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EFFECTS OF PRE-HARVEST TREATMENT ON THE YIELD AND QUALITY OF WINTER OILSEED RAPE

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by

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ABSTRACT

This review considers the effects of pre-harvest treatments on the yield and quality of winter oilseed rape (Brassica napus). All available published UK data have been included, and such unpublished data as could be obtained. In all 50 experiments, done between 1975 and 1990 and involving comparisons of pre-harvest treatments, were reviewed. Data quoted by commercial firms in advertising or promotional literature have been ignored.

In favourable ripening and harvesting conditions, the pre-harvest treatments, swathing, desiccation with diquat or glyphosate, direct combining or use of a pod sealant, had little effect on yield. Harvest losses ranged between 20 and 50 kg/ha of seed with little difference between treatments. However, these losses are high in relation to the quantity of seed that is planted to establish the crop (approximately 6 kg/ha), and pose problems for the future because volunteer oilseed rape is a troublesome weed in other broad-leaved crops. Losses of between 50 and 150 kg/ha commonly occurred in less than ideal harvesting conditions. Standing desiccated crops or crops left to be direct combined were shown to be vulnerable to pod shatter

and seed loss in windy conditions, especially on exposed sites. In these situations, substantial losses of over 200 kg/ha and up to 1.6 t/ha occurred one year in three, when mean daily windspeeds in excess of 11 knots occurred in the ripening and harvesting period. Swathing gave significantly higher yields in these conditions and would be the preferred pre-harvest treatment for crops at risk of wind damage.

In wet and late harvesting seasons, swathed or badly-lodged crops were at risk of loss from seed chitting in pods. Desiccation was the best treatment to ensure fast drying of crops in these situations, provided they were not exposed to wind damage.

Data reviewed in this paper indicate that when choosing a pre-harvest treatment there are no conflicts between yield and quality. However, whatever the treatment, choice of timing is crucial for yield and quality. Premature treatment generally resulted in smaller seed, lower yields, higher moisture contents, lower oil contents, higher glucosinolate contents and higher proportions of red seeds in harvested samples, and a greater risk of seed spoilage in store. Conversely, late treatment favoured seed quality but increased the risk of yield loss.

Several topics have been identified for further research and development. These include quantifying the effects of pre-harvest treatment on the speed and mode of action of crop drying, developing and evaluating techniques to assess crop maturity and to determine seed losses, evaluating pre-harvest treatments for lodged crops, quantifying headland wheeling damage caused by sprayers and swathers, developing and evaluating pod sealants, breeding new cultivars with shatter resistance and defining the role of glucosinolates and sulphur in the metabolism of oilseed rape plants.

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GLOSSARY

assimilate	simple plant foodstuff (e.g. sugars and carbohydrate) built up by the plant
auxins	plant growth hormones
biennial	plant that requires two years to complete its lifecycle
blind pod site	pod-less flower stalk on a pod-bearing branch
carpel	female reproductive organ of a flowering plant
chlorophyll	green pigment found in plant cells, which is essential to the process of photosynthesis
cotyledon	leaf-forming part of the seed which emerges above ground, develops chlorophyll and synthesises food material by photosynthesis
cultivar	cultivated variety
cytokinins	plant growth hormones
dehiscing	splitting of a pod to release seeds
desiccation	process of drying out, ususally after a chemical desiccant has been applied
double low	low in both erucic acid and glucosinolates
enzyme	a protein which promotes chemical change without being used up in the process
erucic acid	long-chained fatty acid present in rapeseed oil
ethylene	plant growth hormone

glucosinolates	a group of sulphur compounds, the breakdown products of which are anti-nutritional
harvest index	proportion of seed in total crop dry matter
hydrolysis	chemical decomposition by water
internode	part of plant stem between two branches
ovary	hollow basal region of the female part of a flower which contains seeds
ovule	developing seed
parenchyma	thin-walled plant cells permeated by a system of intercellular spaces
raceme	a kind of inflorescence, formed from a series of closely-set, stalked flowers, as found in oilseed rape
rhizome	underground stem
ruminants	livestock such as sheep or cattle which have a rumen
SED	standard error of the difference between means. Differences between means need to exceed twice the SED to be significant.
senescence	growing old
sepals	outermost parts of a flower bud
stamens	parts of a flower which produce pollen
stolon	horizontally growing stem that roots at the nodes

swathing mechanical cutting of a crop to aid drying

translocation transport of materials within a plant

µmole/g unit of measurement for glucosinolates

1. INTRODUCTION

The aim of this review was to collate information on the effects of pre-harvest treatment on the yield and quality of winter oilseed rape. The purpose was to identify the main areas of risk, and gaps in knowledge which could be filled by further research and development. Information has been gathered mostly from sources in the UK, where the majority of field R & D has been carried out. All available published UK data have been included. Unpublished data were sought from Research Institutes, Universities and the Scottish Colleges but such data were available only from the Institute of Arable Crops Research (IACR) Rothamsted, the University of Newcastle and ADAS. Results quoted by commercial firms in advertising and promotional literature have been ignored. Little relevant information, apart from anecdotal accounts, was available from other EC sources and so none has been used. Data from North America, Asia and Australia have not been used because cultivars and cropping conditions are not appropriate to the UK.

The approach taken has been to summarise the importance of the oilseed rape crop in the UK, linking this with the importance of achieving the quality standards for oil and meal set by the EC and the oilseed crushing industry. This is followed by a description of the structure of the oilseed rape crop and the flowering and ripening processes leading up to pod and seed development and eventually to pod splitting. The various pre-harvest treatments are then discussed, followed by a summary of the physical effects of pre-harvest treatment on oilseed rape yield.

Some of the data on the effects of different pre-harvest treatments have been published but numerous experiments have not. The main findings have been extracted, the risks of harvest losses assessed and methods of pre-harvest treatment compared. The effects of site, season and timing are discussed. Effects of pre-harvest treatments on seed oil and glucosinolate contents are also described and recommendations for further research and development made.

2. BACKGROUND

Winter oilseed rape is an important break crop in the cereal-dominated rotations on arable farms in the UK, and is the most important alternative combinable crop grown (Bearman, 1989). In autumn 1990, 7.5% of the land sown with winter crops (425 000 ha) was put down to winter oilseed rape. This was an increase of 16% on the previous year and was part of a trend for the popularity of this crop to increase following the sharp decline in area between 1986 and 1988, which had been related to a sudden drop in prices (Anon., 1991). The fluctuations in price paid for the crop greatly influence farmers' decisions to grow it.

Security of yield is an important part of the profitability and popularity of any crop, and oilseed rape yields can be very variable. In particular, the crop is very susceptible to yield loss in the pre-harvest period. Oilseed rape goes through the ripening process to seed shedding much more quickly than do cereals. In addition, oilseed rape needs to be dried down to 91% dry matter to ensure safe storage compared with only 85% dry matter for cereals. This means that oilseed rape needs to be harvested at a later stage of crop maturity than do cereals. These two factors combine to increase the risk of seed loss immediately pre-harvest, and make this one of the most critical periods in the successful production of the crop.

Seed loss is generally a result of adverse weather conditions at the time of ripening and harvesting. MacLeod (1981) described the losses which can occur prior to harvest. In the worst instance, as a result of adverse weather conditions during ripening, more than 1.6 t/ha of seed (approximately half of the total crop yield) were lost prior to harvest from a standing desiccated crop.

In addition to loss of crop yield, lower oil contents or reduced oil quality can occur as a result of choice and timing of pre-harvest treatment and of harvesting conditions. The EC has established basic quality standards for rapeseed to qualify for intervention. However, the majority of rapeseed in the UK is traded on a FOSFA (Federation of Oils, Seeds and Fats Association)/UKASTA (United Kingdom Agricultural Supply Trade Association) contract which sets down certain base specifications, eg. for oil, erucic acid, glucosinolate, moisture and admixture contents, on which price penalties or premia are based.

Oilseed rape is grown for its oil and protein content. High oil content is desirable because it will produce a greater return of crude rapeseed oil. A higher price is paid for seed containing more than 40% oil and conversely payment is reduced for seed with oil content lower than 40%. Oilseed crushers aim to produce the maximum yield of quality crude oil from rapeseed of varying composition. The quality of the crude oil must satisfy oil refiners, and have the required attributes of flavour, texture, odour, colour and stability.

Rapeseed oil is distinct from other major vegetable oils because of its high content of long chain fatty acids, notably erucic acid. This high level of erucic acid (up to 50% of total fatty acids) makes the oil more water repellent than other vegetable oils, and gives it particular value as a lubricant for metal surfaces. However, its usefulness as a cooking oil became uncertain when medical studies indicated that erucic acid was associated with fatty deposits in heart muscles (Scarisbrick, Atkinson & Asare, 1989). In 1976, there was an EC ruling that only edible oils with a content of less than 15% erucic acid would qualify for intervention but from 1979 this was reduced to less than 5% (Thompson & Hughes, 1986). Most modern cultivars now have less than 1% erucic acid in the oil, except those cultivars grown specifically for the production of industrial lubricants. In general, therefore, the effects of pre-harvest treatment on erucic acid content are likely to be negligible and are of little concern.

However, pre-harvest treatment can affect the yield and quality of the oil in two ways. Firstly, chitted or germinated seed can occur in wet harvesting seasons, especially in swathed or lodged crops laid on the ground. Germination leads to chemical changes within the seed which reduce the oil content, as oil is utilised as an energy source. In addition, chlorophyll is synthesised as the cotyledons develop and this can discolour the oil. During germination the protective seed coat is breached and this allows air and moisture to enter, resulting in more rapid and extensive breakdown of oil than in sound seed. Secondly, oilseeds harvested before maturity can have low levels of oils and protein. Immature seeds contain higher levels of free fatty acids rather than oil, and being still metabolically active can produce respiration heat and moisture leading to the possibility of storage damage. Even more important are the high levels of chlorophyll pigments present in immature seeds. These produce green crude oil which requires extra bleaching earth and longer processing time during refining to obtain a desirable pale-coloured end product (Brogan, 1986).

In addition to the oil, the meal which is left after the oil has been expelled is a saleable commodity, as the protein component of animal feeds. However, the rates of inclusion in livestock rations, especially for pigs and poultry, were severely limited by the presence of glucosinolates in the meal which occurred in single low cultivars (low in erucic acid alone). Glucosinolates are a complex group of compounds (thioglucosides) that give the characteristic 'mustard' flavour to vegetable and condiment Brassica species (Scarisbrick, Atkinson & Asare, 1989).

During the early stages of oil extraction the heating and rolling processes result in the release of myrosinase the enzyme which hydrolyses glucosinolates. Although the enzyme is partly destroyed by subsequent steam-heating of the crushed seed, some breakdown products of glucosinolates are produced (isothiocyanates, nitriles, thiocyanates and goitrins). Animals fed rapeseed meal containing these products may suffer pharmacological disorders associated with the activity of the thyroid gland. Monogastric animals, such as pigs and poultry, are especially sensitive to these breakdown products. Reduced feed conversion efficiency has also been demonstrated in ruminants and, as a result, the inclusion levels of oilseed rape meal in compound feeds for dairy cows have been limited to 10-20% (Stedman & Hill, 1987).

Such nutritional concerns led to the production of double low cultivars which were low in both erucic acid and glucosinolates. In order to implement its policy of increasing the use of rapeseed meal for animal feed, the EC instituted a bonus subsidy for rapeseed containing below 35 µmol of glucosinolate per gramme of seed. The intention was to grant subsidy only for rapeseed below 20 µmol per gramme from 1991 but the 35 µmol limit has been retained until 1992 (Milford & Evans, 1991). However, the proposed new support scheme for oilseeds, which will apply from 1 July 1992, will remove the obligation by growers to meet any glucosinolate standard in harvested seed, although seed that is sown must be of an appropriate quality.

Prior to the introduction of the new support scheme for oilseeds, considerable importance was placed on the level of glucosinolates in seed and a large programme of research was undertaken to determine what factors affected their accumulation. Whilst it might now appear that the information from this research is no longer relevant to oilseed rape growers, market forces may still require growers to produce seed of the right quality so that outlets for rapeseed meal are not limited. Consequently, information on the effects of harvesting methods on glucosinolates is still included in this review.

Surveys of seed glucosinolate concentrations in commercial crops were conducted soon after the EC announced its intention to introduce a market limit for glucosinolates. Findings from the surveys showed considerable national variation (Anon., 1988a). At the time (1987), it was not known how far the differences depended on where the crops were grown (site/season effects) or how they were grown (different husbandry/ agronomic practices). Subsequent studies at IACR Rothamsted and at the University of Newcastle have provided information on the relative importance of these factors. Other factors which could influence glucosinolate concentrations are pre-harvest treatments and the times at which these are done. Whereas a national survey had indicated no discernible relationship between seed glucosinolate concentration and pre-harvest treatment (Anon., 1988a), there was circumstantial evidence that different pre-harvest treatments might have created differences in seed glucosinolate concentrations in some National Institute of Agricultural Botany cultivar experiments (Parnell, Craig & Draper, 1983).

It is against this background that there has been a considerable research on the physiology of oilseed rape growth and ripening, and on evaluating pre-harvest treatments to reduce losses and maximise seed quality. This paper reviews the information available on these topics.

3. PLANT DEVELOPMENT AND PHYSIOLOGY OF RIPENING

3.1 Oilseed rape species

Brassica napus is the most commonly grown species of oilseed rape for seed production in the UK, with the winter-sown biennial types predominating. Annual spring-sown cultivars are also grown but on a much smaller scale (Bunting, 1986; Bearman, 1989).

3.2 Reproductive development

Physiological studies on winter oilseed rape in South-East England by Daniels et al. (1982) showed that, when the winter crop is sown in late August, reproductive development begins in early November. The first reproductive parts to develop are those on the terminal raceme, followed sequentially by branches 1, 2, 3, 4 and 5. The oilseed rape plant emerges from the winter as a rosette of leaves in the axils of which the reproductive parts are developing. Stem elongation begins in early spring with a rapid increase in crop height when the flower buds appear. Elongation continues up to the end of flowering, with the major increases occurring in the terminal raceme and the internodes between the lateral branches (Tayo & Morgan, 1975).

3.3 Flowering and pod development

Brassica plants, such as oilseed rape, flower progressively. The lower buds on the main raceme open first and gradually flowering develops upwards till the uppermost group of buds opens. The secondary branches follow the same pattern and the process is spread over a period of four to six weeks, depending on the cultivar (MacLeod, 1981; Evans, 1984; Daniels, Scarisbrick & Smith, 1986; Scarisbrick, Atkinson & Asare, 1989). Flowers are produced on the main stem and branches until competition for nutrients from the earlier pods causes abortion of the youngest pods, flowers and buds. This type of growth is completely indeterminate (Thompson, 1982). The remainder of the cycle, through pod-set to seed ripening, follows the same sequence.

About two to three days after flower opening, the stamens, petals and sepals senesce and drop off, leaving an ovary approximately 1 cm long. If this potential pod has been successfully fertilised it will continue to develop and increase in size. As it does so, the fertilised ovules grow and change colour from translucent through green and brown to black (Scarisbrick, Atkinson & Asare, 1989). The first two to three weeks of flowering are important in determining yield as the majority of pods which survive to maturity develop from flowers opening during this period (Tayo & Morgan, 1975; Scarisbrick, Atkinson & Asare, 1989).

3.4 Plant structure

Once flowering is complete the oilseed rape plant consists of a main stem, bearing a terminal raceme of pods, and several lateral racemes or branches also carrying pods or blind pod sites. The numbers of lateral racemes and pods vary according to cultivar and other external influences e.g. crop husbandry practices and seasonal effects.

Plant populations can have a marked effect on plant structure and can also affect the length of the flowering period and the range of pod and seed maturity. Plants grown in low density situations initiate many branches (lateral racemes) which decrease in productivity with depth in the canopy, and the bottom ones often fail to produce seed. The terminal raceme is usually the dominant pod-bearing site. This is also the case with plants that are grown in high density situations but fewer lateral racemes are initiated on these plants because of competitive effect between plants. Ogilvy (1984) found that the numbers of pods on terminal racemes were similar on plants from high and low density populations, whereas the numbers of pods on lateral racemes varied. The terminal raceme develops first and remains dominant throughout the rest of the life cycle unless it is damaged by pest or disease (Daniels et al., 1982). Because flowering commences on the terminal raceme and top-most branch and progresses downwards to the lower racemes the length of the flowering period and subsequent range of seed maturity are greater on plants with more branches i.e.

those grown at lower populations. This has been reflected in higher seed moisture contents at harvest (Scarisbrick, Daniels & Noor Rawi, 1982). In addition, plants from low density crops tend to stay greener for longer and have much thicker stems (Ogilvy, 1984).

The diverse structure and the compensatory ability of oilseed rape plants, whilst having advantages in coping with damage from pigeons or disease, cause particular problems because of the range of maturity of pods which is produced. This range can be narrowed by growing high density crops in which terminal racemes dominate, but harvest index is reduced (Scarisbrick, Daniels & Noor Rawi, 1982). High density crops also tend to be weak-stemmed, more prone to stem diseases and lodging, and are often lower-yielding.

3.5 Ripening period

The period of ripening from the end of flowering can vary from seven to ten weeks (MacLeod, 1981). During this time, most leaves senesce and drop off, and the stem and pods take over as the main photosynthetic areas for seed assimilate production (Bilsborrow & Norton, 1984; Chapman, Daniels & Scarisbrick, 1984; Addo-Quaye, Scarisbrick & Daniels, 1986). The compositional changes in developing seeds were studied by Norton & Harris (1975). The 12 weeks of seed development were divided into three phases. In phase 1 (weeks 1 to 4), starch and water-soluble constituents accounted for 80% of seed dry matter, whereas oil and protein accounted for 15%. In phase 2 (weeks 5 to 6), there were marked rises in oil and protein contents (to 40 and 20% of DM respectively) and an almost equal fall in starch. In the final phase (weeks 7 to 12), oil and protein deposition rates were high but remained in fixed proportion. Seed weight almost doubled between weeks 6 and 9 by which time seed development was complete, with only dehydration occurring in the last two weeks. More recent research has shown that seed glucosinolate concentrations increase whilst the seeds are actively growing, but they remain more or less constant during seed maturation (Milford et al., 1991). When seed fill is complete the whole plant starts to senesce and the pod splitting process begins.

3.6 Pod shatter

Oilseed rape pods are designed to split, when ripe, to release their seed. This is called dehiscing. The two halves of a pod (the carpels) are separated by a papery layer of tissue (the replum) which runs the full length of the pod. The replum is separated from the actual edges of the carpels by a layer of parenchyma cells on each side. These layers of cells are called the "dehiscence zones" because when they break down the two halves of a pod become easy to separate.

Picart & Morgan (1984) have described four processes involved in regulating pod splitting or dehiscence. These are:-

1. Onset and rate at which the parenchyma cells in the dehiscence zones are broken down by the action of their own enzymes.

2. Onset and rate at which the pod walls die.

3. Onset and rate of water loss from pod walls which causes shrinkage, especially in the outer layers of cells.

4. The tensions which this shrinkage sets up within the pods.

It is the tensions set up by differential shrinking of different layers of cells within the pod walls which eventually cause disruption of the dehiscence zones, and bursting of the pod.

Attempts to control pod shatter in oilseed rape should recognise these stages and be aimed at delaying or slowing down one or other of them. For example, inhibitors of ethylene production might delay the onset of cell breakdown in the dehiscence zones; cytokinins and auxins might delay or slow down the rate of water loss from pod walls and delay the build-up of tensions needed to burst the pod. Finally, pod sealants might be used actually to seal the two halves of pods together.

4. METHODS OF PRE-HARVEST TREATMENT

Some oilseed rape growers direct combine their crops with no pre-harvest treatment at all and some use pod sealants. However, the majority of growers use pre-harvest treatments to even-up ripening, ease combining, reduce drying costs and sometimes to kill weeds. The main methods of pre-harvest treatment are swathing or desiccation with diquat or glyphosate. For example, in 1988 in the UK, 66 000 ha of oilseed rape were treated with diquat and 15 000 ha were treated with glyphosate, 22% and 5% of the total UK oilseed rape area respectively (Anon., 1990). There are no figures for the percentages of crops which were swathed, direct combined or received a pod sealant, but swathing and direct combining are known to be common and widespread. A new desiccant, glufosinate-ammonium, has recently been approved and released for use on oilseed rape, but as yet is not widely used.

The various pre-harvest treatments are described in this chapter, covering time of application and mode of action. Details of application rate, water volume etc. are not given. They can be found on product labels or in product manuals available from the manufacturing companies. Comparisons of costs between the various treatments have not be made either, as this information is very variable and subject to change.

4.1 Direct combining

Direct combining without mechanical or chemical treatment is a popular method of harvesting the crop especially in dry, fast-ripening seasons. This method is most suited to crops which are evenly ripening, with no patches of backward crop and no weed problems. Crops that are standing or leaning will dry out more evenly and more quickly than badly lodged crops, which may take a long time to ripen close to the ground. A well-intermeshed crop canopy will help reduce pod shatter which can occur in standing crops in exposed situations.

Direct combining is most common in areas such as the south and south-east of England where harvest is early and usually occurs in dry weather conditions. In less favourable crop and weather conditions, direct combining can result in late harvests and consequent seed loss from the more mature parts of the crop, particularly if combining is delayed until the majority of the crop is ripe. Higher seed moisture contents, and consequently higher drying costs, may result if crops are combined early to minimise losses. Direct combining can be a risk in areas where harvesting is often delayed by wet or cool weather, as in the west and north of the UK, when the crop can take longer to ripen and harvesting opportunities are often reduced.

4.2 Swathing

Swathing or windrowing is one of the traditional methods of accelerating crop ripening and has the advantage of safeguarding crops from seed losses in windy weather (MacLeod, 1981; Bailey, 1982; Bowerman, 1983). It is usually done by contractors using specifically designed, self-propelled, oilseed rape swathers.

Swathing standing crops of oilseed rape protects them from wind damage which can result in pod shatter and seed loss, especially in exposed situations. Crops should be laid on sufficient stubble (approximately 20 to 35 cm) to allow air to pass freely underneath to aid drying, otherwise seed may start chitting in the pods in wet conditions. Swathing is not suitable for badly lodged crops in which the stubble may be insufficiently upright to support the swaths and allow them to dry out.

Work by Ogilvy (1989a) has shown that the optimum time to swath oilseed rape is approximately six weeks after the end of flowering, when the seed should be dark brown in the bottom pods, red-brown with some green in the middle pods and green just turning brown in the top pods of the terminal raceme. Crops are usually fit for combining seven to ten days after swathing.

4.3 Desiccation

Diquat, sold as Reglone or Power Diquat, is the main desiccant used on oilseed rape (Anon., 1990). It has a rapid contact action on all green plant parts, and is unaffected by rainfall even if this occurs shortly after application (Sanderson, 1976).

Crops usually reach the stage suitable for desiccation two to three days later than the stage suitable for swathing. They should be desiccated when all the seed is dark-brown to black in bottom pods, 90% of seed is reddish-brown to dark-brown in middle pods and more than half the seed is still green in the top pods of the terminal raceme. Combining can normally begin seven to fourteen days after the desiccant has been applied.

Desiccated crops that are standing in exposed situations are vulnerable to pod shatter in windy conditions. Crops that are leaning and have a well-intermeshed canopy are ideally suited for desiccation especially in less windy areas. Desiccating badly-lodged crops with diquat can be difficult as spray penetration into the crop canopy can be limited, and there is no translocation of the desiccant within the plants. High water volumes are recommended for such crops and timing should be based on seed colour in pods on the top side of the canopy, not on the shaded pods underneath. This avoids excessive seed loss from ripe pods while waiting for immature pods to ripen.

The other main desiccant is glyphosate. This is a foliar-applied herbicide/desiccant which is rapidly translocated from treated foliage to the rest of the plant, including roots, rhizomes or stolons. It has a slower action than diquat. It is primarily used to desiccate crops in which the control of annual and perennial grass weeds is needed but may be used for desiccation in the absence of weeds. Several products containing glyphosate are approved for pre-harvest use on oilseed rape, namely Roundup, Roundup Four 80, Muster, Barclay Gallup, FAL Glyphosate and Portman Glyphosate 360. Application rates vary according to product and the presence or absence of weeds.

Application timing is usually when seed moisture content is below 30% and the majority of seeds are changing from green to brown in pods in the middle sections of the main racemes. Crops are usually ready for combining 14 to 21 days after treatment.

Glyphosate is not generally recommended for seed crops or crops that are heavily laid, with significant amounts of green growth. Crops with areas of uneven ripening, which may have resulted from uneven establishment, pest or pigeon damage, are also unsuitable for desiccation with glyphosate. In addition, crops that are suffering from stress factors such as disease, extreme heat or drought may not ripen evenly after treatment. As with diquat, glyphosate treatment of standing crops in exposed situations may increase the risk from pod shatter.

Glufosinate-ammonium is the active ingredient of a new contact-acting desiccant called Challenge, which was released in February 1991. Timing of application is similar to that for diquat, when seeds are mostly reddish to dark-brown in the middle pods of the main raceme, approximately 14 days before harvest. The desiccation effect of this product is claimed to be slower than that of diquat in the initial stages of ripening but catches up in the later stages. As a result, the plants do not become so brittle as they dry out, and the risk of pod shatter is reduced.

4.4 Pod sealants

A terpenoid polymer of cyclohexane, 1-methyl-4-(1-methyl ethyl) is the main constituent of two pod sealants, Spodnam DC and Desikote. These products are not classified as pesticides. It is claimed that this active ingredient forms a membrane around pods which permits the passage of gasses and water vapour but is highly resistant to the passage of liquid water as rain or dew. This allows the crop to ripen naturally without the danger of high seed losses. Spodnam DC can be applied from late petal fall up to the stage when pods are yellow but still pliable, and is recommended for use on crops to be direct harvested. Desikote is recommended for use with a desiccant or for application 2 to 15 days prior to swathing.

5. SEED LOSSES

One of the main reasons for applying pre-harvest treatments to oilseed rape crops is to prevent seed loss by hastening the ripening process so that immature seed will ripen before more mature seed is shed. Seed loss can occur at three stages, pod shatter during the ripening phase, cutterbar losses as the crop is swathed or when it enters the combine and losses which come out through the combine with the straw and chaff. Losses through the combine tend to be the lowest, they can be minimised by adjusting the settings on the combine and they are likely to be little affected by pre-harvest treatment. The other two are more variable and are dependent upon pre-harvest treatment.

5.1 Pod shatter

Pod shatter prior to harvest is generally caused by weather damage, usually wind or rain. Tall, standing, thin crops tend to be the most vulnerable as plants can move easily against each other in windy conditions. The abrasion between plants and pods accelerates the pod splitting process. Crops with dense pod canopies which are well-intermeshed suffer less wind damage. Leaning and lodged crops are also less at risk. Heavy rain or hail can cause direct damage to the upper-most pods of the crop canopy resulting in pod shatter. In addition, long periods of wet weather can cause seed loss because of seed chitting in the pods. This can be a particular problem in badly lodged or swathed crops in which drying is restricted.

Premature pod splitting can also be caused by insect damage, especially by the brassica pod midge, Dasineura brassicae, and as a result of pod diseases such as dark pod spot, caused by Alternaria brassicae. Diseases such as stem canker, Phoma lingam, and stem rots caused by Sclerotinia sclerotiorum and Botrytis cinerea can result in premature senescence and shedding of seed from whole plants.

5.2 Harvest method

Cutterbar losses can be very variable and are affected by a number of factors. These include state of the crop at swathing or harvest (brittle or pliable), the presentation of the crop (standing, leaning, lodged or swathed), the direction of leaning, lodging or swathing in relation to the combine header and the combine header itself (width of table, pickup method, presence or absence of side knives and reel).

Brittle crops are very prone to seed loss because pod shatter occurs as soon as any machinery, such as a swather or a combine, enters the crop. This can be a particular problem in very dry, fast-ripening seasons, especially if the crop has been desiccated or affected by insect or disease damage.

The presentation of the crop and its direction of leaning or lodging in relation to the direction of combining are also important. Erect crops are relatively easy to harvest as they can be approached from any direction but, with leaning, lodged or swathed crops, it is necessary to make sure that the pods enter the combine before the stalks. Otherwise, seed can be shaken out of the pods before they reach the combine table.

The combine header itself can also affect losses. The width of the table should match the width of the swath in swathed crops, to avoid damaging adjacent swaths, but a wide header will help reduce edge losses in standing crops. An extended cutterbar table can help reduce the quantity of seed falling on the ground rather than into the combine. The combine header reel can cause tremendous pod shatter if it is used in a ripe crop. It is generally recommended that use of the reel is kept to a minimum or that it is taken off altogether to avoid damage. Side knives are recommended for use in standing crops. However, losses are still unavoidable at the cut edges even when side knives are used.

An alternative header, the Draper pick-up, is available for harvesting swathed crops. This is claimed to have a gentler lifting action than the conventional cutterbar. Combine losses have been found to be slightly lower with these headers, the harvested seed is often drier because the green stems of the stubble do not enter the combine, and there are advantages in terms of increased speed of harvesting (Bailey, 1982; Butterworth, 1983). However, these benefits need to be weighed against the cost of an additional combine header.

5.3 Assessment of seed losses

Seed losses have been measured by a number of methods; collecting shed seed, counting shed seed on the ground or estimating seed loss using a photographic index system.

Seeds have been collected by strategically placing wax-covered dishes, sticky strips of paper, plastic guttering or foil trays in the crop to catch shedding and cutterbar losses. Straw and chaff have been collected out of the back of the combine to assess combine losses. Vacuum suction devices have also been used to collect seed from the soil surface. In some assessments, seeds have been counted on the ground using small quadrats. An alternative method of assessing seed loss was adapted from a technique used to assess straw cover (E. T. Chittey, personal communication). Shed seed is allowed to chit and, when seedlings have reached the cotyledon stage, 0.25 m^2 quadrats are photographed. An acetate with a 100 points marked at random within the sample area is then laid over each photograph. The number of points coincident with chitted seeds is counted to give an index of shedding. This method assesses total losses only.

Overall however, losses have been assessed in very few experiments because of the difficulty in sampling and obtaining accurate and repeatable results. Generally, losses have been indirectly assessed as yield differences between treatments.

5.4 Effect of pre-harvest treatment on seed losses

Between 1974 and 1976, on 26 farms in Humberside and North Yorkshire, harvest losses were assessed using the seed counting technique in commercial crops of oilseed rape which had been either swathed or desiccated with diquat (Bailey, 1982). Losses as a result of swathing averaged 112 kg/ha with a range from 22 to 224 kg/ha, and losses as a result of desiccating were slightly higher with an average of 129 kg/ha with a range from 45 to 353 kg/ha. Losses were also measured, by the same technique, in commercial crops at High Mowthorpe EHF between 1975 and 1980. The results showed a greater penalty to desiccating. Over the six-year period, losses averaged 174 kg/ha from swathed crops with a range from 50 to 650 kg/ha, whereas losses from diquat-treated crops averaged 473 kg/ha with a range from 50 to 1654 kg/ha (MacLeod, 1981; Bailey, 1982).

Seed losses were measured in experiments at Boxworth EHF between 1978 and 1982 and at High Mowthorpe in 1980, 1982 and 1983, mainly using seed collection methods (Bowerman, 1984). In contrast to the survey results, Boxworth experiments in 1978 and 1979 showed higher total losses from swathed crops (300 kg/ha) compared with diquat-desiccated crops (200kg/ha). Shedding losses pre-harvest were similar for both treatments (100 kg/ha) but cutterbar losses were higher from swathed crops. This was probably because crops had been swathed with a Reco tractor-mounted, side-delivery swather which is known to leave uneven swaths which are difficult to combine (Bailey, 1982). Losses out of the back of the combine were similar for both treatments and averaged less than 20 kg/ha. In other experiments at Boxworth from 1980 to 1982, in ideal harvesting conditions, total losses were much lower at less than 50 kg/ha, and there were no treatment differences. Results from the experiments at High Mowthorpe supported the survey data in that losses from standing crops were generally higher than those from swathed crops. Most of the losses occurred at the cutterbar, except in windy years when shedding losses pre-dominated.

In an unpublished experiment at High Mowthorpe, sponsored by Mandops, losses were assessed by the chitted-seed index method. An index of 0.14 was recorded for the swathed crop which was significantly lower than that recorded following direct combining (6.54), or the use of diquat (10.66) or Spodnam DC (11.56). This pattern of results was confirmed by the seed yield responses which gave a yield advantage to swathing.

5.5 Effect of weather on seed losses

At High Mowthorpe, an assessment of weather conditions at harvest in relation to seed loss assessments from swathed and desiccated crops was undertaken by an ADAS Regional Agricultural Meteorological Officer between 1980 and 1985 (M. N. Hough, personal communication). He suggested that seed losses of about 1% resulted if a mean daily wind speed of 7-8 knots occurred once during the 10 days or so before harvest. In addition, heavy rain caused seed losses if a pod was hit by a raindrop at least 10 times, which may occur if there is more than 10 mm of rain in an hour. Hail causes more damage. As well as physical damage, a good soaking followed by drying may cause stresses in the pod which are sufficient to cause shatter, as described in detail by Picart & Morgan (1984).

Experience has shown that seed losses due to wind can start when the mean daily windspeed at 2 metres height above ground level exceeds 7 knots, although the damage may be limited to crop edges (M. N. Hough, personal communication). At mean daily windspeeds of 11 knots, pod shatter becomes widespread and losses can reach substantial levels, up to 50 % of the total seed yield, if a crop is standing and plants can move freely. Such windspeeds are likely to be critical only for the period between desiccation and harvest, which, at High Mowthorpe, normally falls within the period of 24 July to 20 August. Mean windspeeds of 7 knots are regularly experienced at High Mowthorpe, at least once in every year during this period. However, the 11 knot criterion is exceeded less frequently. In a period of 27 years from 1959 to 1985, 11 knot winds were experienced in only eight years. In the six years covered by the detailed weather monitoring (1980-1985), 11 knot winds were recorded only in 1980 and 1985, the two years in which large shedding losses were measured. The greatest seed losses recorded at High Mowthorpe from desiccated and swathed crops, 1654 and 650 kg/ha respectively, occurred in 1977 when the 11 knot criterion was exceeded on two occasions in the 10-day period before harvest. These results support Hough's hypothesis. At High Mowthorpe, long-term data predict substantial yield losses one year in three where the crop is desiccated rather than swathed.

Hough calculated the annual median windspeed at High Mowthorpe and mapped all other areas in the North of England with annual median speeds equal to or greater than this. Only arable areas east of the Pennines were considered. In 1985, of the 60 859 ha of oilseed rape grown in Humberside, Yorkshire, Cleveland, Durham and Northumberland, 31 658 ha (52%) were considered to be at risk from shedding on exposed sites. Even in areas not considered to be at risk, fields with a fetch to the west unobstructed by hedges and trees, and towards the tops of west-facing slopes could have a high risk of shedding.

From the experiments at High Mowthorpe between 1980 and 1985, there was a yield penalty of 0.95 t/ha in windy years when crops were desiccated rather than swathed. In calm years, there were no differences in yield. Typically, crops at High Mowthorpe are short, remain standing and are very vulnerable to pod shatter as pods move against each other. In years when crops lodged, forming a protective mesh, seed and yield losses from desiccated crops were low.

In summary, seed losses are generally lower from swathed crops than from crops desiccated with diquat because swathed crops are usually protected from the wind damage which causes pod shatter. Very few comparisons have been made with other pre-harvest treatments. In good harvesting conditions, losses are about 20 to 50 kg/ha, with little difference between pre-harvest treatments. However, this is high in relation to the quantity of seed that is planted to establish the crop (approximately 6 kg/ha), and poses problems for the future because volunteer oilseed rape is a troublesome weed in other broad-leaved crops. Losses of between 50 and 150 kg/ha commonly occur in less than ideal harvesting conditions. In very unfavourable conditions, which can occur one year in three on exposed sites, losses over 200 kg/ha and up to 1.6 t/ha are possible and these have serious effects on the financial returns from the crop. Recognition of when these high risk situations are likely to occur should help growers adjust their harvesting practices to minimise seed loss.

6. EFFECT OF METHOD AND TIMING OF PRE-HARVEST TREATMENT ON SEED YIELD

Over the last 17 years, pre-harvest treatments for winter oilseed rape have been compared in 50 experiments in the UK, undertaken by ADAS, IACR Rothamsted and the University of Newcastle. Some of the data have been reported (Harris, 1981; Bowerman, 1984; 1985; Freer et al., 1989) but most is unpublished. Experiments have mostly been funded by MAFF but some have been funded by commercial companies.

6.1 Effect of pre-harvest treatment on yield

Treatment effects on yield are discussed by reference to published data and then summarised as paired comparisons of treatments from both published and unpublished data. Each such comparison consists of two treatments taken from a particular experiment at one site in one year. In general, treatments were applied at their optimum timing, as recommended at the time of the experiment. However, approach to time of harvest varied according to the experiment. If a treatment was compared at more than one timing then the timing giving the highest yield has been used. The pairs of treatments were either harvested on the same date or on different dates according to when seed on each treatment reached a particular dry matter content. All yield data have been adjusted to 91 or 92 % dry matter.

6.1.1 Swathing versus direct combining

Some of the earliest work on pre-harvest treatments was undertaken at Bridgets EHF in Hampshire (BG), from 1975 to 1977, and compared swathing with direct combining, both at several timings (Harris, 1981). Swathing was carried out with a self-propelled, centre-delivery swather which was a non-commercial machine based on a Massey Ferguson tricycle tool bar. The optimum timing for harvesting the direct combined treatment was four to seven days later than for the swathed crop. Taking the optimum yield for each treatment in each year, swathing significantly outyielded direct combining in only one of the three years (Table 1).

Table 1. Yield of swathed and direct combined treatments (t/ha at 92% DM) Bridgets EHF 1975-77.

Year	Pre-harvest treatment Swath	Direct combine	SED	df
1975	2.19	1.68	0.106	18
1976	1.76	1.96	0.143	15
1977	1.69	1.55	0.093	22

However, Bowerman (1984) reported that there were no significant yield differences between swathing and direct combining at Boxworth EHF in Cambridgeshire (BW), when both treatments were harvested on the same date (Table 2). At this site a Reco, tractor-mounted, side-delivery swather was used. In 1978 and 1979, the swathed crop was drier at harvest but in 1980 and 1981 the standing crop dried out more quickly.

Table 2. Yield of swathed and direct combined treatments (t/ha at 92% DM) Boxworth and High Mowthorpe EHFs 1978-83.

Year	Site	Pre-harvest treatment Swath	Direct combine	SED	df
1978	BW	2.72	2.68	0.181	6
1979	BW	2.66	2.67	0.288	6
1980	BW	3.62	3.47	0.117	12
1981	BW	3.26	3.16	0.139	12
1983	HM	2.10	2.53	0.100	12

Similar results were found when swathing was compared with direct combining at four sites in Skane in Sweden between 1982 and 1984. Time and method of pre-harvest treatment had no significant effect on yield but it was noted that pod shattering occurred under windy conditions (Bengtsson, 1985).

In contrast, in 1983 there was a significant yield advantage to direct combining at High Mowthorpe EHF (HM), in N. Yorkshire, in a year when secondary flowering and pod development increased the range of seed maturity in the crop (Table 2). In this experiment, the timing for the swathed treatment was based on seed colour in the first-formed pods which constituted the major part of the crop. Seeds in the later-developed pods were still immature at this stage. The direct combined treatment was harvested seven days later than the swathed crop and this allowed the immature seeds time to develop and contribute to the overall yield.

In a further series of experiments in 1984 and 1985 at High Mowthorpe (Bowerman, 1985), there were two dates of harvest for each treatment (Table 3). The first date was when diquat-treated plots were judged to be fit for combining and the second date was seven to fourteen days later. This was to allow late-ripening treatments sufficient time to mature. Only one result, the highest-yielding from each treatment, is quoted in the table. In 1984, in the ideal harvesting conditions which prevailed, there was no yield difference between swathing and direct combining but in 1985, in wet and windy harvesting conditions, nearly 1 t/ha more was lost from the standing crop, than from the swathed crop.

Table 3. Yield of swathed and direct combined treatments (t/ha at 91% DM) High Mowthorpe EHF 1984-85.

Year	Pre-harvest treatment		SED	df
	Swath	Direct combine		
1984	3.74	3.71	0.145	23
1985	3.22	2.27	0.189	23

In the most recent experimental series in 1987 and 1988 (Freer <u>et al</u>., 1989), there were no significant yield differences between swathing and direct combining, when meaned over four sites (Rothamsted, Newcastle, Bridgets and High Mowthorpe) (Table 4). In these experiments individual treatments were harvested on different dates according to when they were fit for combining.

Table 4. Yield of swathed and direct combined treatments (t/ha at 91% DM) mean of four sites 1987-88.

Year	Pre-harvest treatment		SED	df
	Swath	Direct combine		
1987	3.42	3.28	0.151	15
1988	3.07	3.23	0.110	15

In all, between 1975 and 1990 there were 38 comparisons between swathing and direct combining in experiments carried out by ADAS, IACR Rothamsted and the University of Newcastle (Figure 1). These included published data as discussed above and results from 26 unpublished comparisons. On average, there was a 3.6% yield benefit to swathing. In 23 of the comparisons, there was a benefit to swathing but only seven of these results were significant. The largest response to swathing was 1.78 t/ha. The higher yields from the swathed treatments were generally found at the exposed site at High Mowthorpe EHF. At this site, the yield loss from standing crops was usually linked to pod shatter in windy conditions. In 15 of the comparisons, there was a benefit to direct combining, and six of these were significant results. The largest response to direct combining was 0.55 t/ha and this occurred at Boxworth EHF in 1988. There is no recorded reason for this result.

This summary of data corresponds well with the published data, in that overall, swathing was more likely to give higher yields than direct combining but this was only likely to be significant in situations where the risk of seed loss from pod shatter was high.

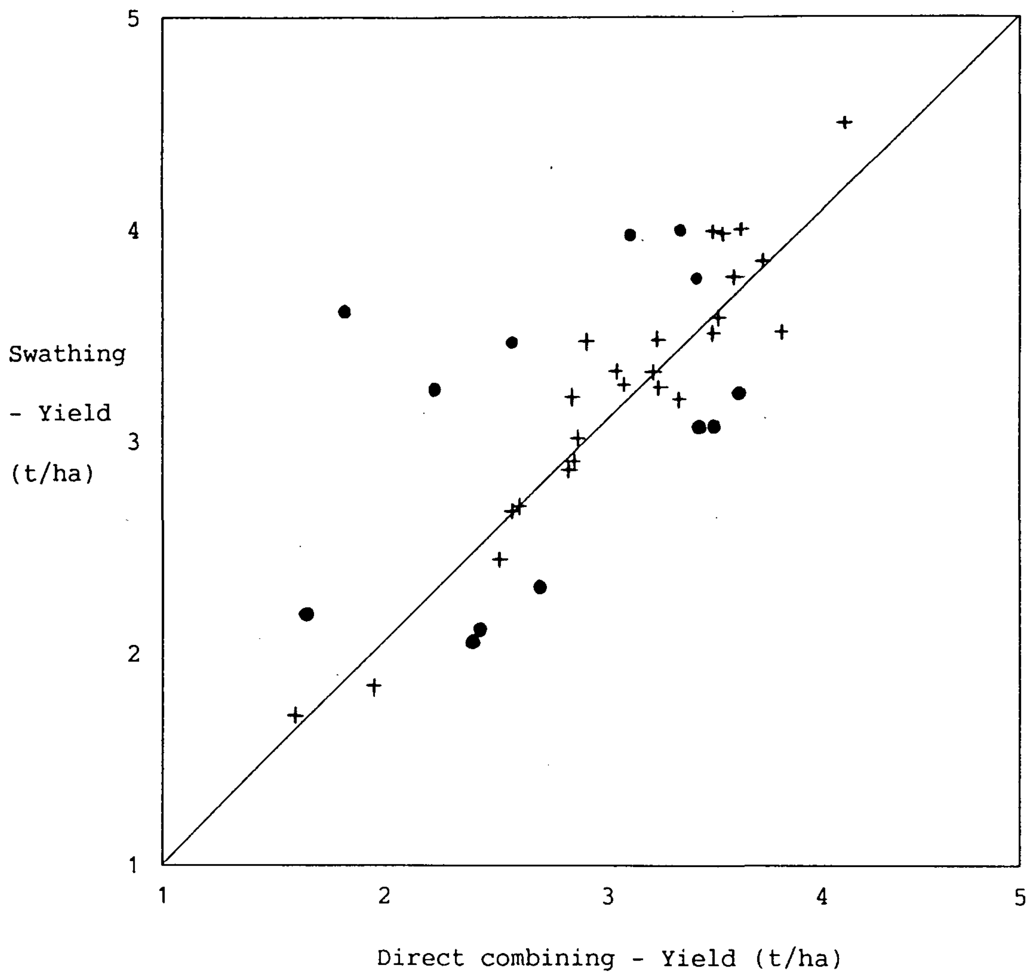

Figure 1 Yields of oilseed rape after swathing compared with direct combining. (Diagonal line represents equal yields from the two treatments. Significant treatment differences are denoted by ● .)

6.1.2 Desiccation with diquat versus direct combining

Desiccation with diquat and direct combining were compared in six experiments at Boxworth EHF between 1978 and 1983 and in one experiment at High Mowthorpe EHF in 1983 (Bowerman, 1984) (Table 5). At Boxworth, both treatments were harvested on the same day. On average, over the six years, the yield benefit to desiccation with diquat was only 0.07 t/ha but the moisture content of seed was 3.3% lower (14.2% compared with 17.5%). At High Mowthorpe in 1983, when the direct-combined crops were harvested seven days later than the desiccated plots, direct combining gave a significant yield advantage of 0.34 t/ha, but seed moisture content was 6.7% higher. The increase in yield was a result of an increased period of ripening in the direct-combined treatment in a crop with a significant proportion of secondary growth.

Table 5. Yield of diquat-desiccated and direct-combined treatments (t/ha at 92% DM) Boxworth and High Mowthorpe EHFs 1978-83.

Year	Site	Pre-harvest treatment		SED	df
		Diquat	Direct combine		
1978	BW	3.00	2.68	0.181	6
1979	BW	2.78	2.67	0.288	6
1980	BW	3.45	3.47	0.117	12
1981	BW	3.30	3.16	0.139	12
1982	BW	3.81	3.88	0.116	9
1983	BW	2.72	2.79	0.137	11
1983	HM	2.29	2.53	0.100	12

However, this apparent difference in treatment effect by modifying harvest dates was not supported by subsequent work. In experiments in 1984 and 1985 at three sites, Bridgets EHF, High Mowthorpe EHF and a site in Norfolk (NF), involving two harvest dates seven to fourteen days apart, there were no significant yield differences between direct-combined and diquat-desiccated treatments when each was harvested at its optimum timing (Bowerman, 1985) (Table 6). The direct-combined treatment benefited significantly from delayed harvesting on only two out of five occasions and the diquat-desiccated treatment on one out of five.

Table 6. Yield of diquat-desiccated and direct-combined treatments (t/ha at 91% DM) Bridgets and High Mowthorpe EHFs and Wood Farm, Norfolk 1984-85.

Year	Site	Pre-harvest treatment		SED	df
		Diquat	Direct combine		
1984	BG	4.39	4.18	0.116	32
1984	HM	3.49	3.71	0.127	23
1985	BG	2.61	2.79	0.252	35
1985	HM	1.92	2.27	0.189	23
1985	NF	3.87	3.79	0.162	10

Similarly, experiments undertaken by ADAS, Rothamsted and the University of Newcastle between 1987 and 1988 (Freer et al., 1989) showed no significant yield differences between direct combining or desiccating at the optimum timings when meaned over four sites (Rothamsted, Newcastle, Bridgets and High Mowthorpe) (Table 7).

Table 7. Yield of diquat-desiccated and direct-combined treatments (t/ha at 91% DM) mean of four sites 1987-88.

Year	Pre-harvest treatment		SED	df
	Diquat	Direct combine		
1987	3.26	3.28	0.151	15
1988	3.19	3.23	0.110	15

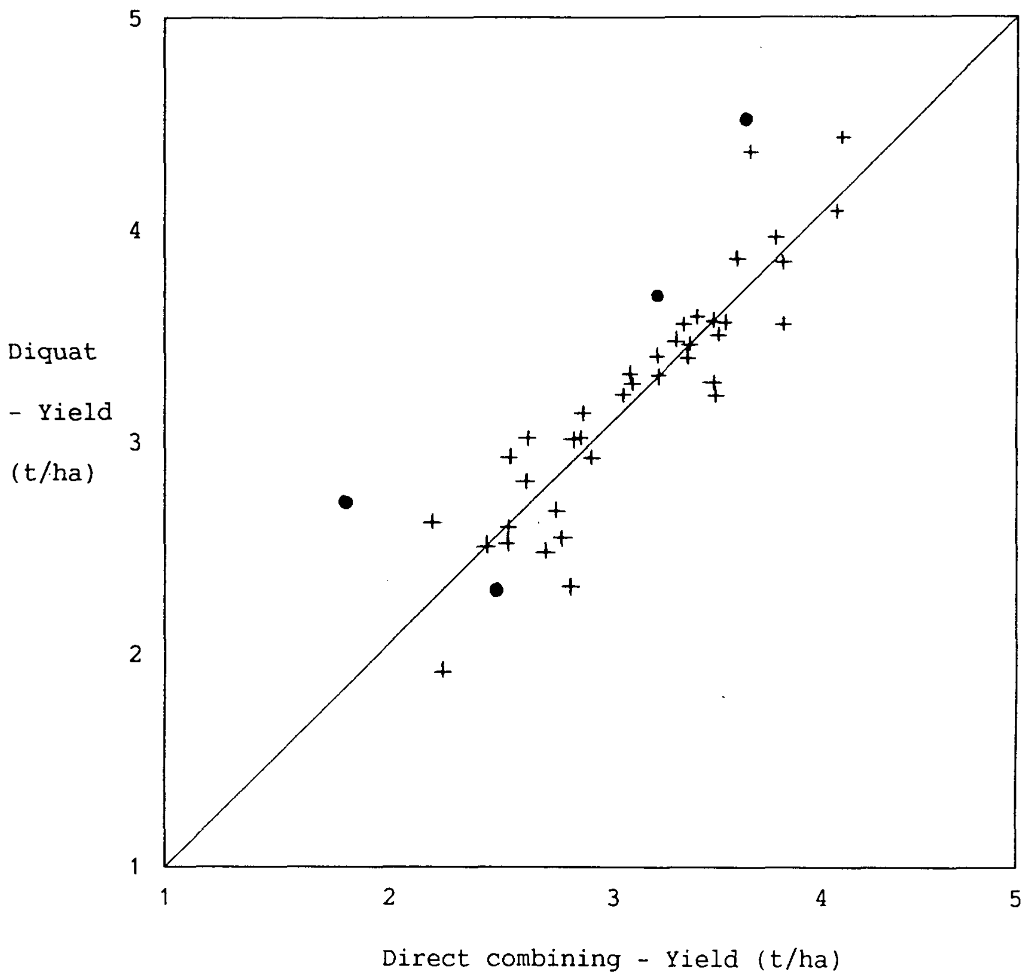

Figure 2 Yields of oilseed rape after desiccation with diquat compared with direct combining. (Diagonal line represents equal yields from the two treatments. Significant treatment differences are denoted by ●.)

In all there were 42 comparisons between desiccation with diquat and direct combining, in 42 experiments undertaken by ADAS, IACR Rothamsted and the University of Newcastle (Figure 2). On average, desiccation with diquat gave a 1.5% yield advantage. On 22 occasions, there was a yield benefit from desiccation compared with 17 when direct combining gave the higher yield. However, there were very few significant differences in yield between the two treatments. On three occasions there was a significant advantage to desiccation with diquat, and these occurred at High Mowthorpe, Boxworth and Newcastle. The maximum benefit of 0.88 t/ha occurred at High Mowthorpe EHF in 1986 when all standing treatments were subject to pod shatter in windy conditions, but the direct combined treatment suffered most because it took longer to ripen. There was one significant response to direct combining and this occurred at Bridgets EHF and was the result of lower seed losses from the untreated crop than from the desiccated crop in wet and windy conditions before harvest.

This summary of data gives a slightly different picture to that suggested by the published data. The summary suggests that desiccation with diquat is more likely to give greater yields than direct combining, whereas in the published papers there was little difference between the two techniques except in one experiment which gave a significant benefit to direct combining because of the unusual flowering and ripening pattern of the crop in that year.

6.1.3 Swathing versus desiccation with diquat

In experiments at Boxworth and High Mowthorpe between 1978 and 1983, reported by Bowerman (1984), there was little difference in yield between swathing and desiccating with diquat (Table 8). However, there was a significant advantage to swathing at High Mowthorpe in 1980, a wet and windy year, because of seed loss from the standing crop.

Table 8. Yield of swathed and diquat-desiccated treatments (t/ha at 92% DM) Boxworth and High Mowthorpe EHFs 1978-83.

Year	Site	Pre-harvest treatment		SED	df
		Swath	Diquat		
1978	BW	2.72	3.00	0.181	6
1979	BW	2.66	2.78	0.288	6
1980	BW	3.62	3.45	0.117	12
1980	HM	3.98	3.53	0.169	24
1981	BW	3.26	3.30	0.139	12
1981	HM	3.53	3.72	0.151	24
1982	HM	3.02	3.01	0.152	12
1983	HM	2.10	2.29	0.100	12

A similar pattern emerged from further experiments at High Mowthorpe EHF in which differences between swathing and desiccation with diquat were negligible in 1984 in good harvesting conditions, but in 1985 in a wet and windy harvest there was a significant advantage to swathing because of seed loss from the standing desiccated crop (Bowerman, 1985) (Table 9).

Table 9. Yield of swathed and diquat-desiccated treatments (t/ha at 91% DM) High Mowthorpe EHF 1984-85.

Year	Pre-harvest treatment		SED	df
	Swath	Diquat		
1984	3.74	3.49	0.127	23
1985	3.22	1.92	0.197	23

In the most recent experiment series in 1987 and 1988 (Freer et al., 1989) there were no significant differences in yield between swathing and desiccation when meaned over four sites (Rothamsted, Newcastle, Bridgets and High Mowthorpe) (Table 10).

Table 10. Yield of swathed and diquat-desiccated treatments (t/ha at 91% DM) mean of four sites 1987-88.

Year	Pre-harvest treatment		SED	df
	Swath	Diquat		
1987	3.42	3.26	0.250	15
1988	3.07	3.19	0.375	15

There have been 40 comparisons between swathing and desiccation with diquat in experiments done by ADAS, IACR Rothamsted and the University of Newcastle (Figure 3). Overall, the two treatments gave very similar yields, with an average benefit of only 1.2% to swathing. In 20 of the comparisons, there was a yield benefit to swathing and in 20 others, a benefit to desiccation with diquat. However, in only six of the experiments was there a significant yield advantage to swathing, with a maximum response of 1.3 t/ha. The yield responses to swathing generally occurred at High Mowthorpe EHF, an exposed site, where seed

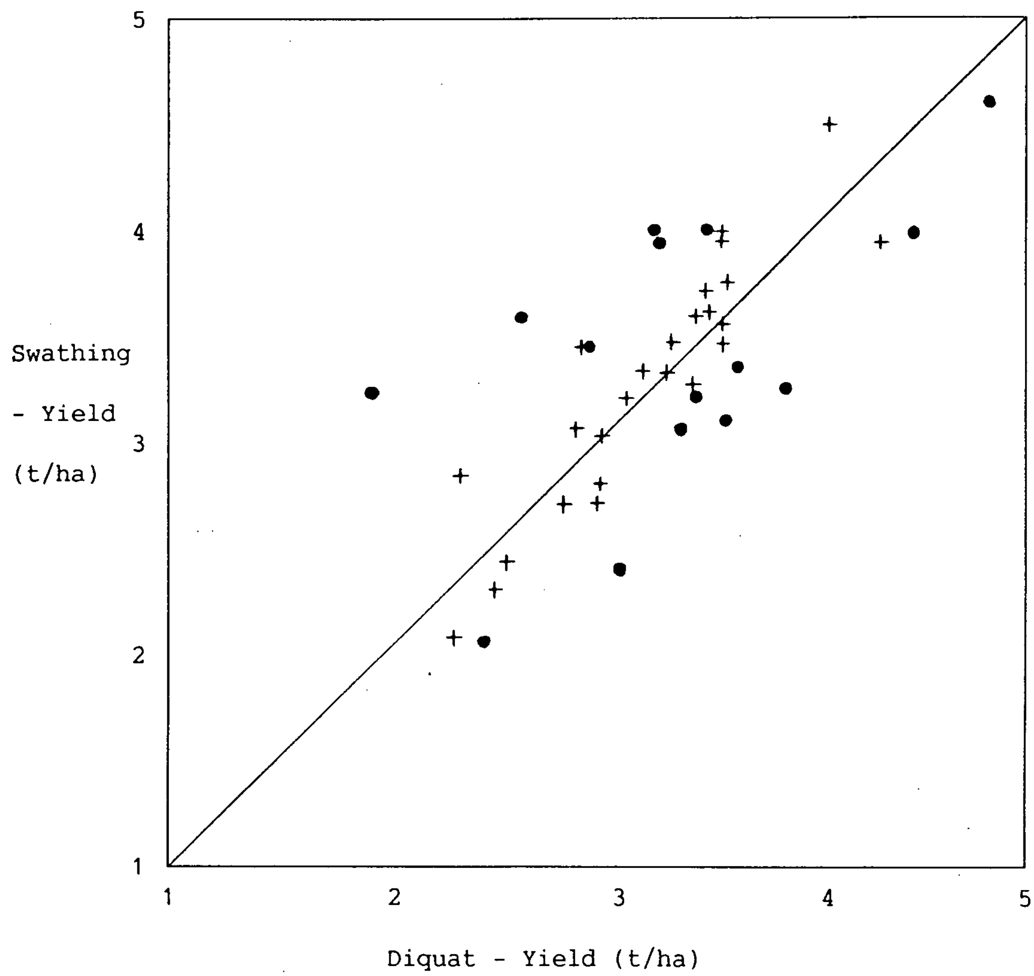

Figure 3 Yields of oilseed rape after swathing compared with desiccation with diquat. (Diagonal line represents equal yields from the two treatments. Significant treatment differences are denoted by ● .)

losses are often high in standing crops in windy conditions (MacLeod, 1981; Bailey, 1982; Bowerman, 1984). There was a significant yield advantage to desiccation in nine of the comparisons, with a maximum response of 0.8 t/ha, and these responses occurred at a range of sites. The reasons for the benefits to desiccation varied. They included yield loss due to premature swathing, wet weather affecting the amount of harvestable seed in swathed crops due to seed chitting in pods, and easier harvesting with fewer combine losses from the desiccated crop.

In general, the summary results are in line with the published data in that there was generally little difference between the two methods. However, the potential loss of seed due to pod shatter is greater from desiccated crops than from swathed crops in unfavourable ripening and harvesting conditions in wet and windy sites or seasons.

6.1.4 Swathing versus desiccation with glyphosate

The only three published experiments in which there were comparisons between swathing and desiccation with glyphosate were all done at High Mowthorpe EHF. In 1982 (Bowerman, 1984) there was little difference in yield between swathing and desiccation with glyphosate (Table 11). There was a similar result in 1984, a calm year, but significantly greater losses from the standing desiccated crop in 1985, a wet and windy year (Bowerman, 1985).

Table 11. Yield of swathed and glyphosate-desiccated treatments (t/ha at 92% DM) High Mowthorpe EHF 1982, 1984 and 1985.

Year	Pre-harvest treatment		SED	df
	Swath	Glyphosate		
1982	3.02	2.91	0.152	12
1984	3.74	3.64	0.127	23
1985	3.22	2.58	0.189	23

When the published and unpublished data were considered there were still only 11 comparisons between swathing and desiccation with glyphosate (Figure 4). These experiments were done by ADAS alone. There was an average yield benefit to swathing of 4.2%. Nine of the 11 comparisons showed a benefit to swathing, four of these results were significant, with a maximum response of 0.64 t/ha. There was a significant advantage to desiccation with glyphosate in two comparisons and these occurred at Bridgets and Boxworth. The main reason for the benefits to swathing was higher seed losses from the standing desiccated crops, both at High Mowthorpe and Boxworth, as these crops are more vulnerable to wind damage than swathed crops, in exposed situations or early ripening seasons.

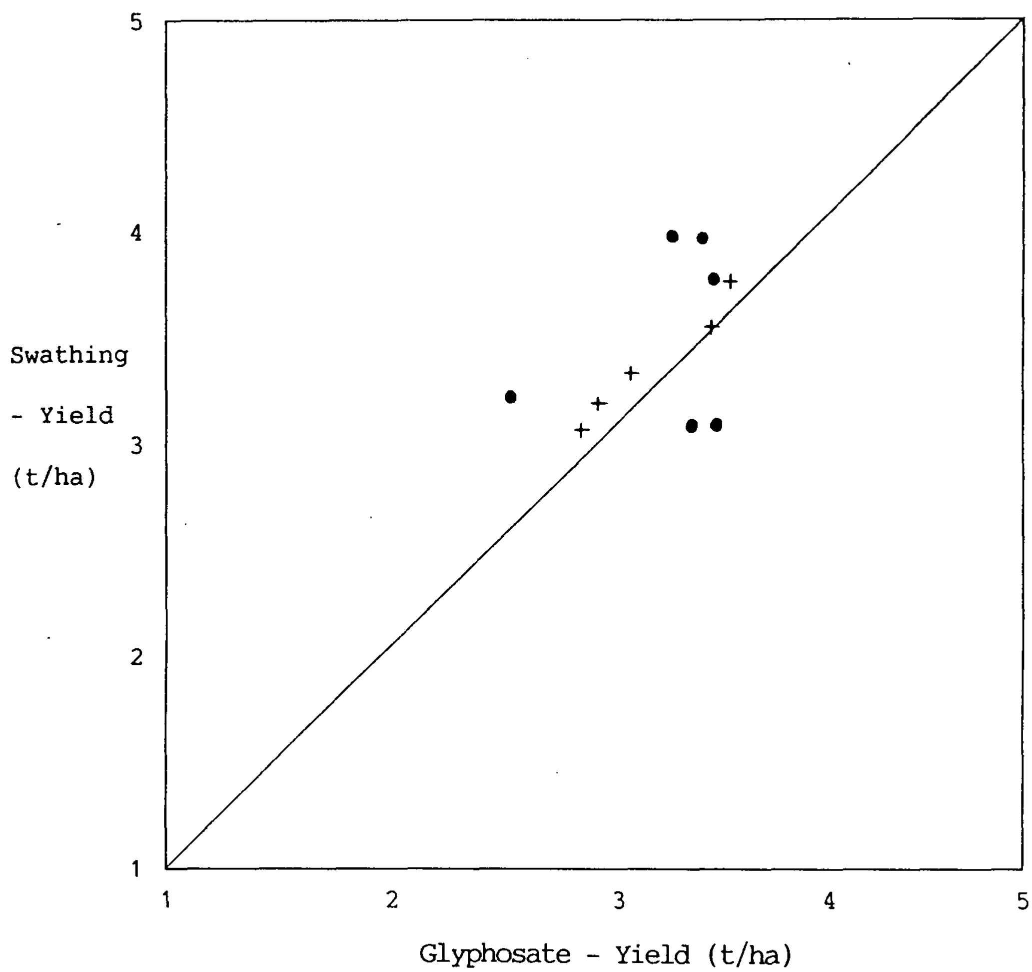

Figure 4 Yields of oilseed rape after swathing compared with desiccation with glyphosate. (Diagonal line represents equal yields from the two treatments. Significant treatment differences are denoted by ● .)

6.1.5 Desiccation with diquat versus desiccation with glyphosate

In experiments at High Mowthorpe and Boxworth in 1982 and 1983 (Bowerman, 1984), yields following desiccation with glyphosate were not significantly different from those following desiccation with diquat (Table 12). Similarly, there were no significant differences between yields following the two methods of pre-harvest desiccation at Bridgets in 1984 and 1985 or High Mowthorpe in 1984 (Bowerman, 1985). However, desiccation with glyphosate gave a significantly higher yield than desiccation with diquat at High Mowthorpe in 1985. This appeared to have been the result of lower seed loss from the glyphosate treatment in a wet and windy harvesting season.

Table 12. Yield of diquat-desiccated and glyphosate-desiccated treatments (t/ha at 91% DM) Boxworth, Bridgets and High Mowthorpe EHFs 1982-85.

Year	Site	Pre-harvest treatment		SED	df
		Diquat	Glyphosate		
1982	HM	3.01	2.91	0.152	12
1982	BW	3.81	3.90	0.116	9
1983	BW	2.72	2.68	0.137	11
1984	BG	4.39	4.50	0.131	32
1984	HM	3.74	3.64	0.127	23
1985	BG	2.61	2.55	0.252	35
1985	HM	1.92	2.58	0.189	23

Overall, the two methods of desiccation were compared in 16 published and unpublished ADAS experiments, at High Mowthorpe, Boxworth and Bridgets (Figure 5). There was an average yield response of 1.8% in favour of glyphosate. Six of the comparisons favoured glyphosate, six favoured diquat and four gave equal yields for the two methods. However, only one of the comparisons showed a significant yield difference between the two treatments and this was in favour of glyphosate. This result occurred at the exposed High Mowthorpe site, where again less seed was lost from the glyphosate-treated crop in windy conditions. The maximum benefit to glyphosate was 0.66 t/ha compared with 0.12 t/ha to diquat. These results reflect those found in the published work.

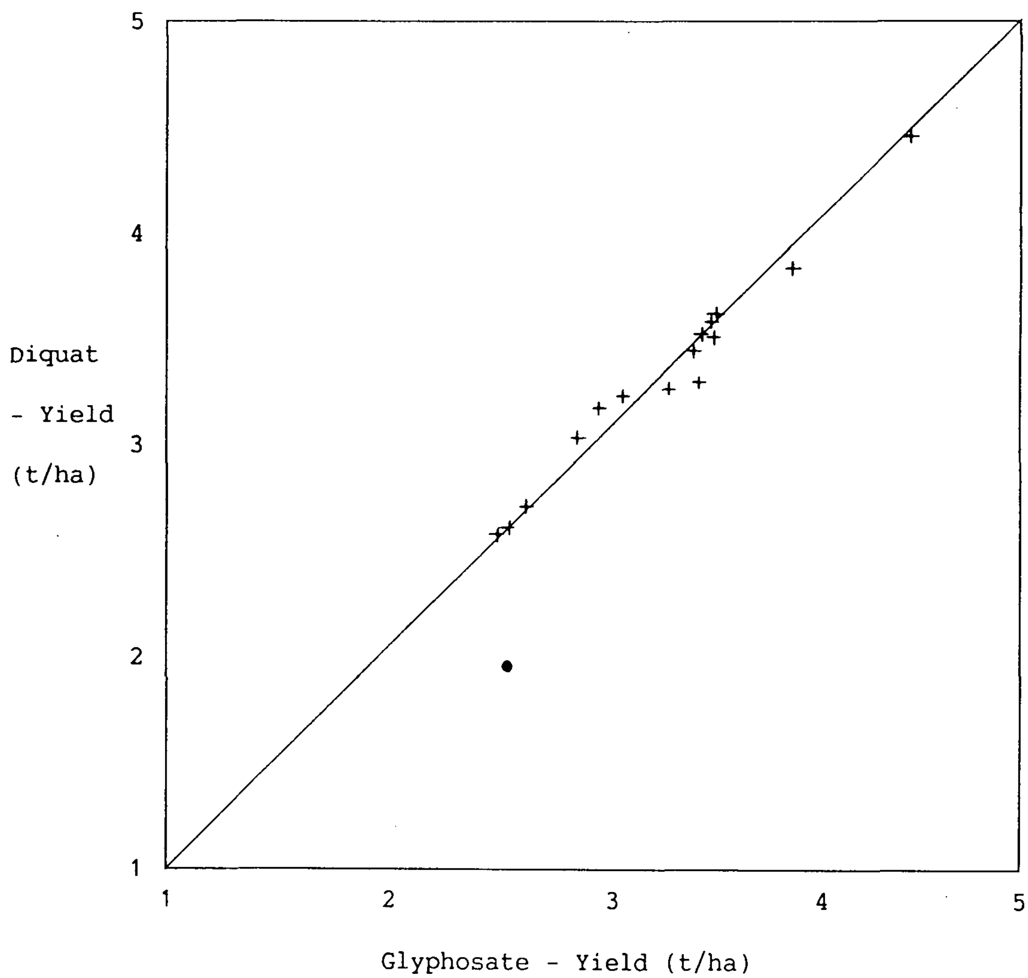

Figure 5 Yields of oilseed rape after desiccation with diquat compared with desiccation with glyphosate. (Diagonal line represents equal yields from the two treatments. Significant treatment differences are denoted by ● .)

6.1.6 Spodnam DC versus direct combining

Direct combining following the application of Spodnam DC was compared with direct combining without any pre-harvest treatment in eight ADAS experiments reported by Bowerman (1984; 1985). There were no significant differences in yield between direct combining with or without the pod sealant (Table 13).

Table 13. Yield of Spodnam DC and direct-combined treatments (t/ha at 91% DM) Boxworth, Bridgets, High Mowthorpe EHFs and Wood Farm, Norfolk 1982-85.

Year	Site	Pre-harvest treatment		SED	df
		Spodnam DC	Direct combine		
1982	BW	3.94	3.88	0.116	9
1983	HM	2.44	2.53	0.100	12
1983	BW	2.85	2.79	0.137	11
1984	BG	4.24	4.18	0.098	32
1984	HM	3.71	3.71	0.127	23
1985	BG	2.90	2.79	0.252	35
1985	HM	2.28	2.27	0.197	23
1985	NF	3.80	3.79	0.162	10

There was a total of only 11 comparisons between these two treatments from published and unpublished data (Figure 6). The average yield difference between the two methods was small, at 1.2 % in favour of Spodnam DC. The maximum yield difference between the two methods did not exceed 0.17 t/ha, and there were no significant treatment effects.

From the sources used for this review there are no published or unpublished data on the effects of Challenge or Desikote as pre-harvest treatments.

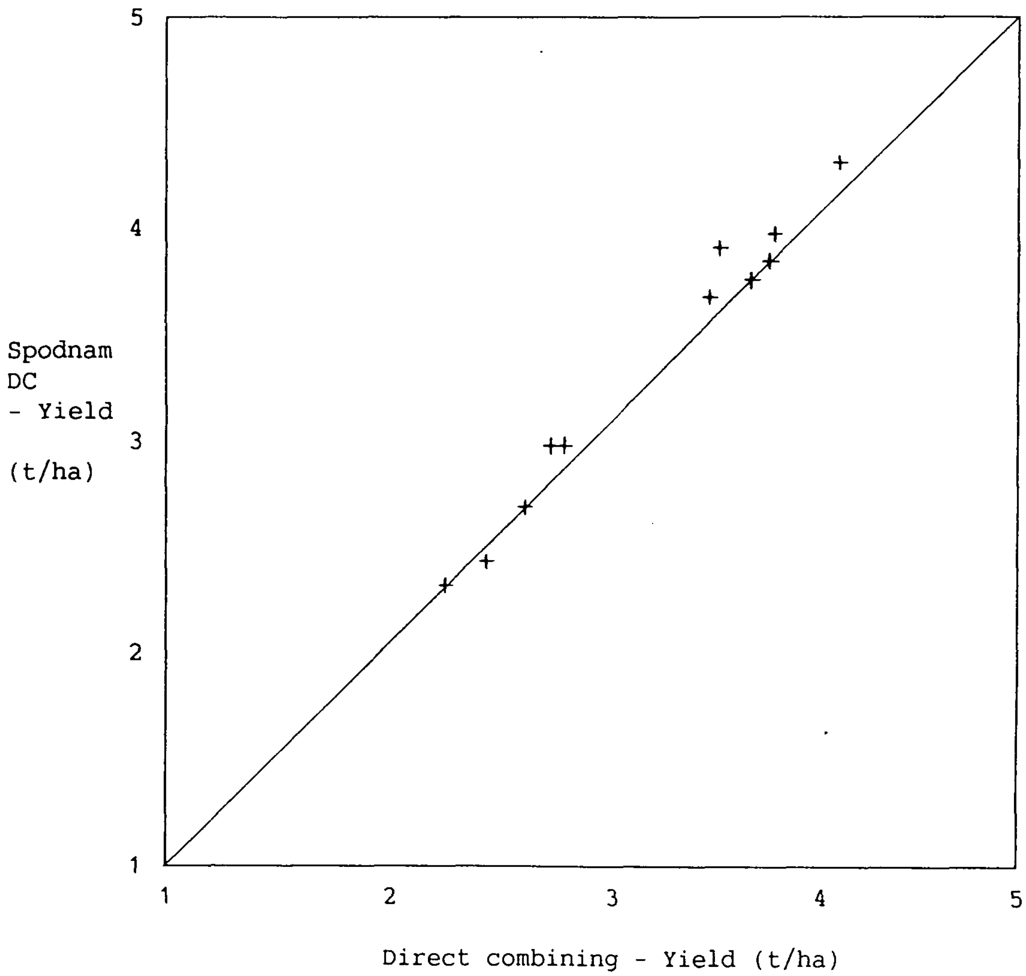

Figure 6 Yields of oilseed rape after Spodnam DC compared with direct combining. (Diagonal line represents equal yields from the two treatments. Significant treatment differences are denoted by ● .)

6.2 Effect of pre-harvest treatment timing on yield

Weather and condition of the crop can have marked effects on the optimum treatment timing. In dry years, ripening can occur very rapidly and this can make estimating the time to treat a crop very difficult. In addition, in very dry years, the pods can senesce faster than the seed ripens and this may result in premature pod shatter. However, rapid ripening may offer advantages in terms of reduced seed loss because crops are generally harvested earlier and this reduces the risk of exposure to windy weather. Generally however, the drier the harvesting conditions the more brittle and fragile the crop. This increases the risk of pod shatter and seed loss both before and during combining. In slower ripening or wet conditions, the seed can ripen ahead of the pods and stems. This has the benefit of reducing the urgency of pre-harvest treatment but can result in seed chitting in pods if wet conditions persist.

Therefore, it is important to use the correct treatment timing to obtain optimum yield and quality. However, assessment of timing is difficult in a crop which has an extremely wide range of seed maturity. Previously, timing was based on the colour of the crop but this did not correlate well with the maturity of the seed, and so now the most commonly used criterion is seed colour in pods on terminal racemes. A method based on accumulating temperature (thermal time) was developed for the series of experiments reported by Freer et al. (1989). The means of the daily maximum and minimum temperatures were accumulated from the onset of flowering until treatment application. Treatments were applied early - seeds all green (800 accumulated day degrees Centigrade, AD°C), normal timing - seeds ripening (1000-1100 AD°C) and late - seeds all ripe (1100-1200 AD°C). This method correlated well with seed colour in these experiments, but further evaluation is required before a system based on thermal time can be recommended for general use.

Swathing winter oilseed rape too early, when all seeds were still green, resulted in an average yield loss of 28% (Ogilvy, 1989a). Yield loss declined if swathing was delayed until seed started to ripen. This effect was also shown by Freer et al. (1989), when a 30% yield loss occurred when the crop was swathed when seeds were still green. Swathing too early has also resulted in reduced seed weight, lower oil content, higher glucosinolate content (Ogilvy, 1989a) and a higher proportion of red seeds in the sample. Red seeds still contain chlorophyll which could potentially lead to undesirable green coloration of the extracted oil (Brogan, 1986). The optimum time to swath appeared to be when the seed was just starting to turn from green to brown in the top pods of the main raceme (Ogilvy, 1989a). On average, this was 84 days and 1031 AD°C after the start of flowering. Delaying beyond this stage tended to reduce yield but the effect was variable according to the season, ranging from an increase of 8.7%, in a slow ripening year when no seed loss occurred, to a loss of 11.8% which occurred because of pod shatter caused by the swathing operation in a dry year. Similarly, Freer et al. (1989) found that 3.5 to 6.5 % of yield was lost when swathing was delayed until seeds were mostly ripe in pods on the main raceme.

Treatment timings for the desiccants are detailed on the manufacturers' product labels, and usually relate to colour of seed in the pods on main racemes or to an overall seed moisture content, both of which are difficult to assess. Experiments by Freer et al. (1989) have shown that premature desiccation with diquat, when all seeds were still green, resulted in significant yield reductions of 41 to 46 %. Measurements showed that this was caused by prematurely curtailing seed dry matter accumulation, leading to lower seed weights. Early desiccation also resulted in higher glucosinolate contents. Desiccating slightly later than recommended, when the majority of seed was ripe in all pods on the main raceme, resulted in a non-significant yield increase in 1987 and a reduction in 1988.

There is no published or unpublished information on the effect of timing of application of glyphosate on yield or seed quality.

6.3 Effect of harvest timing on yield

Oilseed rape is usually combined when the seed reaches at most 20 %

moisture content and can be easily threshed from the pods, although growers will aim for lower moisture contents to reduce drying costs. Combining winter oilseed rape too early, before the seed is fully ripe, can result in high drying costs, immature/red seed in the sample and seed losses, as unthreshed pods are discharged over the back of the combine. Harris (1981) found that it was possible to combine an untreated crop at around 30% moisture content but wrapping of green stem material around the combine table auger was a problem. Threshing was incomplete, and led to lower yields but oil contents were not affected. Danish work on spring oilseed rape showed that harvesting too early resulted in a higher chlorophyll content in the seed (Augustinussen, Nordestgaard & Flengmark, 1983).

Delaying combining until the seed reaches at least 90 % dry matter can save money from reduced drying costs but may result in heavy seed losses from pod shatter in windy years.

In experiments at High Mowthorpe between 1980 and 1981 (Bowerman, 1984), oilseed rape was harvested at three target seed moisture contents, 20, 15 and 10%. Yields of swathed and desiccated crops tended to decline between harvest dates. Oil contents were not affected by harvest timing. In other experiments (Bowerman, 1985), treatments were first harvested when the the diquat treatment was judged to be fit for combining, at around 15% moisture content, and the second harvest date was 7-14 days later (Table 14).

Overall, the results were variable but losses from delaying harvest were generally greater than gains. Diquat-treated crops mostly lost yield if harvest was delayed, whereas glyphosate-treated crops seemed to benefit from the delay. Overall, the direct combined and Spodnam DC-treated crops tended to lose yield if left until the second harvest date. There are insufficient data to comment on the effect of delaying harvest for swathed crops but they would be expected to be more robust and suffer less pod shattering during ripening, but seed germination in pods could be a problem in wet conditions.

Table 14. Effect of delayed harvest on seed yield (t/ha at 91% DM and difference, ± %)

Pre-harvest Method	Site and Year									
	Bridgets				High Mowthorpe				Wood Farm	
	1984		1985		1984		1985		1985	
	N	L	N	L	N	L	N	L	N	L
Direct combine	3.91	+ 7*	2.79	-10	3.58	+ 4	2.27	-11	3.79	- 2
Swath	-	-	-	-	3.71	+ 1	3.22	- 5	-	-
Diquat	4.39	-10*	2.61	- 8	3.24	+ 8	1.92	-11	3.87	- 7
Glyphosate	4.50	-12*	2.29	+11	3.53	+ 3	2.50	+ 3	-	-
Spodnam DC	3.87	+10*	2.90	-13	3.46	+ 7	2.28	- 8	3.80	-14*

N = timing when diquat treatment judged to be at approximately 85% DM

L = 7-14 days later than N.

* = significant yield effect.

6.4 Effect of pre-harvest treatment on dry matter content of seed

Pre-harvest treatments are applied to achieve more even-drying of the crop but they might reasonably also be expected to increase the rate of drying. This has been demonstrated by the use of diquat compared with direct combining on large field areas in Czechoslovakia and Poland (Maciejewski, 1975; Sanderson, 1976), where desiccated crops were easier and faster to combine and seed dry matter contents were higher.

The effects of pre-harvest treatments in accelerating drying have been confirmed in several experiments in the UK (at Boxworth in 1978, 1979, 1982 and 1983, at High Mowthorpe in 1983 and 1984 and at Bridgets in 1984) (Table 15). In these experiments, swathing and desiccation with diquat or glyphosate have been shown to be equally effective, giving crops with generally higher dry matter contents than direct combined crops harvested on the same day. However, the relationships between treatments have been affected by harvest date and season. Differences have generally declined with later harvesting and have often been reversed in wet seasons when standing crops, whether desiccated or not, have dried better than swathed crops (e.g. at Boxworth in 1980 and 1981). The drying rate of standing crops has not been affected by the application of Spodnam DC.

Table 15. Dry matter content of seed (%) when treatments were harvested on the same date

Pre-harvest Method	Site and Year												
	Boxworth						High Mowthorpe				Bridgets		Wood Farm
	1978	1979	1980	1981	1982	1983	1982	1983	1984	1985	1984	1985	1985
(SED)	(0.49)	(0.86)	(0.99)	(0.83)	(0.81)	(1.74)	(0.52)	(1.56)	(0.89)	(2.14)	(0.45)	(0.07)	(1.04)
Direct combine	75.6	84.6	84.2	84.5	81.0	85.1	-	83.0	86.1	74.9	76.8	88.5	77.7
Swath	78.8	89.7	83.2	73.9	-	-	88.2	90.7	87.5	77.8	-	-	-
Diquat	76.7	91.6	87.7	84.6	84.9	89.3	88.1	89.7	88.3	76.0	88.5	88.5	79.9
Glyphosate	-	-	-	-	85.0	90.0	88.1	-	87.8	76.1	85.6	88.5	-
Spodnam DC	-	-	-	-	81.1	84.6	86.9	83.6	85.5	72.7	76.1	88.5	78.8
df	6	6	12	12	9	11	12	12	23	36	32	35	10

7. EFFECT OF PRE-HARVEST TREATMENT ON SEED OIL CONTENT

The effects of pre-harvest treatment on the oil contents of seed have been examined in the majority of the experiments detailed in the previous section. Again only a proportion of the data have been published (Harris, 1981; Bowerman, 1984; 1985; Ogilvy, 1989a).

Oil contents were assessed either by ether extraction or by NMR (nuclear magnetic resonance) on samples of seed taken off the combine at harvest.

In the comparisons between swathing and direct combining at various timings undertaken at Bridgets EHF between 1975 and 1977 (Harris, 1981), swathing the crop at different timings from 13 % seeds black up to all seeds black had no effect on oil content. Delaying direct combining reduced oil content slightly in 1975, but in the other two years there were no significant differences between treatments or timings.

In a series of ten experiments undertaken at Boxworth and High Mowthorpe EHFs between 1978 and 1983 it was found that overall there were no differences in oil contents of crops receiving different pre-harvest treatments. Data for four of the experiments are given in Table 16. (Data for the other six experiments were not published and are not included here.) Even of the four years published, in only one

Table 16. Effect of pre-harvest treatment on oil content (% at 100% DM) Boxworth EHF 1978-81.

Year	Site	Pre-harvest treatment				
		Swath	Diquat	Direct combine	SED	df
1978	BW	46.1	46.4	46.8	0.43	6
1979	BW	41.3	42.2	41.7	0.35	6
1980	BW	41.7	41.7	41.7	0.21	12
1981	BW	44.8	44.3	44.8	0.33	12

experiment was there a significant treatment effect which gave a small advantage to desiccation with diquat compared with swathing at Boxworth in 1979, a wet harvest.

Pre-harvest treatments, including swathing, direct combining, desiccation with either diquat or glyphosate, and using Spodnam DC were compared in five experiments at Bridgets and High Mowthorpe EHFs and a site in Norfolk (Bowerman, 1985). Treatments were applied at recommended timings and plots were harvested on two dates. Pre-harvest treatments had no effect on oil contents and delaying harvest reduced oil contents only at Bridgets in 1984.

Oil contents were also examined in the timing of swathing series of experiments reported by Ogilvy (1989a). Swathing too early, when seed was still green in all the pods on the main raceme, or just turning brown in the bottom pods, significantly reduced oil content (Table 17).

Table 17. Oil content (% at 91% DM) and thousand seed weight at harvest (g) High Mowthorpe EHF. Means of six years - 1984-89.

Days after onset of flowering	Seed colour in pods on main raceme	Oil content (%)	Thousand seed weight (g)
		(SED 0.50)	(SED 0.146)
68	Green in all pods	36.4	3.73
74	Turning brown in bottom pods	38.0	3.97
79	Turning brown in middle pods	39.2	4.54
84	Turning brown in top pods	39.5	4.55
89	Seed mostly brown in all pods	39.2	4.69
df		12	16

In summary, it would appear that choice of pre-harvest treatment generally has little effect on oil content, but timing of treatment does have an effect. This is consistent with the pattern of seed development as outlined by Norton & Harris (1975). If a pre-harvest treatment which effectively stops seed growth and development is applied during the phase when the seed is actively developing and oil content is increasing (weeks 5 to 9 of seed development) then it is likely that oil content and seed weight will be reduced (Table 17). If the treatment is applied during the dehydration phase (weeks 10 to 12 of seed development), after seed development is complete, then oil content is unlikely to be affected but speed of drying will be affected.

8. EFFECT OF PRE-HARVEST TREATMENT ON SEED GLUCOSINOLATE CONTENT

Since the introduction of double-low cultivars, several series of experiments have been done to examine the effects of pre-harvest treatments on seed glucosinolate concentrations. These have been undertaken by ADAS, IACR Rothamsted and the University of Newcastle.

These experiments examined whether the accelerated drying of crops by swathing or the use of desiccants, produced higher seed glucosinolate concentrations than allowing them to naturally ripen before combining.

8.1 Experimental work

Very few of the experimental results have been published. For this review, data have been used from experiments funded by both MAFF and commercial companies.

Early ADAS experiments on the effects of timing of swathing done at High Mowthorpe between 1984 and 1988 were reported by Ogilvy (1989a). In these experiments, crops were swathed at five stages of seed maturity which ranged from 68 to 89 days after the onset of flowering. In the early experiments, single-low cultivars were grown (Bienvenu in 1984 and 1985 and Rafal in 1986), and the double-low cultivar, Ariana, was grown in the final three years.

In 1986 and 1987, another series of ADAS experiments on the double-low cv. Liradonna was commissioned by Nickerson's Seed Specialists Ltd at Bridgets, Boxworth and High Mowthorpe EHFs. In these experiments, glucosinolate levels in crops that were swathed or desiccated with diquat at five stages of seed maturity were compared with those in a crop that was direct combined at the most appropriate time.

Another three year series of experiments was done jointly by ADAS at Bridgets and High Mowthorpe EHFs, by IACR Rothamsted and by the University of Newcastle between 1987 and 1989. These were done on the cv. Ariana. Seed glucosinolate contents of crops that were swathed or desiccated with diquat at early, normal and late stages of maturation were compared with those in seed of crops that were direct combined at the most appropriate time. Some information from these trials has been published by Freer et al. (1989).

In an experiment commissioned by ICI at the University of Newcastle's Cockle Park Station in 1988, the effects of early and late-timed applications of diquat to the crop were compared with the effects of normally-timed treatments in which crops of Ariana and Libravo were swathed, desiccated with glyphosate, or direct combined.

Seed glucosinolate contents were measured at harvest in all experiments. In some experiments, more detailed studies were made of the patterns of change in seed weight and glucosinolate concentration, either throughout seed growth or during the final stages of seed maturation.

In most cases, the pre-harvest treatments were timed according to recommendations based on seed colour in the terminal raceme as outlined in the ADAS advisory leaflet (Anon., 1988b). The earliest swathing and desiccation treatments were applied at the beginning of pod senescence (when pod fill was complete, pod colour was turning to light green and all seeds were still green, approximately 65 days from the onset of flowering), and at defined intervals through the optimal time to late harvest at approximately 90 days from the onset of flowering. In an attempt to obtain consistency of timing across the widely dispersed sites in some experiments, treatments were timed according to accumulated temperature rather than chronological time after the onset of flowering. On thermal time, crops were considered to be ready for combining at about 1000 AD°C after the onset of flowering. Early treatments were applied at 800 AD°C and late treatments at 1200 AD°C.

8.2 Experimental results

Results are available from 22 experiments comparing time and method of pre-harvest treatment. These were spread over six years (1984-89) and three double-low cultivars (Ariana, Liradonna and Libravo). In each, a direct-combined crop was used as the standard treatment against which to assess the effects of swathing and desiccation. The seed glucosinolate concentrations of crops that were swathed and desiccated at the different times have been plotted against the concentrations measured in the direct-combined crops (Figure 7).

The experiments produced a generally consistent set of results from which the main conclusions were:

1. When crops were swathed or desiccated (with either diquat or glyphosate) at, or later than, the recommended times based on seed colour, glucosinolate concentrations in the harvested seed were no different from those of crops that were direct-combined.

2. In the majority of experiments glucosinolate contents were greatly increased if crops were swathed or desiccated with diquat too early, whilst a large proportion of seeds were still green (at about 800 AD°C from the onset of flowering).

Seed glucosinolate concentrations were increased by the early pre-harvest treatments at all sites, in cultivars of different background glucosinolate concentration (from 9 to 35 μmol/g) and in most years. The effect was absent in only a few experiments.

The early pre-harvest treatments did not significantly increase glucosinolate concentrations in the harvested seed in only six of the experiments. In some, the early treatments were delayed because conditions were unsuitable and might not have had an effect anyway. In most experiments, both early swathing and early desiccation with diquat increased seed glucosinolate concentrations to similar extents. Sometimes only one early treatment had an effect, desiccation with diquat in the experiments at Cockle Park and Bridgets and High Mowthorpe EHFs in 1987 and swathing at High Mowthorpe in 1988. Early

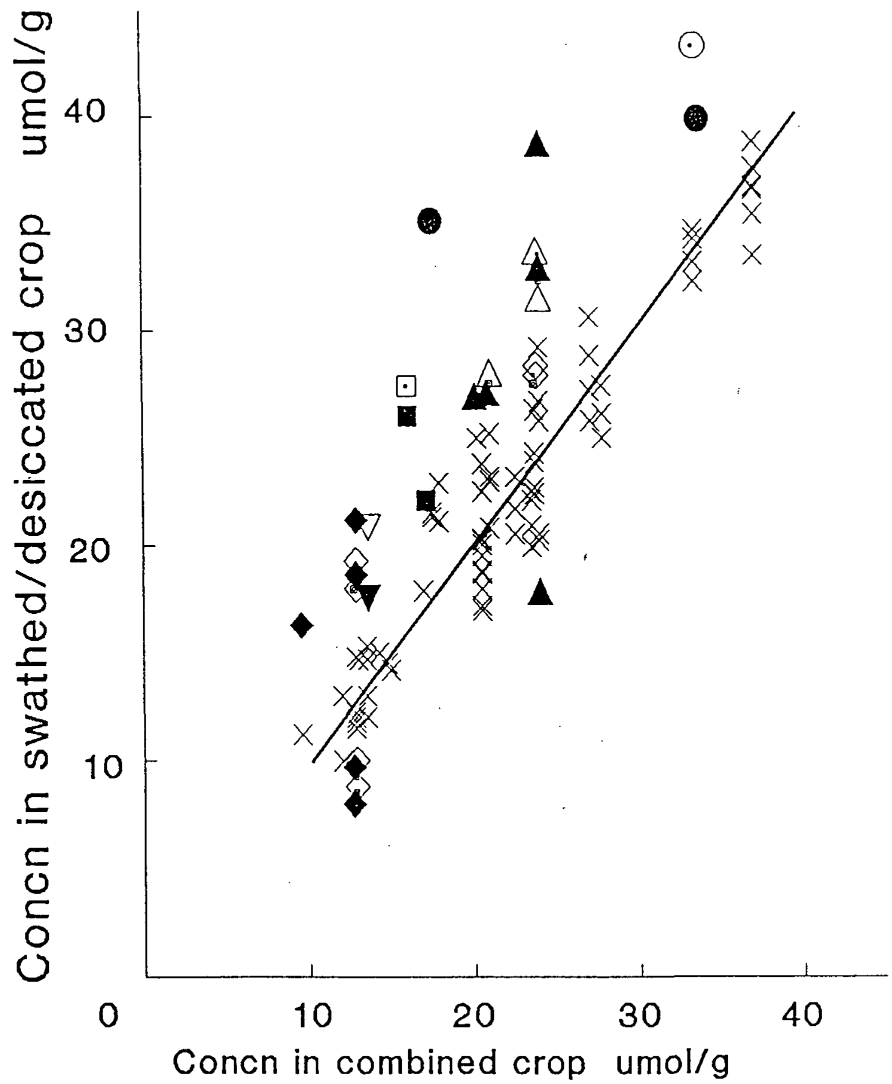

Figure 7 Comparison of the effects of time and method of harvest on seed glucosinolate concentrations. Swathing and desiccation treatments comparisons in which seed glucosinolate concentrations were not significantly different from those of direct combined crops are denoted by x. Treatments which were significantly different are denoted by (○,●) for Cockle Park, (□,■) for Rothamsted, (△,▲) for High Mowthorpe, (◇,◆) for Bridgets and (▽,▼) for Boxworth. (Open symbols represent swathing and closed symbols represent desiccation.)

swathing and desiccation gave lower glucosinolate concentrations than direct combining on only five occasions and this was particularly significant at Bridgets EHF in 1987. In this case, glucosinolate concentration was measured only in seed from the terminal raceme, and the low concentration in the early desiccated crop might have resulted from premature shedding of older seed of high glucosinolate concentration from positions low on the raceme.

Glucosinolates were measured by different methods in the various experiments. Seed from the ADAS experiments was analysed by the 'Colworth glucose-release method', that from experiments at Rothamsted was assessed by the FRI-Norwich glucose-release method and that from Newcastle University by X-ray fluorescence spectroscopy. All of these methods were frequently checked against the standard High-Pressure Liquid Chromatography procedure. Comparative tests of the different methods at Rothamsted and Newcastle showed that differences observed between experiments in changes in glucosinolate concentrations during seed maturation could have arisen from the use of different analytical methods. Generally, changes in glucosinolate concentrations during seed development measured by X-RF and the FRI glucose-release methods tend to correlate well with HPLC measurements but those measured by the 'Colworth' method (which relies on the presence of endogenous, rather than added, myrosinase to liberate glucose from the glucosinolate molecule), tend not to be so well-correlated.

When used as desiccants, diquat and glyphosate have different modes and speed of action. The two desiccants were compared directly on two cultivars, Ariana and Libravo, in commercially-funded experiments at Newcastle in 1988 and 1989. When applied at maturity and according to the manufacturer's recommendations, neither adversely affected glucosinolate concentrations in the harvested seed compared with swathed of direct combined crops. Physiological studies at Rothamsted showed that when applied much earlier in seed development than would normally be used in commercial practice, diquat completely stopped seed growth, stimulated glucosinolate accumulation and greatly increased final seed concentrations, whereas the slower-acting glyphosate did not noticeably affect either. This could mean that, despite its slower action, glyphosate may be the safer desiccant for crops that have matured unevenly because they have lodged or have patchy growth as the result of waterlogging or pigeon grazing. This is probably the only aspect of desiccant use or harvesting practice on seed glucosinolate content that would merit further study.

8.3 Physiology of glucosinolate accumulation in seed

There are several ways in which the method or timing of harvest might affect glucosinolate concentrations in the harvested seed:

1. It has been suggested that if seed glucosinolate concentrations either increase or decrease during seed maturation, they might be 'frozen' at acceptable levels by swathing or desiccating at appropriate times. This would provide a practical means of regulating concentrations in harvested seed. Views differ as to whether glucosinolate concentrations increase, decrease or remain stable during seed maturation. In ADAS experiments, seed glucosinolate concentrations increased during seed maturation in some and decreased in others (Ogilvy, 1989a).

2. Artificially accelerated drying during seed maturation, induced by swathing or desiccation, might stimulate the synthesis or accumulation of glucosinolates in seed. Alternatively, high concentrations would occur if pre-harvest treatments stopped the dry matter growth of seeds but not the accumulation of glucosinolates.

3. Glucosinolate concentrations might differ in seed from pods produced at different times during flowering or borne at different positions on the plant. Concentrations in harvested seed would differ if pre-harvest treatments caused premature and differential shattering of the uppermost, early-formed pods. Concentrations would increase or decrease depending on whether the shed seed had a higher or lower concentration than the bulk of the seed that was retained.

In some of the experiments reviewed above, physiological measurements were made at Rothamsted and Newcastle to obtain a better understanding of glucosinolate accumulation during seed development and maturation, and the extent and causes of variations in concentrations within plants and between sites and seasons.

These more detailed studies, which covered the whole of seed development and not just the ripening stages, showed that glucosinolate concentrations increased during active seed growth and remained more or less constant during seed maturation (Figure 8). Swathing or desiccating crops with diquat during the early stages of seed growth greatly and immediately increased glucosinolate concentrations and the changes persisted until harvest. The increase was greater the earlier in seed development the crop was swathed or desiccated (Figure 8). Concentrations were increased by the treatments virtually stopping seed growth and independently stimulating the rapid accumulation of glucosinolates (Milford et al., 1991; Fieldsend et al., 1991).

Other measurements demonstrated substantial gradients in seed glucosinolate concentrations within the plant and considerable differences between individual plants (Table 18). Concentrations are greater in seed from pods on the terminal raceme than on lower

Table 18. Glucosinolate variation with pod position on the plant (µmol/g)

Raceme number	Pod decade 1-10	11-20	21-30	31-40	41-50	Mean*
Terminal	22.5	21.2	20.2	16.7	16.0	21.8
3	17.6	19.6				18.6
6	16.0	15.2				15.6

SED between pod decades (30 df)± 1.15

SED between means for racemes (21 df)± 0.86

* Raceme means based on pod decades 1-10 and 11-20

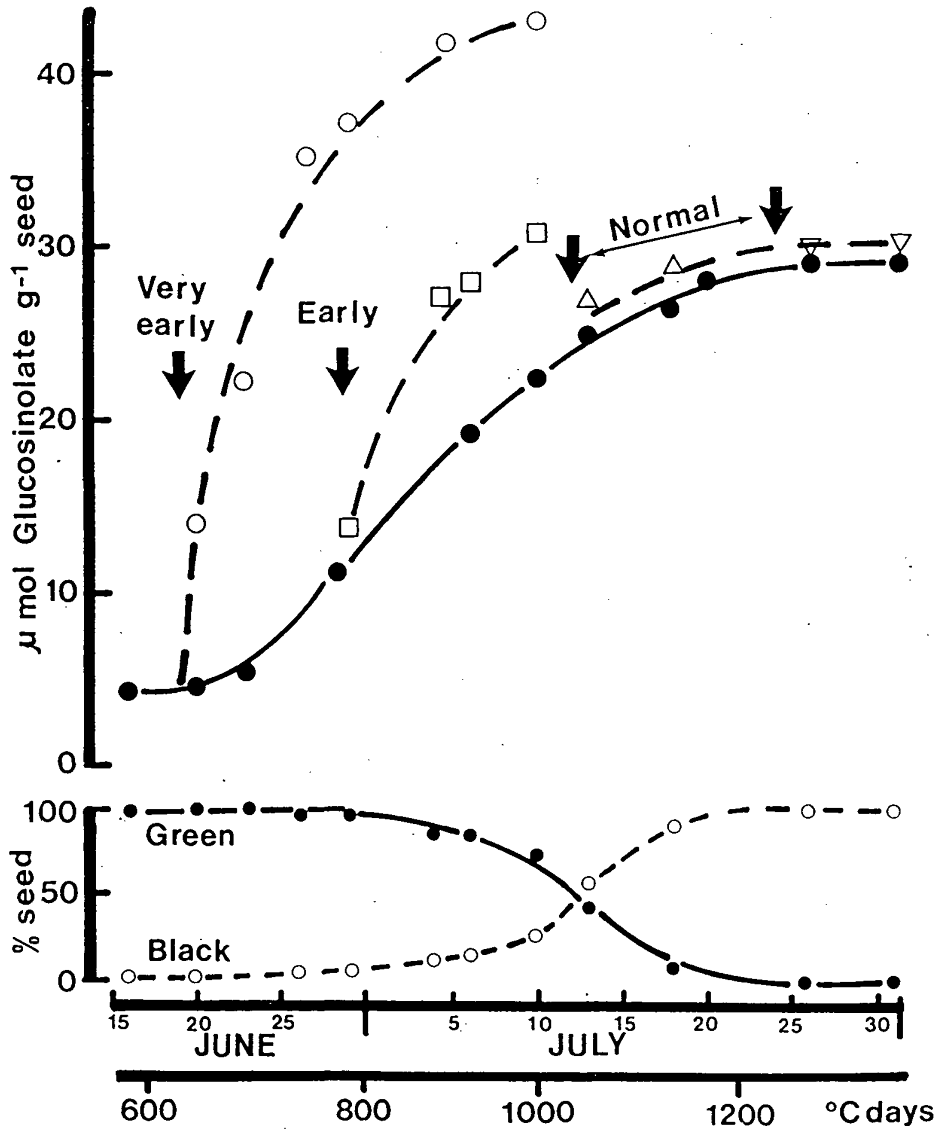

Figure 8 Changes in seed glucosinolate concentration during seed development on the terminal raceme, and the effects of swathing or desiccation at different times. Seed maturation is indicated by the proportions of green and black seed.

racemes, and in seed from the early-formed pods at the base of racemes than those at the top. The shedding of seed from these lower pods would account for observed differences in seed glucosinolate concentrations during seed maturation within the experiments reviewed above, and help explain exceptional results, such as that from the experiment at Bridgets in 1987, where early desiccation with diquat resulted in lower seed glucosinolate concentrations than in the direct combined crop.

9. DISCUSSION

The data reviewed in this paper indicate that, when choosing the method of pre-harvest treatment for oilseed rape, there are no conflicts between yield and quality. Treatment and timing can be chosen to optimise yield without there being any detrimental effects on quality. Consequently, choice of pre-harvest treatment must be related to an assessment of potential risks from seed loss, seed chitting in the pods or long-term grass weed problems.

Shedding or pod shatter can result in substantial yield losses of up to 1 t/ha from vulnerable crops, potentially one year in three. In very windy years they may be considerably higher. Yield loss is not the only problem associated with shed seed. Oilseed rape can be an aggressive weed especially in other broad-leaved crops, and the shed seed can remain dormant and viable in the soil for many years. Seeds of other brassica species have been known to remain viable in the soil for 60 years (G. R. Sansome, personal communication).

Seed chitting in pods can also result in yield loss, although this has not been quantified. Chitted seed can cause combining problems, by forming large matted lumps of green, wet material which can block the combine. The presence of chitted seed in the harvest sample can lead to lower seed dry matter and oil contents and a reduction in oil quality because of increased chlorophyll content.

Weeds in the crop at harvest time can also present problems. Excess green material in an otherwise dry and ripe crop can cause combining difficulties and can result in higher seed moisture contents and higher admixture levels. In addition, large numbers of weed seeds may be returned to the soil.

In ideal ripening and harvesting conditions, when crops are standing or leaning with well-intermeshed pod canopies and are maturing evenly and quickly in dry and relatively calm weather in sheltered locations, the risk of seed loss from shedding or chitting is usually low. In such situations, the choice of pre-harvest treatment is flexible and the most economical option is to direct combine without pre-harvest treatment.

In less favourable conditions, such as windy weather during the ripening period, such crops can be at risk, especially when they are in exposed areas and have been desiccated. In particular, crops with thin canopies, in which individual plants can still move freely against each other, are very vulnerable to wind damage. Swathing is the preferred pre-harvest treatment to prevent seed loss in these situations. An effective pod sealant would also offer protection from shedding but currently available sealants have not shown significant reductions in pod shatter. Further development of effective pod sealants is required. This may involve the use of plant growth hormones. Picart & Morgan (1986) have shown that the auxin 4-chlorophenoxyacetic acid has been found to delay the maturation and splitting of oilseed rape pods, but this has not been evaluated in field situations. An alternative approach to reduce seed shedding losses would be to introduce shatter resistance genes from related species such as brown mustard, Brassica juncea, into new cultivars of oilseed rape (Thompson & Hughes, 1986).

In wet seasons, crop ripening and drying is slow and seed chitting in pods is a potential problem. Pre-harvest treatments will be chosen to speed drying and ease harvesting. Desiccation is the preferred choice in these circumstances but swathing will also be successful if there is sufficient ventilation through the swaths to ensure adequate drying of the crop.

Lodged crops pose particular problems in wet seasons. If they are swathed there is usually insufficient stubble to hold the swath off the ground. Drying is restricted and there is a risk of seed chitting. If lodged crops are desiccated with a contact-acting desiccant such as diquat, the top layer of the canopy may trap all the desiccant so that the underneath is untreated. This makes it difficult to decide when to harvest and causes problems at harvest with seed of different maturity and variable moisture content. Lodged crops are more likely to have high glucosinolate contents as it is very difficult to judge when the crop is at the right stage of maturity for pre-harvest treatments, and these may be applied too early. Very little work has been done on pre-harvest treatments in lodged crops and their effects on yield and quality. However, limited experimental data would suggest that the translocated action of glyphosate may offer advantages in lodged or patchy crops but this has not been fully evaluated, and the product is not generally recommended for use in these situations. Desiccation is generally the best option to ensure quick drying of lodged crops in wet conditions, provided the risk of seed loss from pod shatter is low. Swathing is still an option if there is sufficient stubble to lay the swath on. However, lodged crops pose particular problems as no one method is ideal, and compromises often have to be made between yield and quality.

Unfortunately, it is almost impossible to predict in advance what the weather conditions will be like during ripening and harvest and this makes choice of pre-harvest treatment very difficult. This is compounded by the fact that treatments are usually planned, and contractors booked, before crops reach this stage. Choice will also be limited by what contractors are available, what equipment is available on the farm, cost, prevailing weather conditions and previous experience. As a result, many crops do not receive the most suitable treatment for the season, and losses do occur.

Whatever the treatment, choice of timing is crucial for yield and quality, and this is probably the most difficult decision to get right. Premature treatment is likely to be common, especially in very fast-ripening conditions, to avoid pod shatter. Applying a pre-harvest treatment before recommended timing generally results in smaller seed, lower seed yields, higher moisture contents, lower oil contents, higher glucosinolate contents and higher proportions of red seeds which lead to higher levels of chlorophyll in extracted oil. Immature seed is also more prone to spoilage in store as it is more metabolically active than older seed.

Late application of pre-harvest treatments is also likely to occur in dry seasons when the treatment window is reduced because of the accelerated ripening of the crop. Late treatment may cause problems if there are obligatory harvest intervals between application of desiccants and harvest, and late swathing can cause yield loss through pod shatter. In general, late treatment favours quality in terms of oil, glucosinolate and dry matter contents, at the expense of yield.

Decisions on timing are difficult to make in such a variable crop, with its wide range of seed maturity during the ripening phase. Crops may be swathed or desiccated too early as a result of pressure from contractors who are committed to treating large areas of crop in very short periods of time, and also because growers are anxious to prevent seed loss. Accurate methods are needed to determine crop maturity so that treatments can be applied at the optimum timing. These methods may consist of temperature records or colour charts of seed maturity. They should be easy for growers to use and interpret in the field.

Costs of treatment have not been addressed in this review because of the variable nature of this information but it is generally assumed that the cost of swathing by contractor is usually equivalent to that of a desiccant, applied by contractor. The higher rates of desiccants recommended for weed control, rather than for harvest management alone, are more expensive. However, both chemical and mechanical methods carry additional costs because of the crop damage caused by wheelings from the sprayers or swathers. The effects of wheeling ripe oilseed rape crops at the desiccation stage have been quantified (Ogilvy, 1989b). It was found that on average, 1.6% of yield was lost when the crop was wheeled with a high-clearance sprayer on a 24 m boom system. This cost must be considered when making a decision on choice of pre-harvest treatment based on cost. However, what is not known is what level of damage is caused by sprayers turning on headlands or what effect swathers have when they turn on cut swaths on headlands.

As the pricing structure for oilseed rape alters, growers will need to examine their inputs to the crop more closely in order to maintain profits. Pre-harvest treatments are still likely to continue to be justified because they assist in securing the harvest of the crop. Even when the price of oilseed rape drops to the world market level and subsidies are paid on an area basis, rather than as a crushing subsidy on the seed, it is still in the farmers' interest to minimise yield loss and maximise quality at harvest by choosing the most appropriate pre-harvest treatment for the crop. This in turn should give the maximum return from the crop. The problems associated with increasing the weed seedbank with volunteer oilseed rape, which may affect the profitability and quality of future broad-leaved crops, should also be taken into account before pre-harvest treatments are abandoned to save costs.

10. RECOMMENDATIONS FOR FURTHER STUDY

A considerable amount of R & D has been done on pre-harvest treatments for oilseed rape. Treatment effects on seed yield and quality have been recorded for most of the treatments available. However, several topics which might warrant further action have been identified. Their importance will be influenced by the new support scheme for oilseeds.

1. Further information is needed on the effects of the various pre-harvest treatments on the speed and mode of action of crop drying, especially in relation to total plant and seed dry matter, seed size and glucosinolate content. In particular, little is known about the effect of glufosinate-ammonium on speed of drying or on glucosinolate content. Such data would allow more precise recommendations on pre-harvest treatment.

2. Treatment timing is crucial for yield and quality. Further evaluation and development of the thermal time technique and development of new techniques to assess crop maturity are required. Simple colour keys, detailing the optimum timing for each treatment, should be produced as guides for growers and researchers.

3. Seed loss assessments have proved to be difficult and unreliable in the past. An evaluation of a range of methods is needed, so that accurate assessments of losses can be recorded in future experiments.

4. Lodged crops pose particular problems at harvest. Opportunities should be taken to test the range of pre-harvest treatments in lodged crops so that more precise recommendations can be made. In addition, little is known about the effects of lodging on seed maturity, glucosinolate content in seed in different layers in the pod canopy, rate of drying or yield.

5. Wheeling losses have been evaluated for sprayers going into untouched areas of crop. Some estimate of the damage caused by sprayers or swathers turning on headlands is required so that more realistic estimates of treatment cost can be made.

6. Plant hormones and chemical pod sealants have the potential to reduce seed losses and optimise the yield and quality of crops. Further development and evaluation of potential treatments are required.

7. The possibility of incorporating genes which confer shatter resistance into new cultivars of oilseed rape should be explored.

8. Interest in the quality aspects of glucosinolate research will be limited by the new oilseeds support scheme. However, there is increasing evidence that glucosinolates in the whole plant, not just the seed, may have a central role in the sulphur requirement and turnover of the crop. That role needs to be further explored.

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