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HYBRID BREEDING OF WHEAT, BARLEY AND RYE: DEVELOPMENTS TO DATE AND FUTURE PROSPECTS

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HYBRID BREEDING OF WHEAT, BARLEY AND RYE: DEVELOPMENTS TO DATE AND FUTURE PROSPECTS

by

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SUMMARY

Wheat

Current activity and hybrid yield advantage

Hybrid wheat is commercially available in France. The breeding companies, Hybritech (a subsidiary of Monsanto) and Hybrinova, are most advanced in hybrid wheat production in Europe. Zeneca Seeds, Nordsaat Saatzuchtgesellschaft MBH and Van der Have Royal Group, have also entered hybrids into trials in France, Germany and Holland, respectively. Hybritech have three hybrid wheats registered in France (Domino, Sextant and Twin), which are feed wheats. These hybrids yield more than 5 to 12% over conventional varieties. Hybrinova also have three hybrids registered in France (Hyno-Precia, Hyno-Prima and Hyno-Rista) which yield approximately 8 to 12% more than conventional varieties.

The potential for increased yield with hybrids has decreased due to intense breeding for yield with conventional varieties. High levels of heterosis are more likely to be achieved from low yielding parents than from higher yielding parents. Therefore, improvement in yield from hybrids requires the selection of parental lines with good combining ability for increased productivity. Additionally, the continual increases in yield with conventional varieties also explains the lack of yield advantage in hybrid wheat.

The percentage yield advantage required for commercial success is highly dependent on a number of factors. Models have been developed to give an estimate of the yield advantage required under a range of scenarios, but generally indicate the need for a higher level of yield advantage than is currently being achieved. The success of hybrid wheat will be more likely if improvements in grain quality or disease resistance are demonstrated over conventional varieties. Differences may become more apparent if lower input farming systems are adopted.

Grain quality

Most hybrids tend to be intermediate in quality between the two parents. Premiums from improved quality will improve the prospects of hybrid wheat production in the UK, but advances with conventional varieties in high yielding, high quality varieties may reduce the advantage of hybrid wheats.

Hyno-Precia, Hyno-Rista and Hyno-Kalia (a hybrid still in trials) from Hybrinova, have good bread-making qualities. Hybritech have hybrids in trials that are of bread-making quality and also combine this with high yield and good disease resistance.

Improvements in pest and disease resistance

There has been limited published information on the potential pest and disease resistance benefits of the hybrids currently being trialled. In general, hybrids have not achieved the theoretical potential for greater disease resistance. The recently developed French hybrid wheat, Hyno-Precia, was shown to be susceptible to powdery mildew and yellow-rust in UK trials in 1995, with a single fungicide spray giving a 23 % rise in yield. However, the variety still yielded 7.7 t/ha without fungicide application. Hybrids are reported to produce adequate yields even with high levels of pest and disease attack and show superior performance under lower input farming systems. Further research to validate these claims would be beneficial.

Reduction of seed rates

The reduction of seed rates to reduce costs is a possible method of improving the financial feasibility of hybrid wheat production.

There is insufficient data available to ascertain whether hybrids have adequate improved vigour to compensate for the lower plant population, although Hybritech and Hybrinova recommend lower seed rates for hybrid wheat production. Further research on current hybrids is necessary to compare hybrid and conventional varieties under a range of seed rates and sowing dates. This will allow comparison of any differences in vigour at germination, seedling growth, tillering, and grain filling to determine how far seed rates can be reduced with hybrids. The use of pneumatic seed drills, or even precision drills, may allow a reduction in seed rates and, therefore, seed costs.

Cost of seed production

The costs of seed production are highly dependent on the success of cross-fertilisation and the percentage seed set. Successful cross-pollination is dependent on environmental factors as well as parental synchrony, the cross-fertilisation characteristics of the parents, quality of field management and the timing of application of the chemical hybridising agent (CHA). CHA's are used in the production of all current commercial wheat hybrids as they increase the broadness of the genetic material which can be used, enable easy maintenance of parental lines and speed up production, as alien cytoplasm does not have to be incorporated into the female parent. Hybritech and Hybrinova are using different CHA's named 'Genesis' and 'Croisor', respectively. Genesis was developed by Rohm & Haas and Croisor by Sogetal Inc. Zeneca Seeds are also using a CHA named 'Depollenor' which is similar in chemical composition to Genesis and was also developed by Rohm & Haas. The CHA's achieve levels of greater than 95% male sterility under field conditions.

Substantial advances have been made in seed production techniques since the late 1980s. This is partially the result of the selection of parental lines on the basis of their suitability for female receptivity or pollen production potential. Good accuracy and timing of spraying, in CHA systems, are also necessary to ensure that male pollinators are not sprayed and that the chemical is effective in sterilising the female receptor plants. Weather conditions also need to be good to allow spraying and pollen transfer, and further research on the effects of climatic conditions on pollen transfer would be beneficial.

In theory, the development of a system for hybrid production, similar to SeedLink™ developed for hybrid oilseed rape by Plant Genetic Systems, could provide a solution to a number of the above-mentioned problems. Unfortunately, genetic manipulation of wheat is not at such an advanced stage as that of oilseed rape due to technical difficulties with gene-insertion. Additionally, herbicide-tolerance is conveyed to the hybrid plant and breeders are aware of the potential problem this could cause with volunteer cereals. It is therefore unlikely that such a system will be introduced but breeders are conducting research into alternative methods of removing the male pollinators after pollination.

Conclusions

The interest of breeders in hybrid wheat has been spurred on by the prospect of achieving a large proportion of the market share for wheat seed, and the possibility of reducing the use of home-saved seed. The financial feasibility of hybrid wheat production is largely dependent on factors such as the cost of producing seed. Improvements in grain quality and pest and disease resistance in combination with high yields would also improve the prospects for hybrid wheat production but are dependent on developing parental lines, appropriate to UK conditions, with good combining ability for yield, quality and/or pest and disease resistance. At present, however, the introduction of wheat hybrids in the UK is highly dependent on their success in France.

Gene transfer offers a number of possibilities in improving the seed production system and prospects for hybrid wheat but it may also reduce the advantages of hybrids in combining dominant genes for specific traits.

The beneficial attributes of hybrids may have greater importance in lower input farming systems. Yields in the UK National List trials are obtained using high input techniques and hybrids may show greater yield advantages where reduced levels of input are used.

A reduction in the grain price would, however, result in a greater yield advantage being required. Farmers are attempting to reduce variable costs and will not readily increase them, by using high cost seed, unless there is a substantial advantage in doing so. F_1 hybrid seed cost is also a problem considering the widespread use of relatively cheap home-saved seed.

One of the objectives of an European Union EUREKA[1] project (EU749, Research and development programme on hybrid wheats) on hybrid cereals is to select lines on the basis of statistical data and to integrate the characteristics and criteria obtained over several test years using a computer model. Further research on seed rates, responses to inputs (nitrogen fertilisers and fungicides), pest tolerance and the factors generating quality improvement is also continuing. A further objective of the EUREKA project is the utilisation of hybrids as a medium for improvements resulting from genetic engineering techniques. Therefore, many of the research issues raised are currently being assessed by the EUREKA project.

[1]EUREKA is an EU scheme which works with firms and research centres in the participating countries, assisting them in pooling their resources so as to be at the leading edge of technological development.

The success of hybrid wheat is a complex issue dependent on many factors including European agricultural policy. It is therefore not possible to determine whether hybrid wheat production will become widespread in the near future and individual hybrids will have to be assessed in their own right.

Barley

Interest in the production of barley hybrids has been extensive. Several authors have described significant yield heterosis and efforts have been made to produce a commercial crop through both cytoplasmic male sterility and the use of chemical hybridising agents. However, current levels of yield heterosis and problems with the hybridising chemical have prevented breeders from making hybrid barley available to growers. The availability of a satisfactory chemical for use in wheat hybrid programmes may improve prospects for further work with barley. Less effort has been made by plant breeders, as barley does not have such a large potential seed market as wheat, although some research has been conducted by the EUREKA project. The issues of seed cost, seed rate, grain quality and pest and disease resistance are all applicable to hybrid barley production.

Rye

Hybrid rye varieties are currently being successfully grown commercially. The acreage of rye in the UK is small (6,000 - 9,000 ha from 1990 - 1995) and the crop is grown on contract.

Production of hybrids is by means of cytoplasmic male sterility. As rye is a good producer of pollen, the crossing block consists of approximately 95% male sterile plants with 5% pollinator (restorer) plants.

Parent lines have been bred in Germany where rye is a fairly major crop and the returns on development investment are more likely for the breeder.

The breeding of new rye lines has not been as intensive as in wheat and thus the available inbred varieties are not as 'advanced' as those in wheat, so there is more potential for yield heterosis. Rye hybrids currently on the NIAB Recommended List show a yield advantage of 15% and more over the control variety. For this reason it is likely that the already large proportion of the rye seed market in hybrids will increase further. Hybrids not only offer improved yields, but also have shorter, stiffer straw which allows easier crop care and reduces the likelihood of crop lodging.

RECOMMENDATIONS

1. The performance of hybrid wheat in France will determine whether breeding companies invest further in the development of hybrid lines specifically for the UK. Additionally, the performance of wheat hybrids in UK trials should be evaluated as this will also determine their introduction into British agriculture. This will establish the need for further research.

2. Hybrids should be assessed under different input levels to determine whether they are more suitable for lower input farming systems.

3. Further research to compare the newer hybrids with conventional varieties to determine whether the hybrids have sufficiently greater vigour at germination and during growth to warrant a lower seed rate is required. Experiments on current hybrids under a range of agronomic conditions would be useful.

4. There is a need to investigate market size and potential for premiums for unique qualities (especially industrial) which new hybrids may offer.

CHAPTER 1 BACKGROUND TO HYBRID CEREALS

1.1 Definition

A cross between two varieties is called a hybrid. The first generation following a cross is referred to as the F_1 generation or the F_1 hybrid and the next generation is called the F_2 generation. A variety is said to have good 'combining ability' if it confers beneficial traits to the F_1 hybrid.

1.2 Reasons for interest in hybrid cereals

Pickett (1993) traces research interest in hybrids back to 1909, but the first commercial wheat breeding programme was initiated in 1961. Since then, interest in hybrids has fluctuated.

Conventional cereal varieties are developed by successive inbreeding. This is necessary to produce a uniform crop which breeds true. However, continual inbreeding can result in inbreeding depression (i.e. loss of vigour) especially in outbreeding crops. Loss in yield resulting from inbreeding was demonstrated by Cregan and Busch (1978) who examined inbreeding depression in spring wheat from the F_1 hybrid through to the F_5 bulk generation. They found that mean yield decreased at a linear rate of 0.23 % per 1 % decrease in heterozygosity. Interest in hybrids has developed because of a phenomenon known as heterosis, or hybrid vigour, i.e. plants resulting from a cross between two varieties often possess beneficial characteristics, such as increased vigour, greater fertility and disease resistance, not shown by either of the parents.

Workers reporting instances of heterosis in crop plants have used different descriptions of improvement over the parental lines. "Mid-parent heterosis" describes the improvement over the mean value of the two parents for a specific character. Often the term heterosis is used to describe mid-parent heterosis, which has also been referred to as "true heterosis". "High-parent heterosis" describes improvement over the better of the parents, and gives a clearer idea of the benefits of the hybrid. However, neither of these descriptions gives an indication of how well newer hybrids compare with other conventional varieties. The difference between yields from hybrids and the best conventionally bred variety is known as "standard heterosis". A measure of standard heterosis is needed to evaluate the likely success of hybrids in competition with conventional varieties.

1.3 "Case study" of hybrid maize

Attempts have been made to exploit hybrid vigour in a number of crops. The greatest success to date has been achieved with maize. Development of hybrid maize began during the early part of this century in response to the poor performance of inbred varieties. The progress of hybrid maize, however was not rapid, largely because of difficulties involved in F_1 hybrid seed production. Crosses between inbred varieties produced little seed of low quality (Pickett, 1993; Tudge, 1988).

The first economically important maize hybrids were established by the 1930s. These hybrids were the result of double crossing. It was found that while the cross of variety A with variety B might not be economic and a cross of variety C with variety D might not be economic, crossing the F_1 generations of these two crosses could produce a very vigorous and reasonably uniform crop which gave a yield that justified the extra effort of production (Tudge, 1988). By 1940 the use of hybrids, largely double cross, had risen to 50% (Allard, 1960) and by the 1950s they accounted for practically all the maize grown in the United States corn belt (Tudge, 1988).

Since the 1950s, advances in plant breeding have led to the development of single cross F_1 hybrids which compete well with the double crosses, and these now predominate.

1.4 Relevance of the US hybrid maize situation to hybrid cereals

The success of hybrid maize is significant because it encouraged attempts to develop hybrid cereals in general, and the highly developed seed production system for maize (Curtis, 1980) has set standards for hybrids in other crops.

However, maize differs from cereals such as wheat and barley in some aspects which are important with respect to the development of hybrids.

Firstly, the genetic make up of maize is diploid, i.e. it possesses two copies of each chromosome. In contrast wheat is hexaploid, i.e. it has six complete sets of chromosomes and is therefore more complex with respect to plant breeding.

In addition, while cereals like wheat and barley have a natural tendency to inbreed, or self-pollinate, maize is a natural outbreeder. This is illustrated by the anatomy of the plants. While in wheat and barley the male and female parts are located in the same flower, facilitating self-pollination, in maize, male and female parts are separated. The pollen is borne on tassels at the top of the plant, while the female flowers, which become cobs, are on the side of the plant.

Conventional methods of plant breeding rely on inbreeding to produce a uniform crop. Plants like maize, that are natural outbreeders, are much more prone to inbreeding depression than natural inbreeders like wheat and barley. As a result, the early attempts to breed maize by conventional inbreeding methods produced poorly performing varieties. Although other cereals have been found to display hybrid vigour, inbreeding depression is a relatively minor problem. Therefore, there was not such a strong incentive to develop other hybrid cereal lines.

1.5 Potential advantages of hybrid cereals

1.5.1 Potential advantages for the farmer

The potential advantages to the farmer are related to heterosis or hybrid vigour. Hybrid cereals may yield more than conventionally bred varieties. Grain may also have improved physical characteristics and therefore be more valuable. Increased vigour may allow lower seed rates to be used than with conventional varieties. Improved disease and insect resistance may allow for the use of reduced pesticide inputs. In addition, response of hybrids to heat and moisture stress, combined with such factors as winter survival and earlier maturity may contribute to relative hybrid advantage (Virmani and Edwards, 1983). It should be stressed, however, that with respect to wheat, these are **potential** advantages. Not all crosses will show all of these characteristics and each new hybrid variety must be assessed in its own right.

1.5.2 Advantages to the breeder

The main advantage of hybrids to plant breeders is that, as hybrids do not breed true, farmers cannot home-save seed, but have to buy seed from the breeder or agent each year. This gives breeders a more assured income than from new conventional varieties. In fact, it has been suggested that the interest of the Americans in hybrids is simply a means of reducing home-saved seed as, in the US, there are no plant breeders' rights. In the UK, however, there are now farm-saved seed (FSS) royalty payments on some varieties; the 1996 rate was £22.37/t (Johnson, 1996). Therefore, the US breeders have a greater incentive to develop hybrids as a more secure source of income.

1.6 Factors which may limit development

1.6.1 Disadvantages to the farmer

Hybrid cereal seed does not breed true and home-saved seed is likely to be variable. Additionally, under EU Regulation No. 2100/94 Article 14.1, a farmer would infringe plant breeders' rights by home-saving seed of 'hybrid or synthetic' varieties. If the UPOV 91 Convention (Union for the Protection of New Varieties), a world-wide agreement on plant breeders' rights, is passed through the UK Parliament, it will become possible to apply for a licence to home-save seed from the breeder or the British Society of Plant Breeders (BSPB). An agreed remuneration will then have to be paid by the farmer. Furthermore, the cost of breeders' investment in hybrids coupled with the high recurring cost of producing hybrid seed, particularly in land requirement, could result in an increased cost of seed compared with conventional varieties.

1.6.2 Disadvantages to the breeder

The development of hybrids requires a large capital investment and may therefore represent a high risk, as the success of these hybrids is not guaranteed.

1.7 Objectives

In order to assess whether hybrids represent a profitable option, cereal growers must consider the benefits of potentially higher yields, reduced seed rates, improved seed quality and reduced disease control requirements in relation to the higher seed cost. Maximum benefit from hybrids may be achieved by modifying the current approach to cereal growing.

The overall objectives of this study are:

- to review the current position on hybrid cereal production particularly in relation to the market and the likely yield, quality and disease resistance benefits and the consequences for crop management.
- to provide guidance on the financial and agronomic balance between adjusting seed rates of more costly cereal seed and other inputs and the associated effect on yield.
- to identify further research required.

CHAPTER 2 REVIEW OF BREEDING WORK WITH CEREAL HYBRIDS

2.1 History of development

Pickett (1993) states that work on hybrid wheat has been carried out in the majority of countries with significant cropping areas of this cereal. Major programmes of research have been run in many countries including Australia, Bulgaria, Canada, China, France, Germany, Hungary, India, Italy, Japan, Mexico, Netherlands, Pakistan, UK, USA, USSR and Yugoslavia.

Milestones relating to the development of hybrid wheat and other species are summarised in Pickett (1993).

2.1.1 Background

Hybrid seed is produced by crossing two varieties. This means that breeders require a method to prevent self-pollination of the female parent plants. This is done by ensuring that one of the parents produces no pollen or non-viable pollen. The first and most obvious way would be to remove the anthers physically. However, although this method was the first used for hybrid maize production, for plants like wheat and barley it would not be practical on a large scale.

Two basic approaches to preventing pollen production have been developed.

(*i*) The first approach is based on the use of plant breeding methods to obtain female parents which do not produce functional pollen, i.e. **male sterile lines**. Genes that produce sterility can be inherited as recessive genes in the nucleus, or borne in the cytoplasm, in organelles. These two types of gene have given rise to two methods for producing male sterile lines. The **nuclear male sterility (NMS)** method is based on genes located in the nucleus and the **cytoplasmic male sterility (CMS)** method exploits genes encoding male sterility located in the cytoplasm.

(*ii*) The second approach is the application of chemicals that suppress pollen production in plants that would otherwise produce functional pollen. These chemicals are known as **chemical hybridising agents (CHA)**.

2.1.2 Nuclear male sterility

The first report of male sterility determined by the wheat nucleus was given by Pugsley and Oram (1959). Since then a number of additional genes have been identified and several systems for their utilisation have been proposed. Pickett (1993) reviewed the systems which have been studied and concluded that apart from use in China, there is little evidence to suggest that NMS has yet reached commercial use in wheat, although the first commercial hybrid barley produced in the USA was a NMS line. Limitations to the development of this system include problems with achieving a stable genetic system and large-scale production of uniformly sterile seed. Potential benefits of NMS relative to CMS, are that special varieties are not required to restore fertility to the F_1 hybrid, and damaging side effects which have been found in some forms of CMS are not so apparent.

2.1.3 Cytoplasmic male sterility

2.1.3.1 Breeding scheme for F_1 hybrids using CMS

Figure 2.1 outlines the breeding scheme for F_1 hybrids using the CMS system. Production of the hybrid requires three lines. One line is the male parent which is referred to as the R-line. This line is selected for combining ability but also carries genes to restore fertility (restorer genes) to the F_1 hybrid, as fertility must be restored to the F_1 hybrid so that the crop grown by the farmer can self-pollinate in the same way as a conventional crop. Restorer genes are incorporated into the male parent by a crossing programme which may include back-crossing.

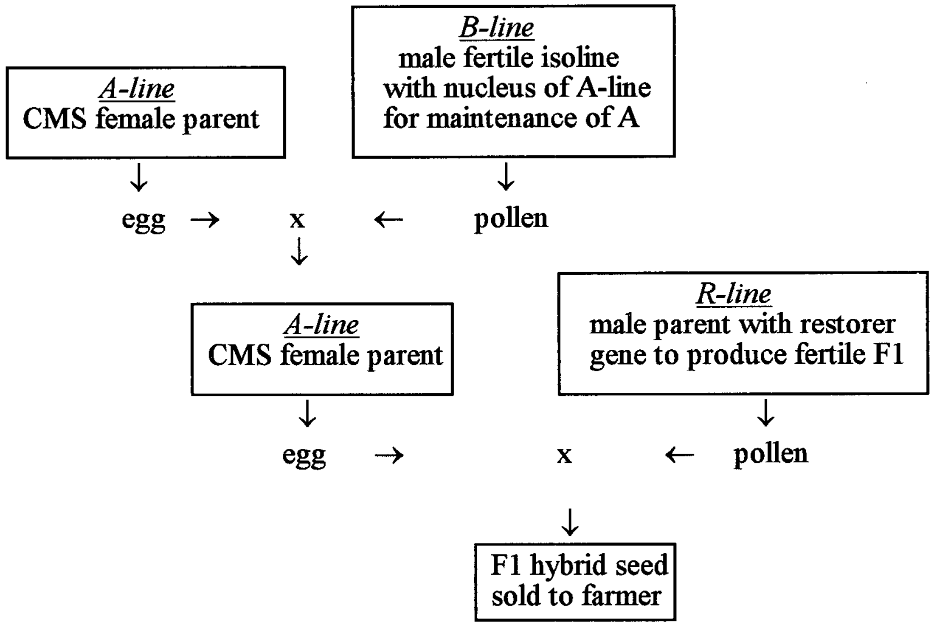

Figure 2.1 Breeding scheme for F_1 hybrids using CMS system (Pickett, 1993)

Two lines are required for the female parent; these are termed the A-line and the B-line. The A-line is the female parent, which is selected for combining ability, but also carries the cytoplasmic male sterility. Because this line is male-sterile a second line, the B-line, is required to pollinate the A-line for maintenance purposes. The B-line has the same nuclear genotype as the A-line, but is male-fertile. Male sterility is maintained in the A-line because the fertile cytoplasm is not transmitted in the pollen, i.e. male sterility can only be inherited from the female parent. CMS is incorporated into a line of the female parent by back-crossing, using the line with the male-sterile cytoplasm as the recurrent parent and the normal male fertile line as the donor parent.

2.1.3.2 History of breeder interest in cytoplasmic male sterility

Although the use of CMS has largely been superseded by the use of CHA's, varieties produced using this method were released onto the market and the discovery of CMS in wheat was important in encouraging breeders to expend considerable effort on the development of F_1 hybrids.

Cytoplasmic male sterility was introduced into wheat in 1951, but the first commercially feasible CMS system was not released until 1974. Plant Breeders Cargill, Dekalb Hybrid Wheat and Pioneer were involved in the development of CMS for the production of hybrid wheat in the US. In the UK, PBI and British Hybrid Cereals (a joint venture between Nickerson Seeds and Rank Hovis McDougal) were involved in research work on F_1 hybrids during the 1970s, which included work on CMS. Commercial wheat hybrids based on CMS were released onto the US market during the 1970s and 1980s. However, in 1990, Cargill discontinued sales of their line of CMS-produced hybrid wheats (marketed under the Bounty brand) (Kidd and Dvorak, 1995).

2.1.4 Chemical hybridising agents

In CHA systems of hybrid seed production, male sterility is achieved by the application of a chemical to a genetically fertile variety. Although some work relating to the development was published in 1953, commercial interest in the development of CHA's was not apparent until the 1970s and '80s. Companies which have invested in development of CHA systems include Eli Lilly, Rohm & Haas, Shell, Du Pont, Monsanto and Orsan, but in many cases their research programmes failed to bring any commercial return, and were abandoned or scaled down, resulting in scepticism over the future of hybrids. For example, Brears and Bingham (1989) reported on the programme of hybrid wheat production undertaken at the PBI. They concluded that considering the problems associated with F_1 hybrid seed production and the levels of heterosis observed in F_1s and F_2s, the case for hybrids seemed commercially marginal. However, despite this scepticism, some companies have continued with development. Recent interest in hybrid wheat production has been largely focused on the use of

CHA's. The main advantage of the CHA system is that breeding procedures are simplified compared to NMS or CMS systems as it is not necessary to incorporate alien cytoplasm in the female parent or restorer genes in the male parent. It also reduces the constraint on the broadness of the genetic material which can be used. This speeds up production, enables easy maintenance of parental lines (no special methods are required) and allows a large number of hybrid combinations to be produced for evaluation by the breeder, much more easily than by NMS or CMS. Because production is theoretically easier using CHA, production costs, and therefore the price at which the seed can be sold to the farmer, may be lower than for seed produced using CMS systems.

Many chemicals, with various modes of action, have been tested as CHA's. The ideal characteristics of CHA's have been described by a number of workers. Chemicals should:

1. be cheap to produce,
2. not have any environmental or health risks,
3. block self fertilisation in a wide range of varieties,
4. be sufficiently systemic and persistent to allow for environmental variation and different stages of maturity in the plant material treated,
5. not cause significant female sterility, and
6. have no detrimental effect on seed quality.

However, in practice, many CHA's do not meet all these specifications. They tend to require precise adherence to a narrow treatment window and many do not affect varieties uniformly. A chemical will have different windows of application in different regions and countries. The cooler conditions in the UK may allow spraying over a longer period as female plants may be receptive for 8 - 10 days in the UK compared to 3 - 4 days under hotter conditions in the south of France. Due to the narrow windows of application, the logistics of spraying may be a problem. Staff must be available and ready to spray expertly at the right moment, and spraying large areas within the required time-span may be difficult. Plant breeders are investigating methods for delayed-action CHA's which can be applied prior to flowering and act only on specifically bred male pollinator plants. This would eliminate the problem of the short time-span for application of the chemical.

In addition, the safety of those CHA's which interfere with the process of cell division was questioned after preliminary work suggested effects on human chromosomes (Pickett, 1993). Of the many CHA's tested for use on wheat, only a small number have approached commercial release. This may be attributed to a number of problems that have arisen in the development of the chemicals. Examples of chemicals which have been targeted for development and some problems which have arisen are described below.

- The chemical Ethrel, also known as Ethephon or 2-chloroethylphosphonic acid, was developed for use with wheat, barley, oats and triticale. Early use of Ethrel as a CHA was successful in that it caused male sterility in wheat without affecting female fertility, but problems arose from its growth regulating effect, i.e. it restricted spike emergence (Ethrel is a component of the commercial growth regulators Cerone and Terpal). This was coupled with the need for very precise timing of application to be effective. Spraying the chemical on the soil avoided phytotoxic effects, but sterility was not complete in the female parent.

- In 1986, a Shell chemical, WL 84811, appeared to be the most effective CHA produced to date, inducing almost complete male sterility and only minimal female sterility. Hybrids produced using this chemical were entered in the National List trials in the UK. However, the chemical was withdrawn from development after some concerns over its safety.

- Currently, Zeneca Seeds UK and Monsanto (Hybritech) are using the chemicals "Depollenor" and "Genesis", respectively, for the commercial production of hybrids in the US and Europe. The chemicals were developed by Rohm & Haas and are similar in chemical composition. Levels of male sterility are reported to be as high as 98-99%. The chemicals are 5-carboxy-oxy-pyridines which are thought to either disrupt meiosis or the later stages of pollen development. The chemical Depollenor is also known as clofenocoet or RH-754 and is applied at flag-leaf elongation. Genesis is most effective when applied to plants with an apex length of between 30 and 60 mm. The time span for this is approximately two weeks in southern England. The recommended rate of Genesis is 5 kg of active ingredient/hectare.

- Orsan, a subsidiary of Copabio in France, in which Lafarge-Coppée have a 66% interest and Crédit Agricole 34%, have developed a CHA named 'Croisor' or SC-2053, in conjunction with their research laboratory, Sogetal Inc., in the US. The chemical name for SC-2053 is 1-(4-chlorophenyl)-4-oxo-5-(methoxy ethoxy) cinnoline-3-carboxylic acid (Guilford *et al.*, 1992; Wong *et al.*, 1995; Cross *et al.*, 1995). SC-2053 is being used by the plant breeders Hybrinova. The chemical is applied just prior to the initiation of meiosis. This is defined, for application in the field, by the length of the main stem spike. Wong *et al.* (1995) found that the chemical was most effective when applied from 11 to 20 mm main stem spike length. The time span for this range was one week in controlled conditions. Over 95% sterility was achieved for the first three ears produced per plant but there was a reduction in sterility for late tillers. In general, the efficacy of SC-2053 depended on the dose of active ingredient (700 - 1000 g/ha), stage of application and the tillering of the plants.

Although the molecular target of SC-2053 is not known, it inhibits development of early microspores at the uni-nucleate stage, and the closely related compounds, SC-1271 and SC-1058, affect the ultrastructure of the tapetal cells which surround the developing pollen grains in the anther (Cross *et al.*, 1995). SC-2053 had no effect on female fertility but did reduce plant height (Wong *et al.*, 1995).

Overall, the use of CHA's as a means to hybrid cereal production has both advantages and disadvantages in comparison to NMS or CMS systems. Some disadvantages are environmental, as safety of CHA's has been questioned, and the system is vulnerable to climatic variation which could interrupt chemical application or lead to other adverse effects. A serious decline in seed purity arising from ineffective application might prevent acceptance under seed regulations, although the regulations have been modified in France to allow for lower levels of seed purity.

2.2 Current activity

2.2.1 Wheat

Attempts during the 1980s to release wheat hybrids had little success, and there is still much scepticism about the potential of hybrid cereals amongst plant breeders and researchers. However, some companies persisted with development work, and a number of new hybrids are currently being trialled and may soon be marketed. Some current activities relating to the development of hybrid wheat are listed below.

- Hybritech-Europe, a subsidiary of Monsanto, have registered three hybrid wheats in France, ('Sextant', 'Domino' and 'Twin'). They are not suitable for the UK market as they are daylength insensitive and mature too early. These are currently only suitable for feed wheats, but Hybritech are hoping to register (in France) a hybrid of good bread-making quality, combined with good disease/lodging resistance, in 1997. Hybrid performance is likely to increase as parental selection is further improved.

- Hybrinova have registered three varieties in France ('Hyno-Precia', 'Hyno-Rista' and 'Hyno-Prima') and are also hoping to register 'Hyno-Kalia' and 'Hyno-Seha' in France in 1996. Hyno-Precia has the same bread-making quality and earliness as Soissons and Sidéral, which are French milling wheats but yields 8 to 10% more. Hyno-Kalia and Hyno-Rista have better bread-making quality and Hyno-Rista combines this with good disease resistance (Gervais, 1996, pers. comm.). Hyno-Precia was grown in the UK at the 1995 Arable Farming Event and yielded 9.5 t/ha with fungicide application (7.7 t/ha without fungicide application) under trial conditions. In the 1995/96 season, yields were similar to Riband at SAC Edinburgh. Hybrinova's partner in the UK is New Farm Crops.

- Zeneca Seeds UK had two hybrids (Z 94-1-N and Z 94-3-N) in the National List trials (Year 1) in 1995. The varieties were developed in conjunction with Unisigma and Serasem. These did not progress onto year 2 as they achieved less than the required 90% varietal purity. The hybrids were of high enough quality for bread-making, but did not have a significant yield advantage over some conventional bread-making wheats, such as Rialto. Zeneca have other hybrid varieties in trials in France in 1996/97.

- Nickerson Seeds have a research association on hybrid wheat with Hybritech. They have crossing blocks in the UK, and are using UK and continental germplasm to produce hybrids, mainly for France, but also for the UK. However, the choice of parental lines is more limited as they need to be daylength-sensitive varieties, which are only available from areas such as the USA, the north-west Pacific region and the British Isles. Nickersons have a variety named Hybritech 95/125 in UK National List (Year 1) trials in 1996/97.

- The German and Dutch plant breeders, Nordsaat Saatzuchtgesellschaft MBH and Van der Have Royal Group, entered hybrid wheats into official trials in their respective countries in 1996/97.

- The US-based breeder, Pioneer, has a satellite hybrid-testing station in Northamptonshire. Hybrids from this programme may be available to UK growers in 5 - 6 years.

- An EU "EUREKA[1]" project is underway, entitled 'Research and development programme on hybrid wheats, EU749', with the aim of developing the necessary technology to allow production and marketing of hybrid wheat seeds. The programme aims to:

(i) improve understanding of the process which generates heterosis. This would allow more targeted selection of parents.

(ii) optimise the heterosis effect

(iii) study interactions between the germplasm and the hybridising agent with respect to: sterility level; response to the doses of the hybridising agent; pollen pressure and factors influencing success in hybrid wheat seed production, such as male/female ratios, width of parent bands and agronomic conditions, in order to breed a hybrid wheat with the desired genetic, agronomic and economic characteristics.

Partners in the project include French (The Cooperative de Pau - Hybritech), Belgian (Clovis Matton), German (Nordsaat Saatzuchtgesellschaft MBH), Spanish (Compania Navarra Productora de Semillas S.A.) and Dutch (Van der Have Royal Group) plant breeding companies.

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[1]EUREKA is an EU scheme which works with firms and research centres in the participating countries, assisting them in pooling their resources so as to be at the leading edge of technological development.

Information on the parents of the hybrid wheats developed by the above companies is confidential.

2.2.2 Other cereals

- Hybrid rye varieties are available commercially. About 60-70% of sales are hybrids and this share may increase. A CMS system has been used for their production. Marder, Amando and Luchs are German rye hybrids marketed by Perryfields Seeds, Pertwee and Nickerson Seeds, respectively.

- The EUREKA hybrid wheat project described above also includes some research on durum wheat, barley and triticale.

2.3 Benefits compared with conventionally bred varieties

2.3.1 Yield

Although hybrids may have a range of potential benefits relative to conventional varieties, increased yield is of most interest. There is little information on the performance of the new hybrids which are currently being trialled in the UK, Europe and elsewhere. However, much has been published on yields of hybrids since the 1960s. Some examples of levels of heterosis reported in the literature are summarised in Table 2.1.

Some of the work carried out on hybrids during the 1960s suggested large effects due to heterosis. For example, Fonseca and Patterson (1968) compared the yields of 21 F_1s from a 7 parent diallel cross with parental yields and found that the F_1s yielded up to 72% more than the higher parent. Other reports have referred to F_1 yields up to 84% more than the higher yielding parent (Briggle, 1963). While these studies give a good illustration of the phenomenon of heterosis, and generated interest in the

Table 2.1 Levels of heterosis reported in the literature

REFERENCE	LEVEL OF HETEROSIS FOR YIELD
Shebeski (1966)	14 hybrids ranged in yield from 28% below to 26% above the best parent. Three of the 14 showed a significant increase in yield over the best parent.
Briggle, Cox and Hayes (1967)	16.5 - 19.5% more grain than the higher yielding parent.
Livers & Heyne (1968)	The mean yield advantage was 31% over the best cultivar.
Wilson (1968)	The mean yield of hand-crossed hybrids was 18.7% greater than the best parent.
Gyawali *et al.* (1968)	The mean yield of hand-crossed hybrids was 24% better than the highest yielding parent in each cross.
Walton (1971)	All but two hybrids yielded between 15% and 88% more (per plant) than the highest yielding parent.
Bitzer & Fu (1972)	Seed produced by hand. Mean heterosis over the better parent was 9.7%. Three F_1s showed heterosis for grain yield of more than 25%.
Auriau (1973)	A small number of hybrids out-yielded their better parent significantly, but the mean gain was too low to be useful.
Varenitsa & Zimina (1976)	Hybrids yielded on average 12.3% more than the standard variety, 13.3% more than the better yielding parent.
Laabassi (1979)	Hybrids yielded between 21 and 29% more than the parents.
Pass & Smith (1983)	Mean hybrid performance was 15% above mean pure line performance. Best hybrid yielded 10% above the best pure line variety.
Edwards *et al.* (1984)	High parent heterosis of top hybrids was 18 - 32%. Standard heterosis was non-significant in the Elite test but approached 20% in the other 2 experiments.
Austin *et al.* (1985)	Mean hybrid grain yield was +10.8 % relative to mid-parent grain yield. The highest yielding hybrid line produced 3.4% more than the highest yielding breeding line and 19.6% more than the 4 varieties included in the trials which were on the Recommended List for 1986 (Fenman; Norman; Mercia and Aquila).

REFERENCE	LEVEL OF HETEROSIS FOR YIELD
Boland & Walcott (1985)	Hybrid yields varied from -0.8 to 19.2% relative to the highest yielding check cultivar at the site.
Rutz (1987)	The mean yield was 8 % higher than conventional varieties; maximum yielding hybrid was 19% higher than conventional varieties.
Brears, Hydon & Bingham (1988)	Average heterosis for yield was 6.8% with standard deviation of 4.6%.
Brears & Bingham (1989)	F_1 hybrids showed between 5 and 25% advantage of the higher yielding parent.
Morgan *et al.* (1989)	Mean heterosis for yield was 3.6 - 5.9% greater than highest yielding parents.
Kratochvil & Sammons (1990)	-11% to +14% relative to high yielding parent.
Perenzin *et al.* (1992)	Best parent heterosis for yield was 5 - 10%.
Oury *et al.* (1990)	Best parent heterosis for yield ranged from -7.4 to +17.4% in the 35 hybrids tested.
Oury *et al.* (1993)	Best parent heterosis for yield ranged from 3 to 4 % in the 29 hybrids tested.
Borghi and Perenzin (1994)	Mean standard heterosis over the best pure line cultivar (cv Eridano) was 3.3%.
Oury *et al.* (1994)	Best parent heterosis for yield ranged from -5.0 to +7.9% in the 33 hybrids tested.
Oury *et al.* (1995b)	Mean mid-parent heterosis for yield was 6.5%.
Harris (1996)	Hybrid yield advantage was approximately 5 to 12% over conventional varieties in Hybritech's farm trials in France.
Gervais (1996, pers. comm.) Thomson (1996, pers. comm)	Hybrinova's variety Hyno-Precia has a yield advantage of 8 to 12% compared with the highest yielding conventional bread-making varieties in trials in France and the UK.
Hoad (1996, pers. comm.)	Hyno-Precia yielded between -4 and -1% lower than Riband at 4 seed rates.
Dunn, 1996	Hyno-Precia yielded 108.9% of the average in its class. Domino yielded 115.2% in official French trials.

possibilities for hybrids at the time, they are obviously not an indication of the levels of heterosis which can be expected from commercially developed hybrids today. These studies are early reports of experimental work rather than the results of advanced breeding programmes. The seed was often produced by hand-crossing in very small trials, and heterosis levels are quoted in relation to the parents used in the cross, rather than the best performing varieties of the time. Crossing two low yielding parents may give very high levels of heterosis, but the yields from the F_1 may be lower than the best performing inbred varieties.

The majority of studies quoted in Table 2.1 indicate levels of heterosis in the range of 10 - 35%. These levels are more realistic in practical terms than the very high levels found by Briggle (1963) and Fonseca and Patterson (1968). The usefulness of these studies in indicating the likely yield of the new varieties currently being developed and trialled is limited, although the research published by Oury *et al.* (1990, 1993, 1994 and 1995a, b) was in conjunction with GIE Hybriblé, a group of plant breeders which included Hybrinova.

Of the work done prior to the development of the new commercial varieties, the best indication of the potential performance of hybrid cereals in the UK was from National List and Recommended List trials of hybrids which were carried out during the 1980s. Thirteen wheat hybrids were tested in England and Wales at this time, but only 2 progressed, in different seasons, to a third year of trial for possible recommendation[2] although neither was successful because of seed production problems. The hybrids showed levels of heterosis of between 2 and 14 % of the mean of three controls, but the highest yielding hybrid had a yield advantage of only 1 % over the highest yielding candidate line variety (Pickett, 1993). It has been argued, however, that the UK

[2]Suitability for National Listing was considered after two years of trial in England and Wales with further data supplied from Scotland. In England and Wales, the most promising varieties may proceed for a further year of trial with a view to addition to the Recommended List.

varietal assessment system is not suited to hybrids, which should be evaluated under lower input (especially reduced fungicide) systems.

A recent report stated that over the past 5 years, yields from hybrid wheat trials in the US have averaged more than double the normal yields (Kidd and Dvorak, 1995). However, greater benefits may be expected from hybrids in the US due to the lower initial yields obtained from conventional varieties. Reports of hybrids that have been tested in Europe indicate lower levels of heterosis. The varieties Sextant and Domino were reported to have yielded, on average, 0.5 t/ha and 1.0 t/ha more, respectively, than conventional varieties, in Hybritech's trials on farms in France (Harris, 1996). This level of yield advantage (approximately 5 to 12 %) is slightly higher than that of the highest yielding varieties trialled in the UK in the 1980s. Hybrinova's Hyno-Precia yielded 8 - 12 % more than the conventional varieties Soissons and Sidéral at their own trial sites in the UK and France (Gervais, 1996, pers. comm., Thomson, 1996, pers. comm.). In general, the level of heterosis in current wheat hybrids is relatively low compared to other crops, such as oilseed rape, but breeders are also concentrating on quality and disease resistance/tolerance and the combined effect of high yields and high quality would increase the profitability of hybrid wheats.

2.3.2 Quality

The development of high yielding, high quality wheat hybrids would be advantageous to the grower in terms of increased premium payments as this would help to offset some of the additional cost of the seed. In general, breeders have not had any difficulty in producing hybrids of satisfactory milling and baking quality (Wilson and Driscoll, 1983), although the overall quality of the hybrid is highly cross-specific (Edwards, 1987). In most cases where baking characteristics have been reported, the individual traits are intermediate between the two parents although a number of specific varietal crosses have shown heterosis for quality traits (Shebeski, 1966;

Wilson, 1968; Boland and Walcott, 1985; Edwards, 1987; Stroike, 1987). The characteristics influencing wheat quality are numerous and depend on the market class. Pickett (1993) provided a detailed review of experiments which have assessed various quality aspects. The general categories are listed below:

- Physical properties of the grain - test weight, packing efficiency and grain colour
- Endosperm texture - hard or soft
- Milling properties - speed of flour extraction and total amount of flour extracted
- Baking properties - dough strength (strong or weak), which is largely dependent on the protein content, and degree of water absorption
- Protein quality and quantity - protein quality is determined by the presence of the storage proteins, glutenins and gliadins, which give strength, elasticity, viscosity and extensibility to the dough
- α-amylase activity - an enzyme which reduces starch to sugar during germination. High activity, indicated by a low Hagberg Falling Number, produces a poor, sticky crumb structure of loaf

Most of the quality characteristics are largely under genetic and, therefore, varietal influence but environmental conditions may accentuate or depress the heritable effects. For example, quantity of protein is determined genetically but is subject to strong environmental influence (e.g. application of nitrogen) whereas quality of protein is primarily genetically controlled but is also subject to a smaller degree of environmental influence (Edwards, 1987). Furthermore, high levels of α-amylase activity are caused by pre-harvest sprouting but varieties with good resistance to sprouting are available.

The isolation of parental lines with high quality characteristics and good combining ability is necessary. Not all varieties are able to convey their quality traits to their offspring (Shebeski, 1966, Oury *et al.*, 1995a). In order to benefit from the combination of dominant alleles in a hybrid, the desirable traits must be dominant or at least partially dominant but, unfortunately, this is not always the case (Pickett, 1993). Therefore, obtaining high yielding, high quality hybrid wheats will be dependent on the careful selection of parental lines, but does not appear to be a major problem in hybrid wheat development (Shebeski, 1966; Wilson, 1968; Edwards, 1987; Perenzin *et al.* 1992; Pickett, 1993; Borghi and Perenzin, 1994; Oury *et al.*, 1994; Laudoyer, pers. comm. 1996). Hybrinova already have hybrid wheats of bread-making quality on the market in France and Hybritech are in the process of registering bread-making varieties. Therefore, both Hybrinova and Hybritech have isolated lines with good combining ability for quality.

There is no indication that hybrids will be of greater quality than conventional varieties. Bread-making wheats tend to be lower yielding than feed wheats. Hybrids may allow higher yields of bread-making wheats and this would offset some of the higher seed cost. However, advances are also being made in the yields of conventional bread-making varieties, such as Rialto, and bread-making premiums are currently low at only £5 - £10/tonne.

2.3.3 Disease resistance

Theoretically, where genes for disease resistance are dominant, the hybrid system can be used to combine resistance of genes which are difficult or impossible to combine and fix using conventional breeding. For example, varieties with race-specific and others with non-race specific genes could be crossed to provide a broader genetic base to disease resistance (Done, 1973; Brears and Bingham, 1989). Furthermore, the incorporation of resistance into a hybrid could be achieved more quickly and with a greater degree of flexibility (Done, 1973; Pickett, 1993). A high level of expression of disease resistance in a hybrid requires the resistance genes to be almost or completely dominant (Done, 1973). Most major genes for resistance to yellow-rust (*Puccinia striiformis*) are dominant, although some are recessive (Brears and Bingham, 1989). In practice, however, only a few hybrids have shown benefits in disease resistance. Shebeski (1966) showed that one out of four resistant or moderately-resistant varieties of wheat conveyed their resistance to the F_1 generation. Done (1973) found that one out of four hybrids of wheat exhibited better disease resistance to yellow-rust when compared with the parents. However, this was with two susceptible parents, both with a resistance rating of 8 (scale of 1-10, 10 = fully susceptible). Where more resistant parents were crossed (ratings 1-4), the F_1 hybrid rating was intermediate between the two parents. This was also true when powdery-mildew (*Erysiphe graminis*) resistance was assessed in barley hybrids.

In general, the hybrids tested have not achieved the theoretical potential for greater disease resistance (Pickett, 1993). The recently developed French hybrid wheat, Hyno-Precia, was susceptible to powdery mildew and yellow-rust in the UK, although it still yielded 7.7 t/ha with high levels of disease infestation. The hybrid variety, Hyno-Rista, however, has greater disease resistance than Hyno-Precia. Hybrids, in general, are more tolerant to disease attack, even if they are not more resistant.

The development of hybrids with improved disease resistance would, as with improved quality, help to offset some of the additional seed costs. This would be achieved by a lowering of variable costs as a result of reduced fungicide inputs. There would also be environmental benefits from reduced pesticide use and hybrids may, therefore, be more suitable to lower input systems.

CHAPTER 3 CONSEQUENCES TO GROWERS

3.1 Opportunity for adjusting husbandry for lower plant populations

The problem of the high cost of hybrid seed was considered to be a potential limiting factor in the acceptance of hybrid wheat by growers from the early days of hybrid research (Briggle, Cox and Hayes, 1967; Briggle, Peterson and Hayes, 1967). Seed cost may have been perceived as less of a problem for hybrid maize and sorghum because seed rates are lower than for wheat and, in addition, field pollination of male sterile wheat has been less successful than the field pollination of maize or sorghum (Briggle, Peterson and Hayes, 1967).

The high cost of hybrid wheat seed has led to interest in the possibility of sowing hybrid wheat at lower seed rates than conventional inbred varieties.

3.1.1 Response of cereal species to seed rate

Seed rate is not a major determinant of cereal yield within the levels conventionally used (Holliday, 1960), due to the ability of cereal plants to compensate with differing levels of tillering. Generally, the yield components (ears/m^2, grains/ear and individual grain weight) tend to buffer the yield of wheat and barley in the UK (Hay and Walker, 1989). However, plant densities vary by variety according to thousand grain weight, grain shape and other seed characteristics which affect the flow from the drill hopper to the ground. Furthermore, varieties with different growth requirements may have different optimum density requirements. The established plant density from a given seed rate can vary from year to year and site to site depending on various factors such as thousand grain weight, percentage laboratory seed germination and 'field factors' which include soil temperature, soil moisture content, pest and disease damage and seed-bed characteristics (Bleasdale, 1982). Sowing date has a strong influence on many of these factors.

Prior to 1960, a large number of seed rate trials with wheat and barley were conducted. Trials were reported by Boyd (1952), Beesley and Bullen (1956), Jackson and Page (1957), Harvey *et al.* (1958), Harvey and Shepherd (1958), Forbes (1960), Holliday (1960), Shepherd (1960) and Mundy and McClean (1965).

Hudson (1941) fitted a quadratic regression to the relationship and, Holliday (1960) showed that the response curve of seed rate with yield was parabolic or asymptotic (Figure 3.1).

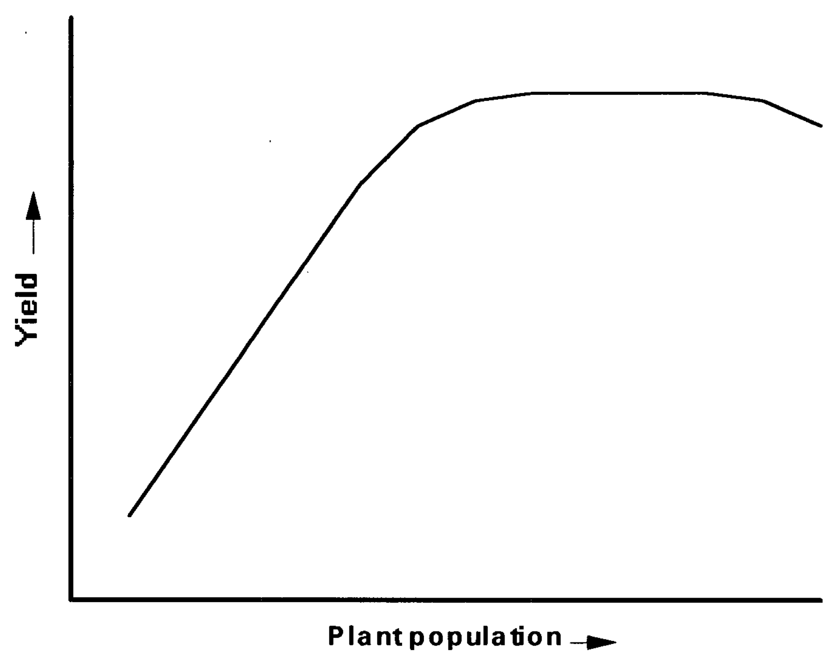

Figure 3.1 Theoretical relationship between crop yield and plant population

The plant population at which the yield plateau occurs depends on factors such as the yield capacity of the variety and nitrogen supply (Hay and Walker, 1989). The farmer must drill enough seed to be on the yield plateau, but if the plant population is too great then the variable costs of the seed are increased with no corresponding increase in yield. The grower is, therefore, engaged in risk management (Lock, 1993).

The current recommendations for seed rates are within the range of:

Winter wheat 150-250 kg/ha (target plant population of 250 - 300 plants/m^2)

Spring wheat 170-220 kg/ha (target plant population of 250 - 400 plants/m^2)

Winter barley 150-180 kg/ha (target plant population of 250 - 300 plants/m^2)

Spring barley 125-180 kg/ha (target plant population of 250 - 300 plants/m^2)

(Wiseman *et al.*, 1993)

More recent investigations on the effects of seed rates on yield are limited. Data from a number of experiments investigating the effects of plant population and/or seed rate on winter wheat yield were plotted in Figure 3.2 (pre-1970 data) and Figure 3.3 (post-1970 data) (Boyd, 1952, Beesley and Bullen, 1956, Jackson and Page, 1957, Harvey *et al.,* 1958, Harvey and Shepherd, 1958, Holliday, 1960, Rule and Fiddian, 1974, Evans, 1977, McClaren, 1981, Lock, 1993, Anon 1996, plus agronomic experiments conducted at SAC Aberdeen from 1985-89 - Taylor, 1996, pers. comm.). In experiments where the actual plant populations were not given, the plant populations were estimated from the seed rate or the seeds sown per m^2 by using a thousand grain weight of 48 g and/or a field establishment of 75%. Due to these assumptions, the plant populations are approximations only. Quadratic curves are fitted to the data for individual experiments as comparison between experiments would not be valid due to variations in variety, nitrogen supply, soil type, time of sowing, climatic conditions during sowing and growth, inter-row and within-row spacing and pest and disease attack. The curves fitted generally show no increase or decrease in yield over the populations tested, indicating that there is a wide range of plant populations that can be used to achieve similar yields.

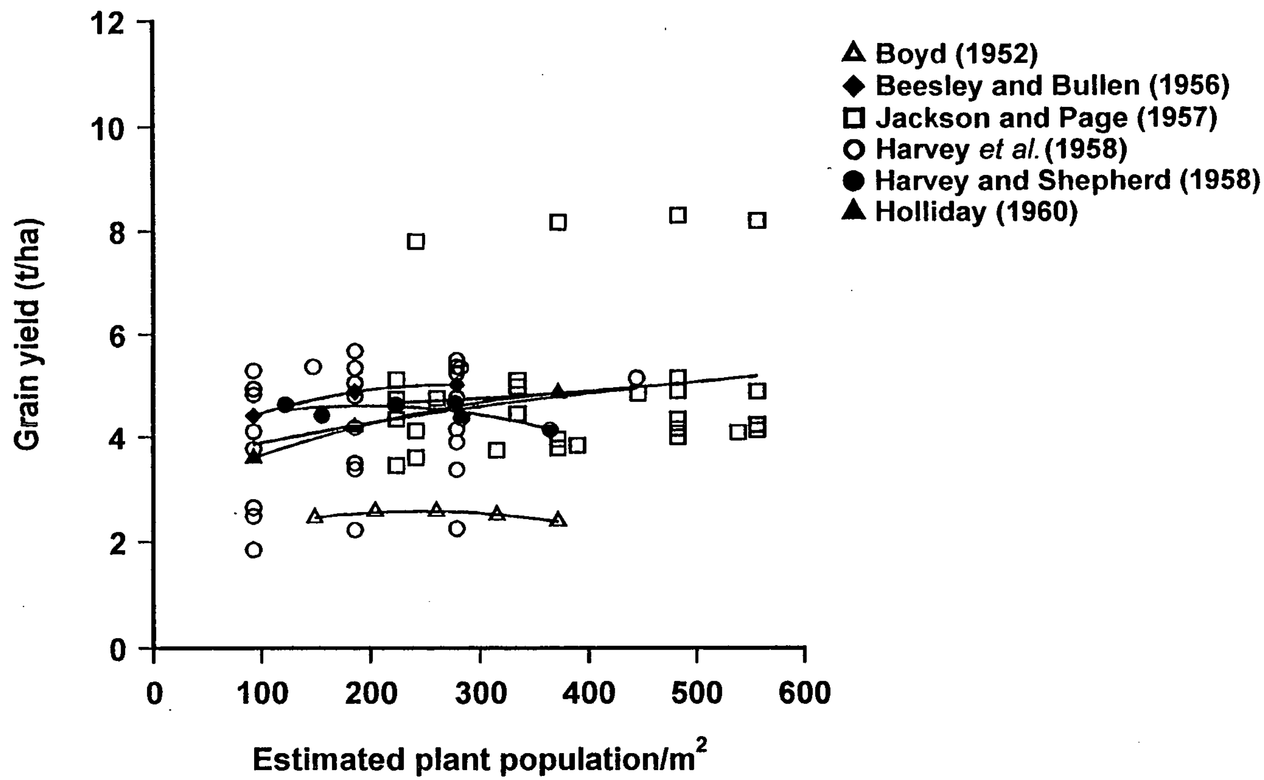

Figure 3.2 Relationship between estimated plant population and grain yield for experiments conducted between 1990 and 1970

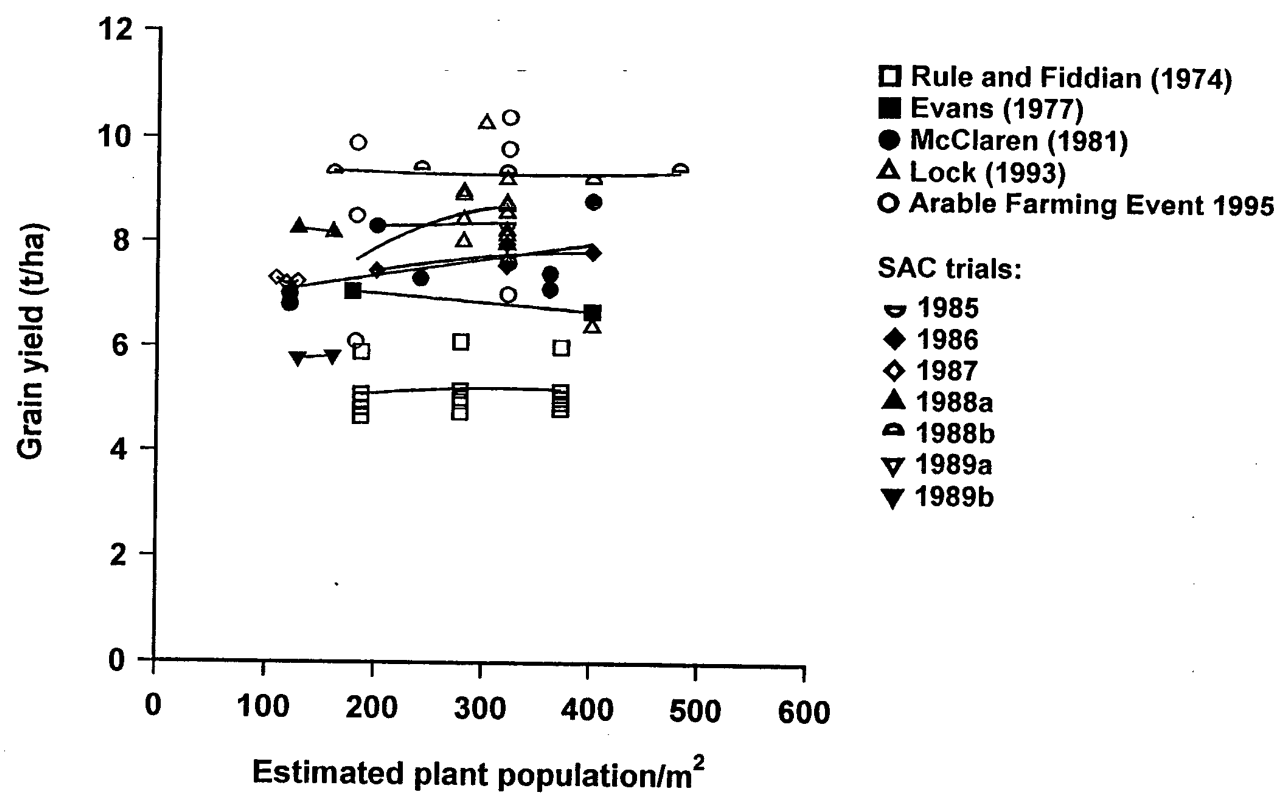

Figure 3.3 Relationship between estimated plant population and grain yield for experiments conducted post-1970

Trials were conducted at SAC Edinburgh in 1996 to compare Hybrinova's Hyno-Precia with Riband at a range of seed rates. The results of this trial are shown in Table 3.2 but should be treated with caution as the data are only from one year's trial. The data, however, indicates that Hyno-Precia yields similarly to or less than Riband. Hyno-Precia is a French bread-making variety, however, and should, perhaps, be compared with a similar variety such as Soissons, as well as the high yielding feed varieties. It should be noted that the high trial yields cannot be extrapolated to field-scale production.

Table 3.1. Mean yields (t/ha) for Riband and Hyno-Precia grown at a range of seed rates (seeds/m^2).

Seed rate	Riband	Hyno-Precia	Mean sowing rate yield
134	11.51	11.08	11.30
200	11.77	11.67	11.72
300	12.07	11.61	11.84
450	11.75	11.54	11.64
Mean variety yield	11.78	11.47	11.62

$LSD_{(5\%)}$ for variety means = 0.33. $LSD_{(5\%)}$ for seed rate means = 0.46.

Source: Hoad (1996, pers. comm.)

3.1.2 Effect of UK weather, soil type and seed vigour on seed rate

There are a number of factors which will influence the seed rate used. Wiseman *et al.* (1993) identified these as:

- seedbed conditions - higher rates for dry, cloddy and stony soils;
- weather and time of sowing - higher for later sowings (could be 30 - 50% higher in November than in September);

- target plant population - a target plant population of 250 - 350 plants/m^2 in the autumn could be reduced to 150 - 300 plants/m^2 in the spring. The target could be as low as 100 plants/m^2 under optimal conditions;

- seed vigour - this will affect the percentage establishment.

Therefore, by knowing the thousand grain weight (TGW) and by taking into account the factors above, the seed rate can be calculated as:

$$\text{Seed rate (kg / ha)} = \frac{\text{no. plants / m}^2 \times \text{TGW}}{\text{\% establishment expected}}$$

The risks involved with lowering the seed rate are greater in certain areas of the country as opposed to others. The amount of time during the year that the land can be worked by machinery (or access days) decrease with increasing rainfall and decreasing evaporation from the soil (affected mainly by temperature, wind and humidity). Fields with heavy clay soil types also have fewer access days than coarser soils with free-drainage. In high risk situations, a greater seed rate is used. Examples of areas where cereals are grown are given in Table 3.2 with corresponding weather and soil factors for the regions. The areas are precisely defined in Smith (1984) for England and in Francis (1981) for Scotland.

The variation in time from return to field capacity to end of field capacity, and the different rainfall levels, indicate the different risks that would be associated with reducing seed rates throughout the UK. In general, areas in the north (due to higher rainfall and colder soil temperatures), west (due to higher rainfall) and the south-east of the UK (due to lack of rainfall) may be the highest risk areas, but the risks also depend on the soil types of the individual fields. Soil factors and other reasons for yield variation of wheat and barley in Britain were reviewed by Gales (1983). There is a need for the individual to assess the risk of reduced seed rates under different sowing conditions.

Table 3.2: The variation in rainfall and duration of field capacity for selected regions

Region No. (Francis, 1981; Smith, 1984)	Area	Total annual rainfall (mm)	Mean date of return to field capacity	Mean date of end of field capacity
29	Suffolk & NW Essex	598	Early December	Late March
42	NE Cornwall	1241	Mid-September	Mid-May
6	Kincardineshire Angus & Perthshire	900	Mid-October	Early March
17	Parts of Dumfrieshire	1070	Early October	Early March

3.1.3 Implication for hybrids

The potential for using reduced seed rates with hybrid seed, has been addressed in a number of studies from the 1960s and '70s (e.g. Briggle, Cox and Hayes, 1967; Briggle, Peterson and Hayes, 1967; Zeven, 1972; Sage, 1973 and Barabás *et al.*, 1973; Hoad, 1996 pers. comm.) but there is no clear agreement between workers on whether the use of low seed rates for hybrids is advisable. Pickett (1993) suggested that the reason for lack of agreement between workers with respect to seed rates may be due to variation in environment and the degree of competitiveness of the genotypes tested. In addition, it should be noted that many of the studies used methods of assessment which may not reflect results which could be obtained on a field scale.

The possibility of reduced seed rates with hybrids relies on increased vigour of the seed at germination and/or increased vigour during growth. Increased vigour at germination may result in increased percentage plant establishment, whereas increased vigour during growth would compensate for the lower plant population by increased tillering, grains per ear or weight of grain. In effect, the yield response plateau must level out at a lower plant population than with conventional varieties or the hybrid yield response curve must show a yield advantage at all plant populations in order to enable a reduced seed rate.

Hybritech recommend that their hybrids are sown with the seed rate reduced by 20 - 30 % (200 - 300 seeds/m^2) or at 120 kg/ha compared to a typical seed rate of 170 kg/ha. Hybrinova recommend a rate of 150 - 200 seeds/m^2 compared to the standard rate in France of 250 - 400 seeds/m^2. However, further research in the UK on the response of individual commercial hybrids to reduced seed rates in comparison with conventional varieties is necessary before any recommendations can be made.

3.2 Possibility of using F_2 or F_3 seed

A number of studies have examined the possibility of using F_2 hybrid or even F_3 seed. The obvious advantage of this for the growers would be that they could use home-saved seed, thus reducing the cost of growing hybrids.

Brears and Bingham (1989) compared the yields of F_1 hybrids, their parents and F_2 populations derived from them. The F_2s showed a yield advantage of between 2 and 6% in comparison to the higher yielding parent, in comparison to an advantage of between 5 and 12% for the F_1. The authors considered that the levels of heterosis shown by the F_2 hybrids were commercially marginal. Other studies have found no significant increase in yield of F_2 plants over the parents (Bitzer and Fu, 1972; Briggle, Cox and Hayes, 1967; Briggle, Peterson and Hayes, 1967). In practice, the performance of F_2 populations is likely to vary depending on the variety, and evaluations of the performance of F_2 populations of commercially released varieties would be required before firm conclusions could be drawn. However, there is little evidence to suggest that F_2 generations will yield more than the best conventional varieties, and they may yield less. Problems are also likely to occur with respect to the uniformity of the crop. Additionally, under EU Regulation No. 2100/94 Article 14.1, a farmer would infringe plant breeders' rights by home-saving seed of 'hybrid or synthetic' varieties. This will be the case under UK, as well as European law, if UPOV 91 is passed by the UK Parliament.

CHAPTER 4 THE FINANCIAL FEASIBILITY OF HYBRID CEREAL PRODUCTION

4.1 Introduction

Hybrid seed will be more expensive than conventional seed. The French hybrid wheats are currently being marketed at 2 - 3 times the cost of conventional seed. Hybritech are selling the seed at the price of approximately 900 FF (French Francs)/ha ≡ £120/ha compared to the cost of approximately 425 FF (£57/ha) for conventional seed (the per hectare price includes the reduction in seed rate for hybrid seed outlined in Section 3.1.3). The price of Hyno-Precia from Hybrinova is between 750 and 950 FF/ha (365 FF for 750 000 seeds) and is therefore comparable to Hybritech's price. The increased cost is a reflection of the higher production costs associated with the processes involved in male sterilisation and cross-fertilisation.

- Labour costs. Breeders will need to employ skilled staff to drill, spray and monitor crossing blocks with accuracy.

- Wheat should not have been grown on land used for hybrid seed production during the preceding season. Volunteer plants arising from any seed shed are likely to contaminate the genotype. Growers will expect to be paid a premium to produce hybrid wheat seed on land free from potentially contaminating volunteer seeds of cereal species.

- Systems for producing hybrid seed require both male and female parents to be present in the field. The yield of hybrid seed, therefore, will not exceed 67% of the field's normal grain production, even without an allowance for lower seed set and may be as low as 40% of the field. A quantity of seed from the male parent will be produced in the hybrid seed production field. This may be sold at the market price for conventional grain which may help offset the costs of the lower yield/ha of hybrid seed. Currently, the male and female plants are grown in separate blocks in the field. In hybrid oilseed rape production (PGS SeedLink™ System), the plants can be grown as a mixture, reducing the proportion of male pollinators required as the female plants have been genetically modified for herbicide tolerance allowing the male pollinators to be sprayed off prior to harvest. Similar systems in wheat are being investigated (Angus, 1996, pers. comm.), but using alternative methods to herbicide resistance for removing the male pollinators.

- It is unlikely that the female parent will, even in favourable seasons, yield as highly as a self-fertile variety. This can be attributed to cross-fertilisation difficulties; Hybritech, however, currently claim to achieve a minimum of 70% seed set (Laudoyer, 1996, pers. comm.).

Taking all these factors into account, the yield of hybrid seed is given by the following equation (Pickett, 1993):

$$\text{Yield of } F_1 \text{ hybrid seed} = a \times b/100 \times c/100$$

where a = normal yield of wheat

b = % area of female parent

c = % seed set

Therefore, a crop of hybrid seed grown on land normally yielding 7.5 t/ha of grain under conventional cropping might produce the following quantity of hybrid seed in a favourable season.

$$\text{Yield of } F_1 \text{ hybrid seed} = 7.5 \times 67/100 \times 70/100 = 3.52 \text{ t/ha}$$

The level of success of the cross-fertilisation has a direct effect on seed yield and the cost of hybrid seed; the higher the percentage seed set and the lower the male proportion in the field, the lower the cost of the seed will be. There will be a considerable risk of lower yields than shown above, although significant improvements have been made in the seed production process over the last ten years (Angus, 1996, pers. comm.). Unsatisfactory cross-fertilisation is also likely to result in variable seed quality. Male sterilisation will add an additional cost to hybrid seed and is also likely to present a further risk since any impairment of female fertility will reduce seed yield and any male fertility will lead to a reduction in trueness to hybrid variety. Therefore, production of one tonne of hybrid seed will require a larger area than that needed to produce one tonne of conventional seed. Lucken (1986) calculated that the area required would be 2.3 times the area needed for inbred varieties, assuming a 2:1 female to male ratio in the field and a 65% seed set.

For farmers, the viability of growing hybrid cereals depends on the hybrids producing high enough yields to compensate for the higher cost of the seed. The level of heterosis required to pay for hybrid seed depends, not only on the cost of the hybrid seed, but also on the yield potential of the land sown with hybrid seed. Where the yield potential is low, higher heterosis will be required to make growing hybrids worthwhile.

Any difference between the price per tonne received for the grain produced by the farmer from hybrid seed and that received for a conventional crop will also affect the profitability of hybrids.

A number of workers have published tables for calculating the level of heterosis required to justify hybrid wheat. These are based on simple calculations indicating the increase in yield needed for a range of costings of seed under different yield expectations. There is considerable variation in the levels of heterosis that workers have estimated are required to pay for the extra cost of hybrid seed. Some examples are given in Table 4.1, but, as mentioned above, the level of heterosis required is dependent on several factors which can vary with site and season. Factors affecting total income include hybrid yield advantage, average yield of the farm using conventional varieties, hybrid quality advantage and the grain price/premium for bread-making quality. Factors affecting the influence of hybrids on a grower's variable costs include hybrid seed cost and the price of conventional seed/use of home-saved seed, plus any differences in seed rates between hybrid and conventional varieties and any hybrid disease resistance advantage.

Table 4.1: Estimates of yield heterosis required to compensate for additional cost of hybrid seed

Country	Author	Heterosis required
USA	Patterson and Bitzer (1966)	15 - 30 %
Bulgaria	Popov *et al.* (1973)	7 - 8 %
UK	Simmonds (1979)	18 - 28 %
UK	Foster (1981)	5 - 7 %
E. Germany	Merfert *et al.* (1987)	5 %
UK	Brears and Bingham (1989)	13 %
UK	Pickett (1993)	6 - 34 %

The number of variable factors affecting the profitability of hybrid wheat make it impossible to make generalisations about the likely benefits or problems that may be associated with the growing of new hybrids. Therefore, three simple spreadsheet models (designed for Microsoft Excel 4.0) have been produced. Model 1 (Boyce, 1993, pers. comm.) is designed to estimate the cost of hybrid seed. Model 2 (developed by SAC) calculates the advantages in hybrid yield, quality and/or disease resistance required to compensate for the additional cost of hybrid seed, under different scenarios. Model 3 (Boyce, 1993, pers. comm.) estimates the gross margin attained from the use of hybrid seed under different scenarios and provides a cost:benefit analysis.

The models allow quick and easy evaluation of hybrid feasibility enabling several factors to be varied (e.g. cost of hybrid seed, seed rates, premium for hybrid wheat, use of home-saved seed, decreased variable costs for increased disease resistance). The models also allow an individual farmer to input his/her own values for the factors, enabling assessment of viability on individual farms.

For each spreadsheet model there is an example spreadsheet and a spreadsheet with the formulae for the calculations. The spreadsheet formulae are designed to be copied on to Microsoft Excel spreadsheets, but could easily be modified to work on most spreadsheet packages.

4.2 Model 1 - Estimation of hybrid seed cost

The likely cost of hybrid seed is estimated in Model 1 (pages 48 and 49), the spreadsheet is designed for Microsoft Excel. The factors that can be varied are described below:

1. Inbred yield - 8 t/ha. Set as an achievable base yield.

2. Grain price - £100/t - no quality premium.

3. Seed premium - £15/t.

4/5. Male/female ratio in the seed production field (60%:40%). 40% female is regarded as the practical limit in 10-20 ha fields taking account of irregular field shapes and experience on cross-pollination.

6. Hybrid seed set - 70%. A target level of seed set.

Model 1 - Spreadsheet Formulas

	A	F	G
41			
42	**Cost of seed calculation**		
43			
44	Conventional seed, Growers variable costs	£/ha	=(F9*F12)+F14+F15
45	Conventional seed growers income	£/ha	=(F4+F5)*(F3)
46	Hybrid seed, Growers variable costs	£/ha	=(F10*F13*F7)+(F11*F13*F6)+SUM(F14:F17)
47	Income on pollinator	£/ha	=F6*F4*H3
48			
49	Margin equalisation	£/ha	=G45-G44-G47+G46
50	Margin equalisation	£/t	=G49/(F7*F8*G3)
51	Hybrid growers margin	£/t	=G50+F23
52	Hybrid seed cost , as grown	£/t	=G51+(SUM(F18:F21)+F26+(F24*F25*F7))/(F7*F8*G3)
53	Income on screenings/t hybrid seed	£/t	=(F29*F4)/100
54			
55	Hybrid seed, bagged cost to merchant	£/t	=((G52+F27+F28)/((100-F29)/100))-((F29*F4)/100)+F30+F31+F3
56	CHA cost/t cleaned seed	£/t	=((F25*F24*F7)/(F7*F8*G3))/((100-F29)/100)
57	Merchants margin	£/t	=((G55*100)/(100-F33))-G55
58	Cost of seed to wholesaler	£/t	=((G55*100)/(100-F33))+((F24*F34*F7)/(F7*F8*G3))+F35+F36
59	Cost of seed to retailer	£/t	=(G58*100)/(100-F37)
60	Cost of seed to farmer	£/t	=(G59*100)/(100-F38)

NB Columns B to E are not shown

Model 1 - Example spreadsheet

	A	B	C	D	E	F	G	H
1	**Model 1 - Estimate of hybrid seed cost**							
2	**Assumptions**					Conventional	Female	Male
3	Inbred yield				t/ha	8	8	7
4	Grain price				£/t	100		
5	Seed premium				£/t	15		
6	Male proportion of the field				%	0.6		
7	Female proportion of the field				%	0.4		
8	Hybrid seed set				%	0.7		
9	Cost of conventional parent seed				£/t	500		
10	Cost of female parent seed				£/t	700		
11	Cost of male parent seed				£/t	700		
12	Drilling rate conventional				t/ha	0.15		
13	Drilling rate hybrid				t/ha	0.15		
14	Standard spray cost				£/t	100		
15	Fertiliser				£/t	97		
16	Hybrid production extra work				£/t	45		
17	isolation cost				£/ha	0	0	
18	Hybrid compensation - rotation				£/ha	80		
19	Hybrid crop inspection				£/ha	24		
20	Hybrid administration				£/ha	17		
21	Acreage fee				£/ha	7		
22	Hybrid growers margin				£/ha			
23	Hybrid growers incentive				£/t	10		
24	CHA rate				kg/ha	1		
25	CHA cost				£/kg	250		
26	Cost of CHA application				£/ha	25		
27	Haulage in				£/t	7		
28	Processing costs				£/t	27		
29	Processing loss				%	14.5		
30	Hybrid certification				£/t	3		
31	Seed dressing				£/t	3		
32	Sack labels				£/t	7		
33	Merchants margin				%	15		
34	Margin on CHA				£/kg	0		
35	Hybrid royalty				£/t	60		
36	Levy				£/t	30		
37	Wholesale margin				%	0		
38	Retail margin				%	12.5		
39								
40								
41								
42	COST OF SEED CALCULATION							
43								
44	Conventional seed, Growers variable costs					£/ha	272	
45	Conventional seed growers income					£/ha	920	
46	Hybrid seed, Growers variable costs					£/ha	347	
47	Income on pollinator					£/ha	420	
48								
49	Margin equalisation					£/ha	575	
50	Margin equalisation					£/t	257	
51	Hybrid growers margin					£/t	267	
52	Hybrid seed cost , as grown					£/t	380	
53	Income on screenings/t hybrid seed					£/t	14.5	
54								
55	Hybrid seed, bagged cost to merchant					£/t	482	
56	CHA cost/t cleaned seed					£/t	52	
57	Merchants margin					£/t	85	
58	Cost of seed to wholesaler					£/t	657	
59	Cost of seed to retailer					£/t	657	
60	Cost of seed to farmer					£/t	751	

7. Cost of conventional parent seed - £500/t. This will be set as part of the seed production contract.

8/9. Cost of hybrid parent seed - £700/t. Represents basic seed price.

10/11. Drilling rates - 150 kg/ha.

12. Spray cost - £97/ha (Chadwick, 1995).

13. Fertiliser cost - £100/ha (Chadwick, 1995).

14. Hybrid seed production, extra work - £45/ha. This assumes extra farming operations resulting from the strip production of hybrid seed, e.g. drilling spraying and harvesting.

15. Isolation cost - £0/ha. Included to compensate for modification to rotation in neighbouring fields to ensure no contamination with stray wheat pollen. Currently set at zero. Any isolation provided by male in the headlands and field boundaries is accounted for in the male/female ratio.

16. Hybrid compensation - rotation - £80/ha. Somewhat arbitrary figure for not being able to produce wheat the previous year.

17. Hybrid crop inspection - £24/ha. Allows for three extra visits to be made to the seed production field.

18. Hybrid administration - £17/ha. Allows for extra work involved in finding farms for seed production and in administering contracts.

19. Acreage fee - £7/ha. Entry fee for crop certification.

20. Proposed hybrid seed grower's margin.

21. Hybrid grower's incentive - £10/t. Allows for extra incentive over and above conventional seed production to be included in the calculation.

22. Chemical hybridising agent (CHA) application rate - 1 kg/ha. Arbitrary rate, to be provided by manufacturer.

23. CHA cost £250/ha. Arbitrary cost, to be provided by manufacturer.

24. Cost of CHA application - £25/ha. Cost will depend on whether CHA is applied by farmer or contractor. Allowance must be made for the absolute requirement for precise application.

25. Haulage In - £7/t. Figure from seed merchant.

26. Processing cost - £27/t. Figure from seed merchant.

27. Processing loss - 14.5 % (wheat). Allows for dust and moisture.

28. Hybrid certification/seed testing - £3/t.

29. Cost of seed dressing - £3/t. Hybrid seed may justify more expensive treatment.

30. Sacks and labels - £7/t.

31. Merchant's margin - 15%.

32. Margin on CHA - £0/t. Included to permit a separate entry but currently included in the CHA price/kg.

33. Hybrid royalty - £60/t. It is assumed that hybrid royalty will be at least equal to the C1 royalty and the royalty on parent seed is included in the parent seed price.

34. Hybrid levy - £30/t. Permits separate entry for an increased royalty for special situations.

35. Wholesaler's margin - 0 %. This step in the chain may, or may not, be included.

36. Retail margin - 12.5 %. The retailer may require around £100/t.

The estimate of seed price under the current setting is approximately £750/t. However, this value is dependent on a number of arbitrary values and therefore, can only be viewed as an approximate guide. The spreadsheet allows the refinement and re-evaluation of the cost as new information emerges. It also facilitates the estimate of changes in seed costs with changes in factors such as percentage seed set, i.e. a certain degree of sensitivity analysis for seed cost.

4.3 Model 2 - Estimation of hybrid yield advantage required to compensate for additional seed cost

Model 2 (pages 53 and 54) can be typed in to a Microsoft Excel spreadsheet. This model allows the input of various factors (a) to (i):

a. Average inbred yield achieved by individual farmer (t/ha).

b. Cost of conventional seed (grain price if home-saved) (£/t).

c. Cost of hybrid seed (£/t).

d. Conventional grain price (£/t).

e. Hybrid grain price (£/t) - allowing increased quality.

f. Conventional drilling rate (kg/ha).

g. Hybrid drilling rate (kg/ha).

h. Conventional variable costs excluding seed costs (i.e. sprays, fertilisers, other).

i. Hybrid variable costs excluding seed costs - allows for reduced or increased inputs with hybrid production.

The factors (j) to (p) and (r) are calculated automatically. The percentage hybrid yield advantage (q) can be inputted, or the increased income required before growing hybrid crops (s) can be inputted and the instructions followed in column (I). This will then calculate the percentage hybrid advantage required. If (s) is set to zero, then the hybrid advantage required to break even will be calculated. This calculation has been performed for a number of scenarios using winter wheat as an example (Figures 4.1 to 4.4).

Model 2 - Spreadsheet Formulas

	A	B	G
1	a.	Average yield (t/ha)	7
2	b.	Cost of conv seed (£/t)	220
3	c.	Cost of hybrid seed (£/t)	700
4	d.	Grain price for conventional (£/t)	100
5	e.	Grain price for hybrid (£/t)	100
6	f.	Conventional drilling rate (kg/ha)	180
7	g.	Hybrid drilling rate (kg/ha)	180
8	h.	Conventional variable costs (excl. seed) (£/ha)	200
9	i.	Hybrid variable costs (excl. seed) (£/ha)	200
10			
11	j.	Additional yield (t/ha)	=G1*(G20/100)
12	k.	Additional income from increased yield (£/ha)	=G14-G13
13	l.	Conventional income	=G1*G4
14	m.	Hybrid income	=G5*((G1*(100+G20))/100)
15	n.	Increased cost for seed (£/ha)	=(G3*(G7/1000))-(G2*(G6/1000))
16	o.	Change in variable costs (excl. seed) (£/ha)	=G8-G9
17	p.	Change in variable costs (incl. seed) (£/ha)	=G15+G16
18			
19			
20	q.	% Hybrid yield advantage required	12.3428571428571
21	r.	Yield required from hybrid (t/ha)	=G1*(1+(G20/100))
22			
23	s.	Increased income (£/ha)	=$G12-$G17
24			

NB Columns C to F are not shown

Model 2 - Example spreadsheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	a.	Average yield (t/ha)					7.0		Instructions:					
2	b.	Cost of conventional seed (£/t)					220		1. Type in values for a to g. (Type over example values)					
3	c.	Cost of hybrid seed (£/t)					700		2. Click on Formula, then Goal Seek					
4	d.	Grain price for conventional (£/t)					100		3. For "Set cell", type G23					
5	e.	Grain price for hybrid (£/t)					100		4. For "To value", type 0 or additional income requried					
6	f.	Conventional drilling rate (kg/ha)					180		before growing hybrid cereals (£/ha)					
7	g.	Hybrid drilling rate (kg/ha)					180		5. For "By changing cell", type G20					
8	h.	Conventional variable costs (excl. seed) (£/ha)					173		6. Click on OK					
9	i.	Hybrid variable costs (excl. seed) (£/ha)					173							
10														
11	j.	Additional yield (t/ha)					0.864							
12	k.	Additional income from increased yield (£/ha)					86.4							
13	l.	Conventional income					700							
14	m.	Hybrid income					786.4							
15	n.	Increased cost for seed (£/ha)					86.4							
16	o.	Change in variable costs (excl. seed) (£/ha)					0							
17	p.	Change in variable costs (incl. seed) (£/ha)					86.4							
18														
19														
20	q.	% Hybrid yield advantage required					12.3							
21	r.	Yield required from hybrid (t/ha)					7.9							
22														
23	s.	Increased income (£/ha)					0							
24														

4.3.1 Scenario 1 - Variation in the cost of hybrid seed

Scenario 1 (Figure 4.1) varies the cost of hybrid seed against the conventional seed price set at £260/t (Chadwick, 1995). The four lines refer to 1½, 2, 2½ and 3 times the cost of conventional seed, although the cost of the hybrid seed in France is approximately equivalent to £1000/t or 2 -3 times that of conventional seed. Other factors and prices/costs are listed below and kept constant:

Grain price for conventional and hybrids = £100/t (Chadwick, 1995).

Seed rate for conventional and hybrids = 180 kg/ha.

Conventional and hybrid variable costs (excluding seed costs) = £200/ha (Chadwick, 1995).

The yield advantage required to break-even decreases with increasing average yield achieved with conventional crops and varies between 19% with a cost of 3 times the conventional seed price and 4 t/ha average yield and 2% for 1½ times the conventional seed cost and 11 t/ha yield. Lower yielding farms require a higher yield advantage before adopting hybrid production.

4.3.2 Scenario 2 - Variation in seed rate with hybrid seed

Scenario 2 (Figure 4.2) varies the hybrid seed rate used (180, 160, 140, 120 and 100 kg/ha). Other factors:

Hybrid seed cost is set at 3 times the price of conventional seed (i.e. £260/t x 3 = £780/t).

Grain price for conventional and hybrids = £100/t (Chadwick, 1995).

Seed rate for conventional variety = 180 kg/ha.

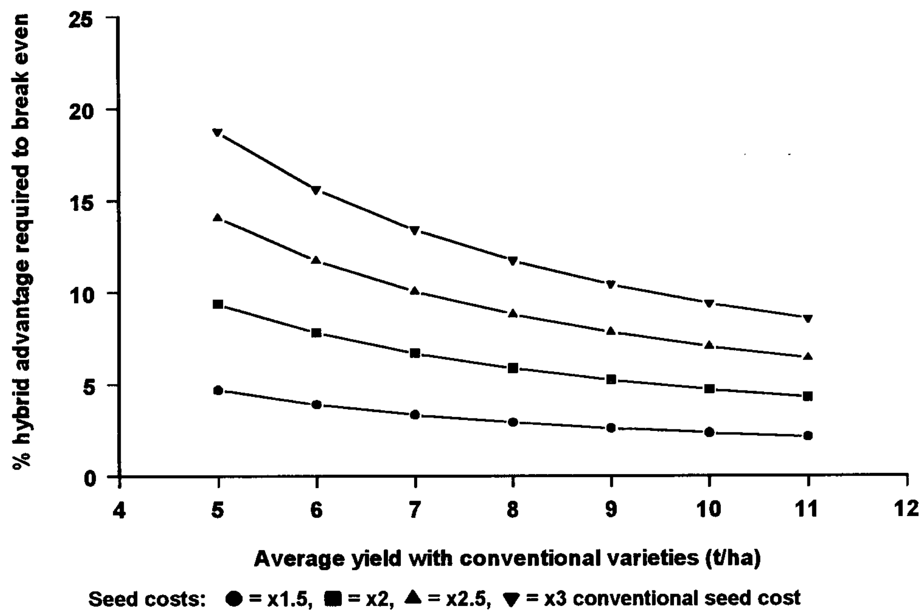

Figure 4.1 **Scenario 1 - The effect of variation in hybrid seed costs on the yield advantage required to compensate for additional seed cost**

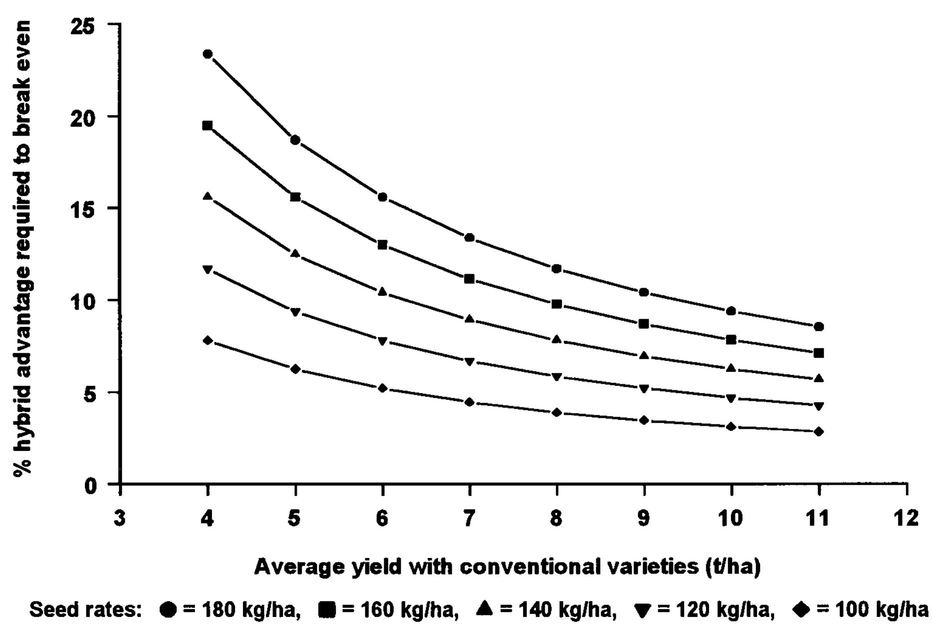

Figure 4.2 **Scenario 2 - The effect of variation in hybrid seed rates on the yield advantage required to compensate for additional seed cost**

Conventional and hybrid variable costs (excluding seed costs) = £200/ha (Chadwick, 1995).

With the seed costing 3 times that of conventional varieties, a yield advantage of 13% would be required at a seed rate of 180 kg/ha and an average conventional yield of 7 t/ha. A yield advantage of 4% would still be required to break-even with the reduction in seed rate to 100 kg/ha and an average conventional yield of 7 t/ha.

4.3.3 Scenario 3 - Variation in seed rate and seed cost

Scenario 3 (Figure 4.3) uses two seed rates (180 and 100 kg/ha) and compares the hybrid yield required with two seed costs (x2 = £520/t and x3 = £780/t). Other factors:

Grain price for conventional and hybrids = £100/t (Chadwick, 1995).

Seed rate for conventional variety = 180 kg/ha.

Conventional and hybrid variable costs (excluding seed costs) = £200/ha (Chadwick, 1995).

The yield advantage required to break even with the seed costing twice that of the conventional variety and a seed rate of 100 kg/ha is negligible (<1% at 7 t/ha average yield) but a grower would expect an increased return for the risk taken in growing a hybrid crop. It is also debatable whether a seed rate as low as 100 kg/ha would be possible.

4.3.4 Scenario 4 - Increased grain price from increased grain quality

Scenario 4 (Figure 4.4) shows the impact of increased grain quality on the feasibility of hybrid production at two seed costs (x2 = £520/t and x3 = £780/t). The premium given for hybrid grain in this case is £15/t (i.e. £115/t compared to £100/t for conventional grain). Other factors:

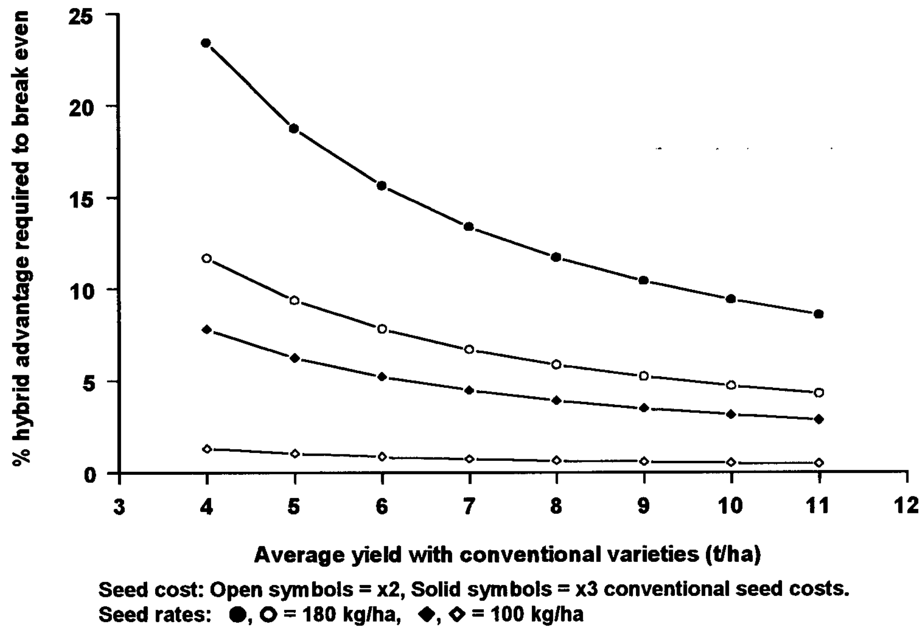

Figure 4.3 Scenario 3 - The effect of variation in hybrid seed rate and seed costs on the yield advantage required to compensate for the additional seed costs

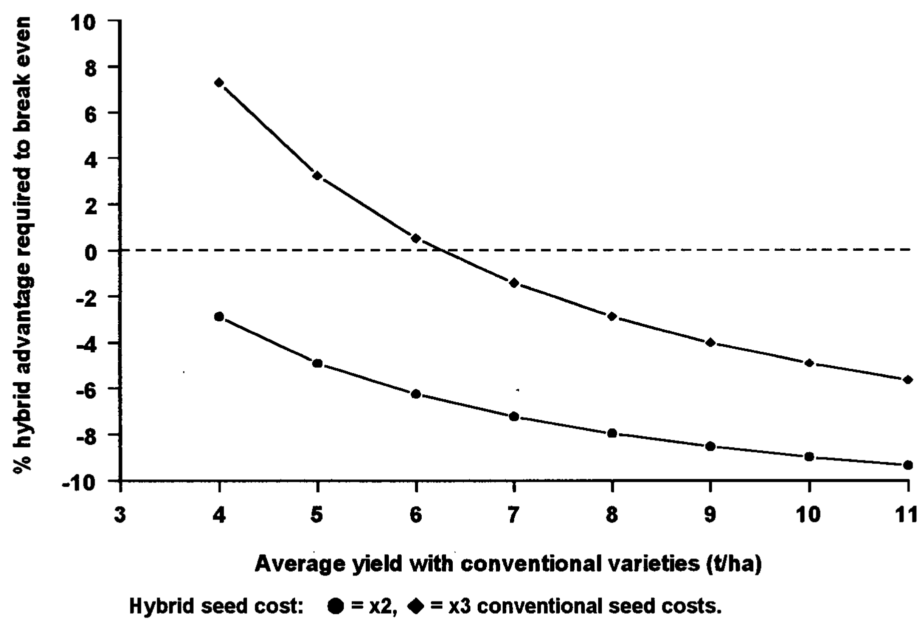

Figure 4.4 Scenario 4 - The effect of improvement in grain quality on the yield advantage required to compensate for additional seed cost

Seed rate for conventional and hybrids = 180 kg/ha.

Conventional and hybrid variable costs (excluding seed costs) = £200/ha.

The results show that the hybrid yield advantage need not be greater than the conventional yield (it could be less in certain cases) for the additional seed cost to be outweighed by the additional quality advantage. Again, however, farmers would require a greater return to warrant the extra risk associated with growing hybrids for bread-making. As mentioned above, the additional income required can be included in the model.

Any reduction in the price of grain in the future, however, would result in increased yield advantage required, in order for the hybrids to be profitable.

The scenarios shown are a few examples of the type of feasibility analysis which can easily be carried out by the farmer or his/her advisor to assess whether it is worth the risk of growing hybrid cereals if and when commercial varieties become available. Other changes can be made to the calculations, for example, if hybrids require less fungicide then the variable costs of the hybrid production can be reduced.

4.4 Model 3 - Comparison of gross margins of hybrid and conventional wheat production under different scenarios

Model 3 (pages 60 and 61) gives an estimate of gross margin for both conventional and hybrid production thus allowing cost:benefit analysis.

Two examples are shown using Model 3. Figure 4.5 uses a hybrid seed cost of twice the conventional seed price, whereas Figure 4.6 uses a cost of three times the

Model 3 - Spreadsheet Formulas

	A	B	C	E	F
1					
2					
3					
4		**Assumptions**			
5					
6	a.	Grain price		£/t	100
7	b.	Conventional seed price		£/t	260
8	c.	Conventional drilling rate		t/ha	180
9	d.	Hybrid drilling rate		t/ha	180
10	e.	Standard spray costs		t/ha	100
11	f.	Fertiliser cost		£/t	97
12	g.	Other variable costs		£/ha	3
13	h.	Hybrid advantage		%	13
14	i.	Hybrid seed price		£/t	750
15					
16					
17					
18	j.		Average base yield t/ha		7
19			**Conventional income**		
20			Income from grain		=F6*F18
21	k.		Income from straw		50
22	l.		Area subsidy		269
23			Total variable costs		=(F7*(F8/1000))+F10+F11+F12
24			Gross margin		=(F20+F21+F22)-F23
25					
26			**Hybrid income**		
27			Income from grain		=(((F13/100)*F6)+F6)*F18
28			Income from straw		50
29			Area subsidy		269
30			Total variable costs		=(F14*(F9/1000))+F10+F11+F12
31			Gross margin		=(F27+F28+F29)-F30
32					
33			**Hybrid v conventional**		
34			Increased seed cost £/ha		=((F14*F9)-(F7*F8))/1000
35			Gross margin difference £/ha		=F31-F24
36			Gross margin difference %		=(F35/F24)*100
37			Benefit:cost ratio		=(F34+F35)/F34

NB Column D is not shown

Model 3 - Example spreadsheet

	A	B	C	D	E	F
1	Comparison of gross margins for hybrid					
2	and conventional wheat					
3						
4		Assumptions				
5						
6	a.	Grain price			£/t	100
7	b.	Conventional seed price			£/t	260
8	c.	Conventional drilling rate			t/ha	180
9	d.	Hybrid drilling rate			t/ha	180
10	e.	Standard spray costs			t/ha	100
11	f.	Fertiliser cost			£/t	97
12	g.	Other variable costs			£/ha	3
13	h.	Hybrid advantage			%	13
14	i.	Hybrid seed price			£/t	750
15						
16						
17						
18	j.		Average base yield t/ha			7
19			**Conventional income**			
20			Income from grain			700
21	k.		Income from straw			50
22	l.		Area subsidy			269
23			Total variable costs			246.8
24			Gross margin			772.20
25						
26			**Hybrid income**			
27			Income from grain			791
28			Income from straw			50
29			Area subsidy			269
30			Total variable costs			335
31			Gross margin			775
32						
33		Hybrid v conventional				
34		Increased seed cost £/ha				88.2
35		Gross margin difference £/ha				2.8
36		Gross margin difference %				0.36
37		Benefit:cost ratio				1.031746

conventional seed price. In both cases the following inputs were used:

a. Grain price = £100/t.

b. Conventional seed price = £260/t.

c.& d. Conventional and hybrid drilling rate = 180 kg/ha.

e. Standard spray costs = £100/ha.

f. Fertiliser costs = £97/ha.

g. Other variable costs = £3/ha.

h. Hybrid advantage = 5, 10, 15 & 20%.

i. Hybrid seed price = £520/t & £780/t.

j. Average yield achieved with conventional varieties = 4 - 11 t/ha.

k. Income from straw = £50/ha.

l. The area subsidy used is £269/ha, but can be changed for individual regions.

The graphs show the difference in the gross margins between hybrid and conventional systems at four levels of hybrid yield advantage (5, 10, 15 and 20%) and with seven base yields (4 - 11 t/ha). The graphs also provide a rough estimate of the yield advantage that would be required before it would be profitable to grow, in this case, hybrid wheat. The proportion of growers that would find it profitable to grow hybrid wheat in the UK could be estimated by calculating the proportion of growers with an average yield greater than the minimum yield at which it is profitable to grow hybrid wheat.

4.5 Factors influencing a breeder's decision to introduce a hybrid

There is a very large investment cost associated with any breeding programme. The production of hybrids incurs a number of additional costs. The major cost for hybrid production is likely to be in the development of a safe and effective CHA.

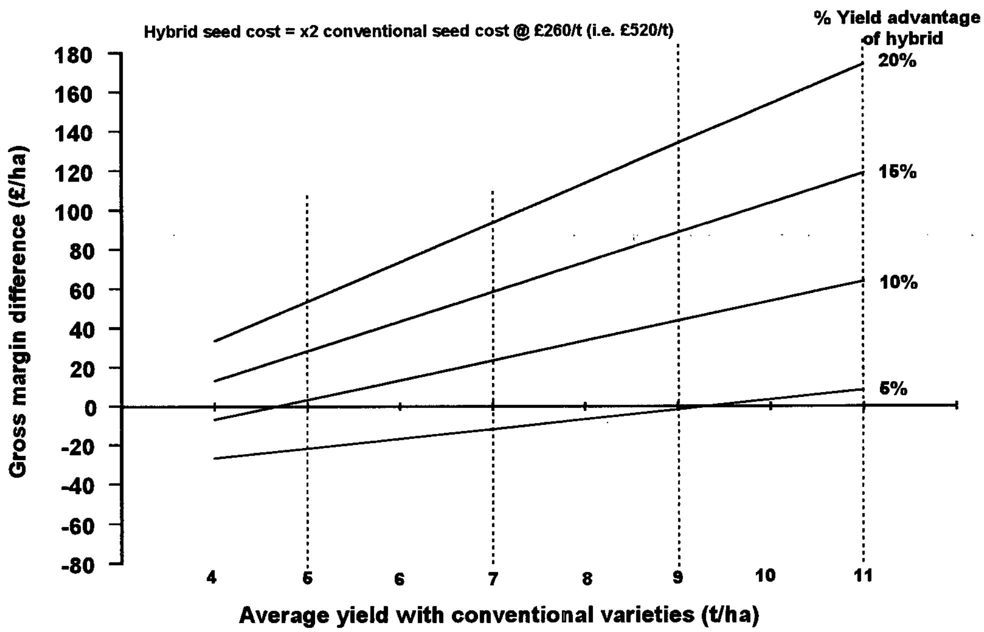

Figure 4.5 Model 3 - Comparison of hybrid and conventional gross margins (Hybrid seed cost = twice conventional seed cost)

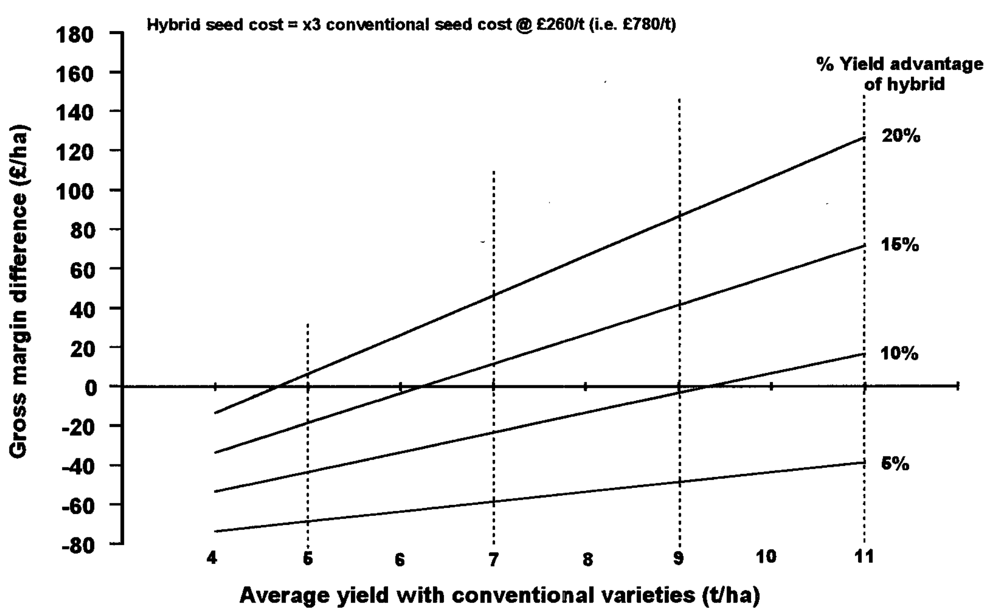

Figure 4.6 Model 3 - Comparison of hybrid and conventional gross margins (Hybrid seed cost = three times conventional seed cost)

For example, Orsan established a research laboratory (Sogetal Inc.) in California in order to develop the CHA, Croisor, for Hybrinova, whereas Hybritech and Zeneca Seeds have bought the rights to CHA's developed by Rohm & Haas. The development of specialist breeding lines adds additional costs to the production of hybrids. In order for a return to be made, these 'fixed costs' need to be spread over a large quantity of seed sales, in addition to the high seed production costs (see Section 4.1) which will be *pro-rata* the amount of seed sold. The breeders must therefore be aiming at a sizeable proportion of the market and be hoping to reduce the amount of home-saved seed.

If hybrids have higher levels of heterosis, it will be economically justifiable to grow them on lower yielding land. Conversely, where the hybrid advantage is low, the best returns will be obtained from growing the crop on higher yielding land. This is illustrated in Figures 4.5 and 4.6. As hybrid yield advantage is likely to be low in comparison to the best conventional varieties, in order to recoup their investment the breeders will need to secure a high proportion of a relatively limited area of land for hybrids. There may, however, be resistance from the growers to a hybrid which cannot be home-saved and a possible reluctance to switch from varietal types for which they have good knowledge. A farmer will not be convinced of the benefits of growing hybrids by a mathematical equation alone. Successful demonstrations of the yield potential and reliability of hybrids will also be essential. Hybritech are currently reluctant to test their French hybrids in the UK as they are ill-adapted to UK conditions (long-strawed, daylength-insensitive) and could create a poor image of wheat hybrids in general (Angus, 1996, pers. comm.).

In France, however, the decision to market wheat hybrids has already been made. It would, therefore, make reasonable sense to spread the costs as widely as possible to dilute the fixed costs of the breeding research and, although the French hybrids may not be well adapted to the UK, the additional costs required to produce hybrids suitable for the UK may be relatively small. Nickerson Seeds have an association with

Hybritech and are producing hybrid wheats mainly for France, but also for the UK. If hybrids are successful in France then more varietal lines will be developed specifically for the UK.

4.6 Conclusions

The financial feasibility of hybrid production is dependent on several factors including:

- Hybrid yield advantage.
- The cost of hybrid seed compared to the cost of conventional seed/use of home-saved seed.
- Average yield of the farm using conventional varieties.
- Hybrid quality advantage and the grain price/premium for bread-making or biscuit quality.
- Hybrid disease resistance advantage.
- Differences in seed rates between hybrid and conventional varieties.

Therefore, the estimation of the hybrid yield advantage required to break even is highly variable depending on the values given for the different factors (as shown in Figures 4.1 to 4.5). This is also true for the different gross margins that would be achieved. Values calculated vary from <1 to 24% yield advantage required to break even. The range would be greater if home-saved seed could be used, or if hybrids produced grain of higher quality.

However, if hybrids become commercially available, the simple spreadsheet models that have been produced allow individuals to input their own factors together with their own information, such as the cost of specific hybrids, into the equation to give an indication of whether the use of hybrids would be more profitable. The models provide a means for easy re-evaluation of the situation.

The models should be used with caution, however, as a yield advantage claimed by a breeder or reported in the Recommended Lists may not necessarily be achieved at farm level due to factors such as poor weather conditions or management. The models are designed to provide a guide to the potential hybrid seed cost and yield advantage required, and to give an estimation of gross margins achieved using the different systems.

CHAPTER 5 CONCLUSIONS

5.1 Wheat

The introduction of wheat hybrids in the UK is highly dependent on the success of hybrids in France. At present, breeders are concentrating on the production of hybrids for the French market, which is the largest in Europe. If successful, more effort will be made to develop hybrids specifically for the UK. As the necessary technology for hybrid seed production has already been developed, the additional costs required to develop hybrid lines specifically for the UK may therefore be relatively small.

The level of yield advantage of wheat hybrids is relatively low compared to other crops, such as oilseed rape and rye. These levels of heterosis are unlikely to compensate for the increased cost of the seed which, in France, is being sold at 2 - 2½ times the price of conventional seed on an area basis. However, taking into account the recommended reduction in seed rate with hybrid wheat, the actual seed cost is 3 or more times that of conventional seed. Therefore, plant breeders are concentrating on improvements in grain quality and disease resistance to produce hybrids that will be attractive to farmers. As commercial hybrid production is now in progress, further developments will occur in parental selection which may result in hybrids combining high quality grain characteristics, good disease resistance and high yields.

Anecdotal evidence suggests that hybrids may have greatest potential in reduced-input systems due to greater resilience or tolerance to pests and diseases. Under such a system hybrids may produce a more consistent yield. Currently, all varieties in the UK Recommended List trials are assessed under a system using with and without fungicide treatments. This may not be advantageous to hybrids, as they are likely to perform comparatively better under a reduced rate fungicide regime.

Seed rate reductions are recommended by the companies producing hybrid wheat but there is little evidence to substantiate the claims that hybrids are more vigorous at lower seed rates.

Transgenic techniques may help reduce the costs of seed production in the future by allowing mixtures of male pollinator plants and female receptor plants. A system similar to SeedLink™, developed by Plant Genetic Systems for hybrid oilseed rape production, may be possible in wheat.

The success of hybrid wheat is dependent on many changeable factors including European agricultural policy.

5.2 Barley

Interest in the production of barley hybrids has been extensive, although less work has been carried out than for wheat, as barley does not have such a large potential seed market. The current levels of yield heterosis and problems with the hybridising chemical have prevented breeders from making hybrid barley available to growers.

The presence of a satisfactory chemical for use in wheat hybrid programmes may improve prospects for further work in barley and some research is currently being conducted as part of an EUREKA project (Project No. EU749, Research and development programme on hybrid wheats).

5.3 Rye

Rye hybrids are successfully grown commercially and account for a large proportion of the rye seed sold in the UK. The total acreage of rye fluctuated between 6,000 and 9,000 ha from 1990 to 1995.

Hybrid rye differs from hybrid wheat in a number of respects. Unlike wheat, rye is produced by the CMS method and, being a good pollen producer, the crossing block consists of approximately 95% male-sterile plants with only 5% pollinator. Therefore, only 5% of the land does not produce seed. Consequently, the costs of production are lower than for hybrid wheat where the pollinator occupies a minimum of a third of the land.

Conventional breeding of rye has not been as intensive as for wheat and, consequently, the available inbred varieties are not as 'advanced' as those in wheat. Therefore, there is more potential for yield heterosis in rye. Hybrids currently on the UK Recommended List and in NIAB trials show a yield advantage of 8 to 24 % over the control variety. For these reasons, it is likely that rye hybrids will increase their already large share of the market. In addition, hybrids not only offer improved yields, but also have shorter, stiffer straw which will reduce the likelihood of lodging.

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