid content and hence a higher content of the other fatty acids, including linoleic and linolenic (Tables 5, 6 and 7 and Appendix B). This was particularly the case in 2006 when it produced the lowest oleic acid content for every treatment and in 2005 it produced the lowest oleic acid content in all but one treatment. In the final year, the Scottish site produced the lowest or second lowest oleic acid content for every treatment.

N (kg/ha)	Fungicide	S (kg/ha)	C18:1 Oleic	Min	Max
26	None	30	78.80	76.80	80.18
26	Winter	30	79.03	76.53	80.55
26	Full	30	78.78	77.03	80.68
190	None	30	78.47	76.35	79.70
190	Winter	30	78.30	76.50	81.10
190	Full	30	77.87	75.78	79.95
240	None	30	78.13	76.10	80.07
240	Winter	30	78.41	76.25	80.05
240	Full	30	78.50	76.00	80.63
190	Full	-	78.46	76.50	79.95

Table 5. Range in % oleic acid in the oil between sites, harvest 2005

N (kg/ha)	Fungicide	S (kg/ha)	C18:1 Oleic	Min	Max
26	None	30	78.12	75.63	79.80
26	Winter	30	78.55	76.35	79.80
26	Full	30	78.97	76.18	79.93
190	None	30	78.31	75.00	79.28
190	Winter	30	78.10	74.68	79.53
190	Full	30	78.45	75.28	79.50
240	None	30	77.93	74.50	79.10
240	Winter	30	77.66	74.65	79.40
240	Full	30	77.87	74.53	79.30
190	None	-	77.85	74.53	79.33
190	Winter	-	77.47	74.45	79.33
190	Full	-	77.67	74.83	79.23

Table 6. Range in % oleic acid in the oil between sites, harvest 2006 (five sites)

N (kg/ha)	Fungicide	S (kg/ha)	C18:1 Oleic	Min	Max
26	None	30	77.97	76.63	79.60
26	Winter	30	77.57	75.38	79.58
26	Full	30	78.11	76.68	79.30
190	None	30	77.96	76.85	79.23
190	Winter	30	78.08	76.75	79.63
190	Full	30	78.05	77.23	78.93
240	None	30	78.08	76.63	79.13
240	Winter	30	77.78	76.38	79.68
240	Full	30	78.00	76.28	80.13
190	None	-	77.72	76.40	79.28
190	Winter	-	77.69	76.83	79.18
190	Full	-	78.09	77.10	79.88

Table 7. Range in % oleic acid in the oil between sites, harvest 2007 (six sites)

Time of harvest

Hand samples were taken from some key treatments eight to eleven days before harvest at the Lincolnshire site in 2006 and 2007 and at Morley in 2007. In two of the sites there was no consistent trend on the impact of this ‘early harvest’ on the fatty acid profile but at the Lincolnshire site in 2007 the level of oleic acid was consistently lower than samples taken on the day of harvest (‘timely’ harvest – Tables 8, 9, 10).

N (kg/ha)	Fungicide	S (kg/ha)	Oil at 9% MC		C18:1 Oleic (%)	
			Early	Timely	Early	Timely
26	None	30	48.0	46.8	78.8	77.5
190	None	30	45.0	45.3	77.7	79.0
190	Full	30	44.8	44.8	78.5	79.2
190	Full	-	45.1	46.4	78.0	76.0

Table 8. Percentage oil in the seed (at 9% moisture content) and percentage of oleic acid in the seed when collected eight days before harvest (early) or on harvest day (timely); Lincolnshire site, harvest 2006

N (kg/ha)	Fung.	S (kg/ha)	Harvest date	Oil % (9% MC)	C:16	C:18.0	C:18.1	C:18.2	C18.3
26	None	30	Early	44.40	3.98	1.85	76.35	14.15	3.73
			Timely	42.95	3.73	1.70	78.40	12.78	3.40
190	None	30	Early	43.60	3.93	1.83	75.88	14.30	4.08
			Timely	45.53	3.75	1.70	78.55	12.55	3.45
190	Full	30	Early	44.75	3.93	1.85	76.43	13.93	3.85
			Timely	44.58	3.73	1.78	78.93	12.53	3.08
190	Full	-	Early	44.98	3.93	1.90	76.58	13.85	3.75
			Timely	43.28	3.60	1.78	79.18	12.30	3.18

Table 9. Percentage oil in the seed (at 9% moisture content) and fatty acid profile (%) in the seed when collected eight days before harvest (early) or on harvest day (timely); Lincolnshire site, harvest 2007

N (kg/ha)	Fung.	S (kg/ha)	Harvest date	Oil % (9% MC)	C:16	C:18.0	C:18.1	C:18.2	C18.3
26	None	30	Early	44.00	3.83	1.88	78.13	13.03	3.10
			Timely	44.03	4.03	1.78	77.65	13.40	3.15
190	None	30	Early	44.30	3.80	1.88	77.65	13.35	3.35
			Timely	43.00	3.93	1.75	77.45	13.58	3.28
190	Full	30	Early	44.40	3.73	1.90	78.38	12.90	3.10
			Timely	43.25	3.88	1.78	77.78	13.18	3.35
190	Full	-	Early	43.50	3.90	1.88	77.65	13.45	3.20
			Timely	43.38	3.88	1.83	77.88	13.18	3.23

Table 10. Percentage oil in the seed (at 9% moisture content) and fatty acid profile (%) in the seed when collected eleven days before harvest (early) or on harvest day (timely); Morley site, harvest 2007

DISCUSSION

Yields from the series of trials with Splendor were generally low, although yields from the treatment most closely reflecting conventional practice (190 kg nitrogen, full fungicide application and sulphur treatment) were around three t/ha on average. This level of yield may be expected for this variety which is known to have a slight yield penalty compared to conventional varieties.

Total oil content of this variety did not appear to respond to latitude effects in this trial series. This contrasts with other research and commercial experience with conventional double low varieties for which it is well recognised that higher oil contents are achieved at Northerly latitudes.

Within sites the fatty acid profiles were remarkable consistent between input treatments. However, there was more variation between sites with the site in Scotland having lower values of oleic acid in all three harvest years. In addition, the linoleic acid levels at the Scottish site on occasions approached the unacceptable levels for frying oils. The lower minimum temperatures experienced during early pod fill is the most likely explanation for the lower oleic acid component of the oil in Scotland. Lower temperatures during pod fill increases the activity of oleate desaturase, the enzyme that catalyzes the conversion of oleic to linoleic acid (Figure 2 and Deng and Scarth, 1998), particularly minimum temperatures during early development of the seed (Izquierdo *et al.*, 2006). Minimum temperatures in May at the Scottish were particularly lower than the other sites in 2006 according to maps on the Meteorological Office website. The oleic acid component of the oil was lower in all treatments at this site in this year.

Date of harvest may be an important factor for the oleic acid content of the oil. Three trials were sampled around 8-11 days before harvest and in one the samples had lower oleic acid content and higher levels of the less desirable linoleic and linolenic acid than at harvest. Commercial experience with Splendor suggests that the oleic acid content also reduces where harvest is delayed.

Tests by Fuchs lubricants in Appendix C suggest that the oleic acid content of the oil needs to increase above 90% for it to be used directly in a range of biolubricants.

Canola with an oleic acid component of oil of above 86% has been produced by genetic modification (Debonte and Hitz, 1996) and the University of Gottingen in Germany has a project to establish high oleic (over 90%) quality in winter rapeseed. However, such high levels set a difficult target that may be more easily achieved with the assistance of genetic modification. However, such oils may not be suitable for frying if they result in an extremely low content of linolenic acid because of a consequential lack of flavour. However, the variety Splendor produces oils that are good for frying but there is a need to ensure that linoleic acid is below 4%.

All the trials were grown after at least a three year break from oilseed rape. Volunteers of more conventional varieties could reduce the levels of oleic acid in the sample but there was only evidence of this in the small hand collected samples in three of the 528 plots analysed. These were treated as missing plots. This demonstrates that sensible volunteer management after harvest and at least three years break from oilseed rape is sufficient basis to grow HOLL varieties. It is accepted that incoming pollen will not affect the oil quality but may affect the oil quality of any crop grown from the seed.

The trials also tested the main input management options for one variety over three seasons. The results clearly demonstrated that responses to fungicides in the variety Splendor are not assured and their use needs to be considered on a field-by-field basis. Disease resistance of this variety is good with low levels being observed in these trials. Hence this variety showed a relatively small response to fungicide application. New HOLL varieties entering widespread cultivation need to be assessed for disease resistance and response to fungicide. The results also demonstrate that early season malate testing is not sufficiently reliable to use as a guide to sulphur application to the current crop at time when it needs to be applied. A more comprehensive assessment is required that also takes into account soil type, previous experience on the farm, rainfall and recent use of sulphur and manures.

ACKNOWLEDGEMENTS

The authors acknowledge the SAC and TAG staff who carried out the individual experiments, Soad Malloul of Monsanto for analysing the samples, NNFCC staff and comments on the results received from AMD.

REFERENCES

Deng, X. and Scarth, R. 1998. *Temperature effects on fatty acid composition during development of low linolenic oilseed rape* (*Brassica napus* L.) Journal of the American Oil Chemists' Society **75**:759-766

Debonte, L.R. and Hitz, W.D. 1996. *Canola oil having increased oleic acid and decreased linolenic acid content and its manufacture using transgenic plants.* Patent application: US 96-675650 960703. CAN 130:65607

Doughty, K.J.; Landon, G.; McCartney, H.A.; Norton, G.; West, G.; Booth, E.J.; Walker, K.C.; Kightley, S.P.J. and Thomas, J.E. 1998. *Effects of disease on seed quality parameters of oilseed rape grown for industrial uses*. Project Report OS 33, HGCA London

Izquierdo, N.G.; Aguirrezábal, L.A.N.; Andrade, F.H. and Cantarero, M.G. 2006. *Modeling the Response of Fatty Acid Composition to Temperature in a Traditional Sunflower Hybrid*. Agron J. **98**:451-461

Lutman, P.J.; Pekrun, C. and Albertini, A. 1998. *Dormancy and persistence of volunteer oilseed rape*. Project Report OS 32, HGCA London

Appendix A

Final protocol – harvest 2005

Winter Oilseed Rape Biolubricant Husbandry Trial (version 2)

National Protocol Number & Type Trial	WR05-010 (Year 1) HGCA Trial
Company	HGCA
Crop & Variety	Winter Oilseed Rape Splendor
Objective	To examine the effects of nitrogen / sulphur fertiliser regime, and fungicide strategy, on the oil yield and quality of winter oilseed rape for biolubricants
Locations: 6	SAC, TAG N, TAG S, TAG E, TAG EC, TAG W

	1st Fertiliser 20-25th Feb	**2nd Fertiliser 15-20th Mar**	**Fungicide Treatment (l/ha) and Timing**		
			Early spring V early stem ext.	**Late Spring** Green bud	**Summer** Early - mid flower
1	26 N + 30 S	0 N (kg/ha)	None	None	None
2	26 N + 30 S	0 N	None	Folicur 1.0	None
3	26 N + 30 S	0 N	Punch C 0.4	Folicur 1.0	Filan 0.5kg
4	90 N + 30 S	100 N	None	None	None
5	90 N + 30 S	100 N	None	Folicur 1.0	None
6	90 N + 30 S	100 N	Punch C 0.4	Folicur 1.0	Filan 0.5kg
7	90 N + 30 S	150 N	None	None	None
8	90 N + 30 S	150 N	None	Folicur 1.0	None
9	90 N + 30 S	150 N	Punch C 0.4	Folicur 1.0	Filan 0.5kg
10	90 N	100 N	Punch C 0.4	Folicur 1.0	Filan 0.5kg
11	90 N + 60 S	100 N	Punch C 0.4	Folicur 1.0	Filan 0.5kg
12	90 N	100 N	None	None	None

Punch C = 125 g/l carbendazim + 250 g/l flusilazole
Folicur = 250 g/l tebuconazole
Filan = 50% w/w boscalid

Treatments 11 and 12 are required only on sites with sufficient plots available, remembering that two Splendour buffers must be left on each side of the trial.

First N doses to be applied as ammonium sulphate (1-3), plus ammonium nitrate to make up N dose (4-9, 11) or all as ammonium nitrate (10, 12). Second N doses to be applied all as ammonium nitrate. Minimum of 3 weeks to be left between first and second fertiliser timings. Minimum of 3 weeks to be left between fungicide timings.

Management Herbicide, insecticide as site standard.

Layout Randomised Block
Plot size: 2.1 m x 12 m (10 m only harvested) 4 replicates

Additional Splendour buffers (two) at top, bottom and sides of trial
Inside buffer of each pair to receive same treatments as adjacent plot

Assessments & Notes
Available soil mineral N and S prior to first N/S applications (0-90cm, or shallower if necessary)
Malate test (treatment 10): sample at start of rapid stem extension in spring, and repeat at late stem extension but before yellow bud. Record growth stage when samples taken.
[For TAG sites, please send soil and malate samples to Hill Court Farm.]

Disease assessments: global foliar disease prior to early spring fungicide application
all treatments foliar disease at green bud application timing
all treatments final leaf, pod & stem disease (pre-ripening)

Record in writing a description of any visible differences between treatments in canopy size, density or green leaf area.

Crop height at the end of flowering.

Score lodging from the end of flowering (or from first occurrence if earlier) at intervals until maturity.

Grain Assessments
Seed yield at 9% moisture content
Seed samples – all plots. Quantity to be confirmed.

Version **2** (final treatment list)
Dated 16 February 2005

Final protocol – harvest 2006

Winter Oilseed Rape Biolubricant Husbandry Trial (year 2 version 2)

National Protocol Number & Type Trial	WR06-010 (Year 2) HGCA Trial
Company	HGCA
Crop & Variety	Winter Oilseed Rape Splendor
Objective	To examine the effects of nitrogen / sulphur fertiliser regime, and fungicide strategy, on the oil yield and quality of winter oilseed rape for biolubricants
Locations: 6	SAC, TAG N, TAG S, TAG E, TAG EC, TAG W

	1st Fertiliser 20-25th Feb	**2nd Fertiliser 15-20th Mar**	**Fungicide Treatment (l/ha) and Timing**		
			Autumn Oct/Nov	**Spring**	**Summer**
1	26 N + 30 S	0 N	None	none	None
2	26 N + 30 S	0 N	Punch C 0.4	none	None
3	26 N + 30 S	0 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg
4	90 N + 30 S	100 N	None	none	None
5	90 N + 30 S	100 N	Punch C 0.4	none	None
6	90 N + 30 S	100 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg
7	90 N + 30 S	150 N	None	none	None
8	90 N + 30 S	150 N	Punch C 0.4	none	None
9	90 N + 30 S	150 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg
10	90 N	100 N	None	none	None
11	90 N	100 N	Punch C 0.4	none	None
12	90 N	100 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg

Punch C = 125 g/l carbendazim + 250 g/l flusilazole
Folicur = 250 g/l tebuconazole
Filan = 50% w/w boscalid

Management Herbicide, insecticide as site standard.

Layout Randomised Block
Plot size: 2.1 m x 12 m (10 m only harvested) 4 replicates
Additional Splendour buffers at top, bottom and sides of trial
Inside buffer to receive same treatments as adjacent plot

Assessments & Notes

Available soil mineral N and S prior to first N/S applications (0-90cm, or shallower if necessary)
Malate test (treatment 10): sample at start of rapid stem extension in spring, and repeat at late stem extension but before yellow bud. Record growth stage when samples taken.
[For TAG sites, please send soil and malate samples to Hill Court Farm.]

Disease assessments: global foliar disease prior to early spring fungicide application
all treatments foliar disease at green bud application timing
all treatments final leaf, pod & stem disease (pre-ripening)

Record in writing a description of any visible differences between treatments in canopy size, density or green leaf area.

Crop height at the end of flowering.

Score lodging from the end of flowering (or from first occurrence if earlier) at intervals until maturity.

Grain Assessments
Seed yield at 9% moisture content
Seed samples – all plots. Quantity to be confirmed.

Version **2** Second draft
Dated 5 February

Final protocol - harvest 2007

Winter Oil Rape Biolubricant Husbandry Trial (Version 1 - Final)

National Protocol Number & Type Trial	WR07-010 (Year 3) HGCA Trial
Company	HGCA
Crop & Variety	Winter Oilseed Rape – Splendor
Objective	To examine the effects of nitrogen/sulphur fertiliser regime, and fungicide strategy, on the oil yield and quality of winter oilseed rape for biolubricants
Locations: 6	SAC (1 site), TAG N (1 site), TAG S (2 sites), TAG E (2 sites)

	1st Fertiliser 20-25th Feb	**2nd Fertiliser 15-20th Mar**	**Fungicide Treatment (l/ha) and Timing**		
			Autumn Oct/Nov	**Spring** Early green bud	**Summer** Early flowering
1	26 N + 30 S*	0 N	None	None	None
2	26 N + 30 S*	0 N	Punch C 0.4	None	None
3	26 N + 30 S*	0 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg
4	90 N + 30 S	100 N	None	None	None
5	90 N + 30 S	100 N	Punch C 0.4	None	None
6	90 N + 30 S	100 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg
7	90 N + 30 S	150 N	None	None	None
8	90 N + 30 S	150 N	Punch C 0.4	None	None
9	90 N + 30 S	150 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg
10	90 N	100 N	None	None	None
11	90 N	100 N	Punch C 0.4	None	None
12	90 N	100 N	Punch C 0.4	Folicur 1.0	Filan 0.5 kg

* - this balance of N and S has been chosen in order that the treatment can be applied as ammonium sulphate.

Punch C = 125 g/l carbendazim + 250 g/l flusilazole
Folicur = 250 g/l tebuconazole
Filan = 50% w/w boscalid

Management Herbicide, insecticide as site standard.

Layout Randomised Block
Plot size: 2.1 m x 12 m (10 m only harvested) 4 replicates
Additional Splendor buffers at top, bottom and sides of trial
Inside buffer to receive same treatments as adjacent plot

Assessments & Notes

Available soil mineral N and S prior to first N/S applications (0-90cm, or shallower if necessary)
Malate test (Treatment 10): sample at start of rapid stem extension in spring, and repeat at late stem extension but before yellow bud. Record growth stage when samples taken.
[For TAG sites, please send soil and malate samples to Hill Court Farm.]

Disease assessments:
Global foliar disease on plots treated in the autumn with Punch C and also on plots not treated in the autumn with Punch C prior to
Early spring (early green bud) fungicide application all treatments foliar disease at early flowering application timing
All treatments final leaf, pod & stem disease (pre-ripening)

Record in writing a description of any visible differences between treatments in canopy size, density or green leaf area.

Crop height at the end of flowering.

Score lodging from the end of flowering (or from first occurrence if earlier) at intervals until maturity.

Grain Assessments
Seed yield at 9% moisture content
Seed samples – all plots. Quantity and type to be confirmed once full analysis of harvest 2006 samples is complete

SOPs – C1, C2, C3, E2, E6, G1, G2

Version **1**
Dated 7 February 2007

Appendix B

SAC 2005 – Wartle, Aberdeen

N	Fung.	S	Yield	Oil	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
(kg/ha)		(kg/ha)	(t/ha)	(9%)						3
										Soil type:
26	None	30	1.31	42.93	4.23	1.83	76.80	13.68	3.45	SL
26	Winter	30	1.46	43.40	4.30	1.83	76.53	13.75	3.55	*Drilling date:*
26	Full	30	1.26	43.60	4.20	1.88	77.03	13.40	3.48	01/09/04
190	None	30	2.89	40.63	4.35	1.80	76.35	14.10	3.45	*Malate/SMN:*
190	Winter	30	3.05	42.03	4.35	1.80	76.50	13.80	3.55	0.7/
190	Full	30	3.05	41.38	4.23	1.80	76.35	14.08	3.58	*Autumn fung.:*
240	None	30	3.02	41.13	4.30	1.78	76.10	14.23	3.60	3/11/04
240	Winter	30	3.40	41.20	4.23	1.78	76.25	14.13	3.63	*Harvest date:*
240	Full	30	3.45	41.58	4.18	1.80	76.00	14.20	3.80	11/08/05
190	Full	-	2.88	42.28	4.25	1.80	76.50	13.88	3.58	*Other:*
										S applied
LSD	P=0.05		0.239	0.695	0.188	0.076	0.555	0.415	0.191	as sulphate
CV	%		6.39	1.14	3.04	2.91	0.50	2.05	3.70	of potash

Great Carlton, Lincolnshire 2005

N	Fung.	S	Yield	Oil	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
(kg/ha)		(kg/ha)	(t/ha)	(9%)						>3
										Soil type:
26	None	30	1.27	46.47	3.58	2.30	80.18	11.15	2.78	Clay Loam
26	Winter	30	0.76	46.57	4.00	2.20	80.13	11.00	2.68	*Drilling date:*
26	Full	30	1.22	46.53	4.08	2.20	78.65	11.78	3.28	10/09/04
190	None	30	2.89	44.75	3.83	2.18	79.38	11.65	2.95	*Malate/SMN:*
190	Winter	30	2.93	45.43	2.68	2.28	81.10	11.28	2.68	0.18/16 (60cm)
190	Full	30	2.77	45.98	3.50	2.18	79.95	11.48	2.90	*Autumn fung.:*
240	None	30	2.70	44.52	3.72	2.17	80.07	11.39	2.63	17/02/05
240	Winter	30	3.03	45.18	3.95	2.15	80.05	11.20	2.60	*Harvest date:*
240	Full	30	2.61	43.68	3.10	2.25	80.63	11.38	2.68	23/07/05
190	Full	-	2.77	45.48	4.00	2.18	79.95	11.13	2.73	*Other:*
LSD	P=0.05		0.53	2.796	1.003	0.197	1.841	0.882	0.648	
CV	%		14.8	4.26	18.94	6.19	1.59	5.37	16.04	

Biggleswade 2005

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
										5
										Soil type:
26	None	30	2.40	44.83	4.23	2.25	79.13	11.80	2.63	Boulder Clay
26	Winter	30	2.49	44.95	3.55	2.25	80.55	11.05	2.58	*Drilling date:*
26	Full	30	2.64	44.83	3.33	2.30	80.68	11.13	2.53	15/09/04
190	None	30	3.45	41.60	3.23	2.10	79.70	12.13	2.85	*Malate/SMN:*
190	Winter	30	3.46	41.55	4.43	2.05	76.95	13.10	3.45	4.4/
190	Full	30	3.73	41.53	4.40	2.13	75.78	14.40	3.35	*Autumn fung.:*
240	None	30	3.72	41.18	3.75	2.03	78.00	12.93	3.33	20/02/05
240	Winter	30	3.28	40.45	3.68	2.20	78.83	12.53	2.80	*Harvest date:*
240	Full	30	3.70	41.68	3.73	2.08	78.78	12.38	3.05	18/07/05
190	Full	-	3.59	41.88	4.15	2.15	78.83	12.03	2.83	*Other:*
LSD	P=0.05		0.324	1.323	1.147	0.14	1.99	1.311	0.512	
CV	%		6.84	2.17	20.55	4.54	1.75	7.35	12.03	

Morley 2005

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
										Virgin crop
										Soil type:
26	None	30	3.25	43.40	4.28	2.23	79.48	11.48	2.58	Sandy Cl. Loam
26	Winter	30	3.24	44.14	4.28	2.20	79.55	11.38	2.60	*Drilling date:*
26	Full	30	3.48	44.46	4.25	2.25	79.60	11.35	2.58	7/09/04
190	None	30	3.73	40.67	4.20	2.03	78.85	12.15	2.75	*Malate/SMN:*
190	Winter	30	3.89	40.70	4.25	2.03	78.90	12.10	2.73	4.4/71 (90 cm)
190	Full	30	3.98	41.38	4.30	2.08	79.10	11.80	2.68	*Autumn fung.:*
240	None	30	3.85	40.38	4.25	2.10	78.70	12.25	2.7	14/03/05
240	Winter	30	3.78	40.60	4.28	2.08	78.90	12.05	2.65	*Harvest date:*
240	Full	30	4.16	40.66	4.15	2.05	79.13	11.98	2.68	2/08/05
190	Full	-	3.84	41.09	4.28	2.05	78.98	12.00	2.75	*Other:*
LSD	P=0.05		0.360	1.21	0.155	0.108	0.587	0.471	0.138	
CV	%		6.66	1.93	2.51	3.54	0.51	2.74	3.57	

Cirencester 2005

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR* >3
										Soil type:
26	None	30	1.62	45.39	4.25	2.19	78.40	12.34	2.85	Shallow Loam
26	Winter	30	1.67	45.87	4.20	2.23	78.40	12.25	2.88	*Drilling date:*
26	Full	30	1.77	45.50	4.30	2.20	77.93	12.53	3.05	7/09/04
190	None	30	2.66	42.25	4.23	2.15	78.08	12.63	2.88	*Malate/SMN:*
190	Winter	30	2.60	42.28	4.28	2.15	78.05	12.68	2.88	24.0/28 (60cm)
190	Full	30	2.65	42.09	4.20	2.18	78.18	12.58	2.93	*Autumn fung.:*
240	None	30	2.90	42.40	4.23	2.13	77.78	12.83	3.03	25/02/05
240	Winter	30	2.72	42.50	4.28	2.18	78.00	12.65	2.93	*Harvest date:*
240	Full	30	2.65	42.25	4.28	2.13	77.95	12.70	2.90	4/08/05
190	Full	-	2.37	44.13	4.35	2.20	78.05	12.40	3.03	*Other:*
LSD	P=0.05		0.265	0.946	0.129	0.077	0.701	0.45	0.287	
CV	%		7.73	1.49	2.08	2.44	0.62	2.46	6.74	

Ashford, Kent 2005

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR* 4
										Soil type:
26	None	30	2.56							Flinty loam
26	Winter	30	2.42							*Drilling date:*
26	Full	30	2.55							1/09/04
190	None	30	2.77							*Malate/SMN:*
190	Winter	30	3.28							2.0/53 (90cm)
190	Full	30	3.18							*Autumn fung.:*
240	None	30	3.14							15/03/05
240	Winter	30	3.39							*Harvest date:*
240	Full	30	3.48							9/08/05
190	Full	-	3.34							*Other:*
LSD	P=0.05		0.289							
CV	%		6.55							

SAC 2006 – Pitcaple, Invercurie

N	Fung.	S	Yield	Oil	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
(kg/ha)		(kg/ha)	(t/ha)	(9%)						3
										Soil type:
26	None	30	2.10	45.65	4.83	1.78	75.63	13.78	4.00	Sandy Cl. Loam
26	Winter	30	2.33	46.38	4.70	1.83	76.35	13.30	3.85	*Drilling date:*
26	Full	30	2.34	47.10	4.83	1.83	76.18	13.28	3.90	2/09/05
190	None	30	3.11	43.18	4.95	1.73	75.00	14.38	3.95	*Malate/SMN:*
190	Winter	30	3.28	42.98	4.98	1.73	74.68	14.53	4.10	2.7/76 (90cm)
190	Full	30	3.77	43.80	4.95	1.70	75.28	14.10	3.93	*Autumn fung.:*
240	None	30	3.16	41.98	4.88	1.65	74.50	14.85	4.12	1/11/05
240	Winter	30	3.36	42.43	4.98	1.68	74.65	14.63	4.08	*Harvest date:*
240	Full	30	4.07	43.53	4.98	1.68	74.53	14.50	4.30	7/08/06
190	None	-	3.12	43.40	5.03	1.70	74.53	14.58	4.18	*Other:*
190	Winter	-	3.11	42.35	5.05	1.70	74.45	14.65	4.13	
190	Full	-	3.67	43.20	4.90	1.68	74.83	14.43	4.18	
LSD	P=0.05		0.338	0.914	0.188	0.071	1.254	0.741	0.479	
CV	%		7.52	1.44	2.64	2.84	1.16	3.6	8.17	

Great Carlton, Linconshire 2006

N	Fung.	S	Yield	Oil	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
(kg/ha)		(kg/ha)	(t/ha)	(9%)						>3
										Soil type:
26	None	30	2.98	46.78	4.68	2.15	77.50	11.85	3.85	Clay Loam
26	Winter	30	3.26	47.53	4.68	2.20	77.60	11.58	3.88	*Drilling date:*
26	Full	30	3.28	47.50	4.50	2.25	79.30	10.90	3.03	8/09/05
190	None	30	4.30	45.30	4.58	2.15	79.03	11.30	2.98	*Malate/SMN:*
190	Winter	30	4.40	45.63	4.68	2.05	77.80	11.93	3.58	4.26/16 (60cm)
190	Full	30	4.64	44.78	4.38	2.13	79.15	11.45	2.88	*Autumn fung.:*
240	None	30	4.57	44.65	4.55	2.10	78.10	12.03	3.25	01/11/05
240	Winter	30	4.61	45.08	4.65	2.05	76.25	12.65	4.43	*Harvest date:*
240	Full	30	4.86	44.80	4.58	2.05	77.48	12.20	3.70	28/07/06
190	None	-	4.24	45.45	4.65	2.08	77.00	12.28	3.98	*Other:*
190	Winter	-	4.2	45.88	4.63	2.13	77.60	12.05	3.68	
190	Full	-	4.47	46.38	4.63	1.98	75.95	12.90	4.53	
LSD	P=0.05		0.272	1.493	0.264	0.148	2.631	1.223	1.355	
CV	%		4.15	2.26	3.97	4.85	2.34	7.1	25.76	

Biggleswade 2006

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
										5
										Soil type:
26	None	30	2.49	44.93	3.80	2.30	79.58	11.50	2.88	Boulder clay
26	Winter	30	2.48	44.70	3.80	2.28	79.20	11.80	2.98	*Drilling date:*
26	Full	30	2.6	45.30	3.80	2.28	79.70	11.33	2.90	7/09/05
190	None	30	2.73	41.43	3.78	2.20	79.00	12.00	3.00	*Malate/SMN:*
190	Winter	30	2.76	43.60	3.78	2.28	79.20	11.78	3.03	31.1/17 (90cm)
190	Full	30	2.97	42.55	3.73	2.20	79.30	11.70	3.03	*Autumn fung.:*
240	None	30	2.77	42.03	3.80	2.13	79.00	12.08	2.98	9/11/05
240	Winter	30	2.84	42.28	3.90	2.13	79.08	11.98	2.93	*Harvest date:*
240	Full	30	3.10	43.05	3.90	2.23	78.88	11.9	3.08	19/07/06
190	None	-	2.86	43.55	3.78	2.23	79.28	11.80	3.00	*Other:*
190	Winter	-	2.82	43.45	3.88	2.18	78.03	12.53	3.38	
190	Full	-	3.21	42.70	3.88	2.20	79.23	11.8	2.93	
LSD	P=0.05		0.287	1.887	0.128	0.093	0.823	0.483	0.335	
CV	%		7.09	3.02	2.33	2.92	0.72	2.82	7.72	

Morley 2006

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
										Virgin crop
										Soil type:
26	None	30	3.49	46.63	3.70	2.10	79.80	11.40	2.98	Sandy Cl. Loam
26	Winter	30	3.57	46.08	3.73	2.13	79.80	11.40	2.88	*Drilling date:*
26	Full	30	3.65	46.78	3.73	2.18	79.93	11.28	2.88	1/09/05
190	None	30	4.49	43.98	3.78	2.10	79.28	11.93	2.98	*Malate/SMN:*
190	Winter	30	4.32	44.03	3.78	2.08	79.30	11.90	2.93	5.97/34 (90cm)
190	Full	30	4.26	43.73	3.83	2.03	79.03	12.18	2.93	*Autumn fung.:*
240	None	30	4.24	43.53	3.70	2.08	79.10	12.10	3.03	7/11/05
240	Winter	30	4.21	42.38	3.73	2.08	78.93	12.33	3.00	*Harvest date:*
240	Full	30	4.23	42.70	3.73	2.10	79.18	12.10	2.90	19/7/06
190	None	-	3.98	44.35	3.78	2.10	79.13	12.00	2.98	*Other:*
190	Winter	-	4.09	44.40	3.73	2.10	79.33	11.90	2.90	
190	Full	-	4.13	44.23	3.73	2.08	79.20	12.10	2.93	
LSD	P=0.05		0.264	0.58	0.091	0.053	0.263	0.223	0.093	
CV	%		4.49	0.9	1.68	1.76	0.23	1.3	2.19	

Cirencester 2006

N	Fung.	S	Yield	Oil	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
(kg/ha)		(kg/ha)	(t/ha)	(9%)						>3
										Soil type:
26	None	30	1.73							Shallow loam
26	Winter	30	1.56							*Drilling date:*
26	Full	30	1.67							5/09/05
190	None	30	2.80							*Malate/SMN:*
190	Winter	30	2.76							28.5/58 (60cm)
190	Full	30	3.02							*Autumn fung.:*
240	None	30	2.64							17/11/05
240	Winter	30	2.68							*Harvest date:*
240	Full	30	2.90							26/07/06
190	None	-	1.45							*Other:*
190	Winter	-	1.45							
190	Full	-	2.18							
LSD	P=0.05		0.415							
CV	%		12.85							

Stapleford, Wiltshire 2006

N	Fung.	S	Yield	Oil	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
(kg/ha)		(kg/ha)	(t/ha)	(9%)						4
										Soil type:
26	None	30	2.17	46.10	3.90	1.98	78.08	12.48	3.60	*Sandy Cl. Loam*
26	Winter	30	2.33	45.33	3.70	2.03	79.78	11.53	2.98	Drilling date:
26	Full	30	2.32	45.78	3.70	2.08	79.73	11.38	3.10	6/09/05
190	None	30	2.63	44.78	3.70	2.08	79.23	11.98	3.08	*Malate/SMN:*
190	Winter	30	2.74	44.43	3.80	1.98	79.53	11.63	3.03	8.3:1/50 (90cm)
190	Full	30	2.87	44.00	3.63	2.00	79.50	11.73	3.03	*Autumn fung.:*
240	None	30	2.55	44.60	3.70	2.00	78.93	12.13	3.28	31/10/05
240	Winter	30	2.67	43.98	3.63	1.93	79.40	11.93	3.08	*Harvest date:*
240	Full	30	2.90	44.00	3.73	1.98	79.30	11.98	3.08	20/07/06
190	None	-	2.57	45.23	3.73	2.08	79.33	11.83	3.10	*Other:*
190	Winter	-	2.52	44.63	3.88	1.98	77.93	12.63	3.60	
190	Full	-	2.69	45.78	3.73	2.08	79.13	11.9	3.18	
LSD	P=0.05		0.251	0.787	0.167	0.100	1.303	0.793	0.481	
CV	%		5.77	1.21	3.10	3.43	1.14	4.60	10.49	

SAC 2007 – Bucksburn, Aberdeen

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR* 3
										Soil type:
26	None	30	2.63	42.33	3.60	1.58	76.93	14.40	3.53	Sandy Loam
26	Winter	30	2.52	42.28	3.65	1.50	75.38	15.30	4.15	*Drilling date:*
26	Full	30	2.64	43.73	3.63	1.58	77.25	14.08	3.53	2/09/06
190	None	30	2.37	42.25	3.60	1.53	77.15	14.25	3.48	*Malate/SMN:*
190	Winter	30	2.55	43.21	3.65	1.55	76.98	14.15	3.65	0.7/48 (60cm)
190	Full	30	2.50	43.65	3.58	1.53	77.33	13.98	3.60	*Autumn fung.:*
240	None	30	2.39	42.63	3.55	1.58	77.18	14.28	3.43	30/10/06
240	Winter	30	2.50	41.75	3.65	1.53	76.75	14.43	3.60	*Harvest date:*
240	Full	30	2.50	43.10	3.65	1.55	77.18	14.18	3.48	14/08/07
190	None	-	2.19	43.53	3.65	1.60	76.88	14.33	3.58	*Other:*
190	Winter	-	2.63	42.85	3.65	1.60	76.90	14.28	3.55	
190	Full	-	2.38	43.68	3.65	1.60	77.10	14.10	3.58	
LSD	P=0.05		0.479	1.109	0.108	0.073	1.323	0.79	0.577	
CV	%		13.38	1.79	2.06	3.22	1.19	3.82	11.12	

Aby, Lincolnshire 2007

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR* >3
										Soil type:
26	None	30	2.03	42.95	3.73	1.70	78.40	12.78	3.40	Clay Loam
26	Winter	30	2.09	44.48	3.80	1.73	78.00	12.80	3.65	*Drilling date:*
26	Full	30	2.54	44.93	3.70	1.78	78.95	12.30	3.25	7/09/06
190	None	30	3.24	45.53	3.75	1.70	78.55	12.55	3.45	*Malate/SMN:*
190	Winter	30	3.05	44.30	3.60	1.83	79.63	11.98	3.03	5.69/12 (60cm)
190	Full	30	3.53	44.58	3.73	1.78	78.93	12.53	3.08	*Autumn fung.:*
240	None	30	3.54	43.55	3.73	1.68	78.45	12.80	3.33	25/10/06
240	Winter	30	3.25	42.90	3.73	1.75	78.48	12.65	3.38	*Harvest date:*
240	Full	30	3.72	43.73	3.75	1.73	78.58	12.50	3.48	27/07/07
190	None	-	3.24	43.60	3.85	1.65	77.98	13.00	3.50	*Other:*
190	Winter	-	2.99	43.83	3.80	1.70	78.08	12.90	3.53	
190	Full	-	3.60	43.28	3.60	1.78	79.18	12.30	3.18	
LSD	P=0.05		0.458	1.579	0.184	0.093	1.253	0.704	0.538	
CV	%		10.35	2.29	0.127	0.064	1.10	3.88	11.11	

Biggleswade 2007

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
										7
										Soil type:
26	None	30	2.37	43.60	4.20	1.80	76.63	13.93	3.45	Boulder clay
26	Winter	30	1.64	43.25	4.08	1.83	76.65	13.98	3.43	*Drilling date:*
26	Full	30	1.79	43.50	4.00	1.85	76.68	13.78	3.63	5/09/06
190	None	30	2.05	41.98	3.98	1.90	76.85	13.83	3.50	*Malate/SMN:*
190	Winter	30	2.15	41.90	3.98	1.85	76.75	13.83	3.60	3.7/17 (90 cm)
190	Full	30	2.78	42.43	3.83	1.83	77.23	13.55	3.55	*Autumn fung.:*
240	None	30	2.13	41.50	3.98	1.80	76.63	13.98	3.63	6/11/06
240	Winter	30	2.23	42.30	3.95	1.83	76.38	14.10	3.75	*Harvest date:*
240	Full	30	2.74	42.28	3.85	2.73	76.28	13.53	3.60	26/07/07
190	None	-	1.93	42.45	4.03	1.88	76.40	14.13	3.65	*Other:*
190	Winter	-	2.13	42.58	3.95	1.85	76.83	13.8	3.55	
190	Full	-	2.34	42.90	3.90	1.90	77.23	13.48	3.48	
LSD	P=0.05		0.596	0.63	0.205	0.693	0.901	0.457	0.302	
CV	%		18.86	1.02	3.57	25.03	0.81	2.29	5.86	

Morley 2007

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR*
										Virgin crop
										Soil type:
26	None	30	3.36	44.03	4.03	1.78	77.65	13.40	3.15	Sandy Cl. Loam
26	Winter	30	3.32	44.00	3.93	1.83	77.88	13.13	3.28	*Drilling date:*
26	Full	30	3.50	44.55	4.00	1.85	77.95	13.00	3.20	7/09/06
190	None	30	4.30	43.00	3.93	1.75	77.45	13.58	3.28	*Malate/SMN:*
190	Winter	30	4.31	43.45	3.90	1.78	77.58	13.40	3.35	1.42/18 (90cm)
190	Full	30	4.65	43.25	3.88	1.78	77.78	13.18	3.35	*Autumn fung.:*
240	None	30	4.41	43.13	3.85	1.88	77.9	13.18	3.23	29/11/06
240	Winter	30	4.32	43.03	3.90	1.80	77.55	13.48	3.28	*Harvest date:*
240	Full	30	4.22	43.05	4.03	1.80	77.73	13.18	3.28	27/07/07
190	None	-	4.02	43.33	3.98	1.80	77.53	13.45	3.23	*Other:*
190	Winter	-	4.22	43.28	4.03	1.83	77.68	13.28	3.23	No hand sample
190	Full	-	4.36	43.38	3.88	1.83	77.88	13.18	3.23	harvest, analysis
										of combine
LSD	P=0.05		0.374	0.88	0.251	0.067	0.57	0.445	0.107	harvested
CV	%		6.34	1.4	4.41	2.56	0.51	2.32	2.28	samples

Cirencester 2007

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR* >3
										Soil type:
26	None	30	1.12	48.18	3.70	2.08	78.58	12.40	3.30	Shallow loam
26	Winter	30	1.40	46.95	3.75	2.05	77.93	12.78	3.48	*Drilling date:*
26	Full	30	1.42	47.63	3.68	2.05	78.55	12.48	3.25	7/09/06
190	None	30	2.33	45.60	3.58	1.95	78.55	12.60	3.28	*Malate/SMN:*
190	Winter	30	2.43	44.50	3.63	1.98	78.38	12.63	3.35	1.28/27 (60cm)
190	Full	30	2.24	45.08	3.55	2.00	78.38	12.58	3.53	*Autumn fung.:*
240	None	30	2.15	45.53	3.48	2.00	79.18	12.20	3.13	7/11/06
240	Winter	30	2.47	44.55	3.65	1.95	77.85	12.80	3.78	*Harvest date:*
240	Full	30	2.44	45.93	3.60	2.03	78.08	12.68	3.68	31/08/07
190	None	-	1.21	44.78	3.98	2.05	78.23	12.38	3.33	*Other:*
190	Winter	-	1.51	44.68	4.13	2.05	77.45	12.68	3.73	
190	Full	-	1.69	44.50	4.10	1.98	77.25	12.78	3.88	
LSD	P=0.05		0.349	1.76	0.284	0.141	1.182	0.73	0.509	
CV	%		12.95	2.67	5.27	4.85	1.05	4.02	10.16	

Stapleford, Wiltshire 2007

N (kg/ha)	Fung.	S (kg/ha)	Yield (t/ha)	Oil (9%)	C16	C18.0	C18.1	C18.2	C18.3	*Years since OSR* Virgin crop
										Soil type:
26	None	30	1.49	48.15	3.48	1.88	79.6	11.88	3.15	Sandy Cl. Loam
26	Winter	30	1.63	47.48	3.50	1.85	79.58	12.03	3.05	*Drilling date:*
26	Full	30	1.77	48.25	3.53	1.85	79.3	12.08	3.25	1/09/06
190	None	30	2.39	45.88	3.58	1.80	79.23	12.18	3.23	*Malate/SMN:*
190	Winter	30	2.55	45.65	3.53	1.80	79.18	12.28	3.25	7.19/18 (90cm)
190	Full	30	2.85	45.58	3.58	1.78	78.63	12.45	3.53	*Autumn fung.:*
240	None	30	2.45	44.95	3.53	1.75	79.13	12.28	3.30	2/11/06
240	Winter	30	2.65	45.50	3.38	1.85	79.68	12.00	3.13	*Harvest date:*
240	Full	30	2.97	45.13	3.40	1.85	80.13	11.7	2.95	25/07/07
190	None	-	1.76	46.68	3.65	1.78	79.28	12.13	3.18	*Other:*
190	Winter	-	1.84	46.43	3.70	1.80	79.18	12.18	3.15	
190	Full	-	2.23	47.10	3.55	1.85	79.88	11.73	3.00	
LSD	P=0.05		0.227	0.636	0.126	0.108	1.381	0.865	0.515	
CV	%		2.22	0.95	2.47	4.10	1.20	4.96	11.22	

Appendix C

Improved Winter Rape Varieties for Lubricants

Report from FUCHS Lubricants plc following work carried out in assessment of higher oleic varieties.

Background

There is nothing new in use of harvestable raw materials for production of lubricants; mineral oils have been on the scene for a relatively short period of 150 years, but previous to this vegetable oils particularly held sway, albeit in a much limited market in both volume and performance requirement terms. Vegetable oil based lubricants with appropriate performance additives offer a number of distinct paper advantages over mineral oils in some, but not all, areas. In particular, their load carrying ability and extremely low coefficient of friction have ensured special consideration in formulations; they have low evaporation rate ideal in some applications; they are naturally “Multigrade”, with excellent temperature/ viscosity behaviour, and therefore offer benefits where there are significant variations of ambient temperature. In addition the low coefficient of friction offers an excellent starting base for lubricant development. Indeed, vegetable oils have often even been used as additives in mineral oils to improve lubricity. Other favourable comparisons include improved flash point, and therefore reduced combustibility, low sulphur levels and very low levels of volatility.

However, vegetable oils such as rape, have a major disadvantage: they have poor oxidative and thermal stability due to the high levels of polyunsaturated fatty acids, and to the overall level of unsaturation. At higher temperatures oil darkening, oxidative breakdown, viscosity increase and raised acidity renders the fluid unsuited for applications other than the least stressed. Indeed, with inappropriate lubricant, the level of stability can result in severe equipment failure, lacquering, corrosion or staining, with significant on-costs and equipment downtime for repair.

As a general rule, it is generally accepted that conventional rapeseed oil is unsuited as a base oil in applications at temperatures greater than 70 degrees C, where the thermal and oxidative stability do not match up to that for mineral oils. Whilst therefore refined rapeseed oil with appropriate additive treatment can be used successfully for manufacture of “total loss lubricants” (i.e. lubricants which are not recirculated in use, such as for chain bars or concrete mould release applications) or for a limited number of less stressed hydraulic applications at ambient temperatures, they are less suited to the majority of mainstream hydraulic uses, or for compressors, turbines, greases, metalworking fluids, gear and transmission oils, engine oils, machine and slideway lubricants, *etc*.

Most other more highly stressed applications where the lubricants industry requires a lubricant sourced from renewable resources, are filled by use of selected single esters, or blends of esters, and so resulting in a formulation of much higher cost base. These esters at one time had been sourced from mineral oil carbon, but are increasingly now sourced from renewable resources.

However, it is hoped that use of low-polyunsaturated oils could extend the platform base for use of the oils themselves, rather than the need to move to the higher cost esters, and to remain with a cost base that could favour introduction of renewable based lubricants.

This report details work carries out by FUCHS Lubricants to assess the oxidation and stability characteristics of the oil conventionally used by FUCHS (approx 60% oleic), with samples of Castille (approx 62% oleic), Cabriolet (approx 73%), Splendor (approx 80%), and with high oleic sunflower.

Testing and results

Physical properties

A number of tests were carried out to characterise the physical properties of the test fluids and to assess whether there were any changes , see results in Table 1.

Laboratory		**71133/1**	**71133/2**	**71133/3**	**K02320**

number:					
Code:		**Rapeseed oil**	**Rapeseed oil**	**Rapeseed oil**	**Rapeseed oil**
		Splendor	**Castille**	**Cabriolet**	**Fuchs quality**
Appearance:		Light amber	Light amber	Light amber	Light amber
Colour:		2.5	2.5	2.5	0.5
Odour:		Mild	Mild	mild	Mild
Spec. gravity 15°C:	g/cm^3	0.917	0.919	0.917	0.921
Refractive index:		1.470	1.472	1.472	1.472
Viscosity 40°C:	mm^2/s	37.3	35,0	36,0	35
Viscosity 100°C:	mm^2/s	8.3	8.1	8.2	8
Viscosity index:		209	215	211	215
Neutralisation number	mg KOH / g	0.2	0.2	0.3	0.1
Iodine number:	mg I_2/g	94	104	102	110
Pourpoint:	°C	-24 (-24,7)	-24 (-24,8)	-27 (-27,8)	< -9
H_2O-Karl Fisher:	mg / kg	458	417	436	-

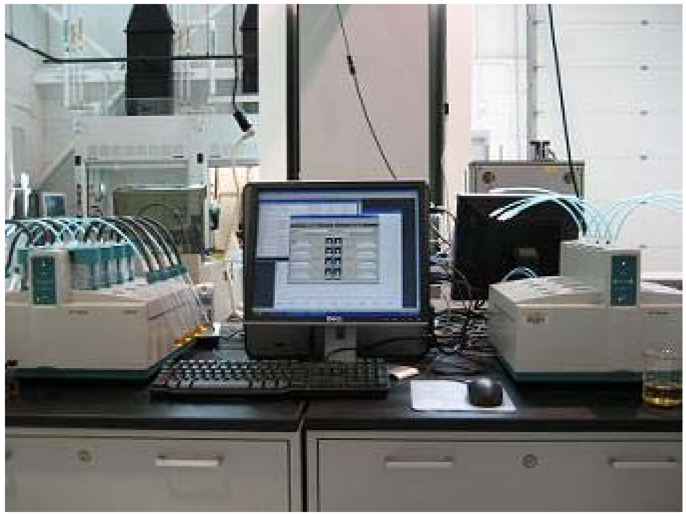
Table 1: Physical and viscometric properties of test fluids

Results showed the fluid to possess similar viscosity characteristics to the usual approx 60% oleic rapeseed oil as currently used by the FUCHS Group. Iodine Number showed the expected trend, i.e. reduction with reduced levels of polyunsaturated materials.

Assessment of stability and oxidation character

Oxidation stability carried out by Rancimat

The Rancimat is traditionally used to determine the oxidative stability of vegetable oil and other fluids derived from them. Tests of the induction period were performed in accordance to EN14112.



The instrument measures the ability of a vegetable oil based fluid to resist oxidation under conditions of heat and continuous air flow. The instrument is used extensively in determining the detrimental effects of metallic contaminants and the ameliorating effects of chelators and antioxidants. Air is blown through the heated and thermostated sample in order to oxidize it. The stream of air then carries over the volatile oxidation products (normally formed at the end of the oxidation process) to a measuring vessel containing deionised water. The readings of the conductivity measurement can be plotted as a function of the time required for the oxidation. The inflection point of this oxidation curve is known as the induction time which serves as a measure of quality of the oil tested.

All samples of vegetable oil in this programme of testing were treated with 0.5% hindered phenol oxidation inhibitor, as would be typical in standard lubricant formulations to improve oxidation stability, and results from the Rancimat Test are shown in Table 2. The three rapeseed oils were tested alongside high oleic sunflower with 90% plus oleic.

Laboratory number:		**71133/1**	**71133/2**	**71133/3**	**K02320**	**LA 38325/3**
Code:		**Rapeseed oil**	**Rapeseed oil**	**Rapeseed oil**	**Rapeseed oil**	**Sunflower oil**
		Splendor	**Castille**	**Cabriolet**	**Fuchs quality**	**HOSO 90plus**
Rancimat 140°C:	h	12.2	6.5	8.4	5.4	39.8
Rancimat 160°C:	h	2.9	1.5	1.9	1.3	8.6

Table 2: Rancimat Test by ISO 6886 (with 0.5% conventional Ionox hindered phenol antioxidant)

Oxidation testing by IP 48

The Institute of Petroleum test method IP 48 was originally developed by the UK Admiralty lubricants laboratory as a method of cross comparing a variety of test formulations by an accelerated method and at high temperatures. It is generally accepted that each 10 degree C increase in temperature doubles the potential oxidation rate of lubricants, 70 to 80 doubles once, and 80 to 90 doubles again, *etc*.

Tests in the current programme were carried out at 130 C, and for mineral oil based fluids, there would be expected to be only minimal change for the tests times.

For these tests, each oil was formulated into a test oil, incorporating anti-oxidant, anti-wear and anti-foam additives, producing a lubricant formulation that might be employed in simple hydraulic applications, and using the formulation for FUCHS Plantohyd 40N, the formulation changing only by use of the different base vegetable oils. For comparison one of the test oils was also prepared using high oleic sunflower (90% plus). FUCHS Plantohyd 40N is a type of formulation currently successfully made and sold in the UK and in other European countries for less stressed hydraulic applications at ambient temperatures.

IP48 - Oxidation test					
(in the formulation of Plantohyd 40 N)					
Laboratory number	LA 71133/1	LA 71133/2	LA 71133/3	K02320	LA 38325/3
Code	Splendor	Castille	Cabriolet	Fuchs Quality	HOSO 90plus
Laboratory code	KB 04/06//3-C	KB 04/06/3-D	KB 04/06/3-E	KB 04/06/3-A	-
Neutralisation number	0.4	0.4	0.5	0.3	0.55
Viscosity at 40°C	47.4	44.6	45.8	43.2	39.5
Viscosity at 100°C	10.1	9.8	9.9	9.3	-
Viscosity index	207	212	210	207	-
Colour	3	2.5	2.5	1.5	-
Spec. Gravity	0.919	0.921	0.920	0.915	-
Oxidation Test by IP 48					
after 1 day					
Neutralisation number	0.3	0.6	0.7	0.5	-
Viscosity at 40°C	49.9	51	49.4	48.9	-
after 2 day					
Neutralisation number	0.6	3.6	1.2	3.1	-
Viscosity at 40°C	52.9	113	57.4	90.1	-
after 3 day					
Neutralisation number	1.3	10.6	3.8	10	-
Viscosity at 40°C	59.3	592	98.6	418	-
after 6 day					
Neutralisation number	-	-	-	-	0.85
Viscosity at 40°C	-	-	-	-	46.3
after 7 day					
Neutralisation number	-	-	-	-	1.3
Viscosity at 40°C	-	-	-	-	49.4
after 8 day					
Neutralisation number					2.3
Viscosity at 40°C					97.3

Table 3: IP 48 Oxidation Tests (130°C, 15 l/h air, without catalyst, formulated into hydraulic formulation, using FUCHS Plantoform 40N basis)

Conclusions

The assessment of physical properties for the oil from Castille, Cabriolet and Splendor showed broadly similar results with exception of Iodine Value where the expected trend was noted due to the variations in polyunsaturated character. Viscosity characteristics of rapeseed oil show good multigrade character, similar values in all samples tested, and confirmed the high flash points.

However, oxidation characteristics of samples tested by both Rancimat and by IP 48 test methods did not show a sufficiently significant improvement. Results did show an improvement with reduced polyunsaturated content, but the overall results were still far inferior to those for standard mineral oil, and markedly inferior to those for >90% oleic sunflower oil.

The results do not suggest or encourage use of only up to 80% oleic varieties, there being no significant stability advantage over 60% varieties.

Nevertheless, it is suggested that work continue, to assess possible rape varieties beyond 90%, preferably beyond 95% C 18:1 fatty acid.