



RESEARCH REVIEW No. 45

**CURRENT PRACTICES AND
FUTURE PROSPECTS FOR
ORGANIC CEREAL PRODUCTION:
SURVEY AND LITERATURE REVIEW**

FEBRUARY 2001

Price £6.00

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CURRENT PRACTICES AND FUTURE PROSPECTS FOR ORGANIC CEREAL PRODUCTION: SURVEY AND LITERATURE REVIEW

by

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This is the final report of a 6 month project which started in April 2000. The work was funded by a grant of £25,210 from the Home-Grown Cereals Authority (Project No 2299).

The Home-Grown Cereals Authority (HGCA) has provided funding for this project but has not conducted the research or written this report. While the authors have worked on the best information available to them, neither HGCA nor the authors shall in any event be liable for any loss, damage or injury howsoever suffered directly or indirectly in relation to the report or the research on which it is based.

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Erratum (pages 32/33)

It is implied that rotenone (extracted from *Derris* spp.) and pyrethrins (extracted from *Chrysanthemum cinerariaefolium*) may control invertebrate pests in cereals and cereal stores. It should be noted, however, that neither is currently approved by MAFF/HSE for use on cereals.

Abstract

Present practices of organic cereal production, grain quality criteria, advisory information available to farmers and research literature on organic cereals were reviewed in order to provide a basis for future research and development. Increased UK production has not met the demand for organic cereals and prices of organic grain are more than double those of conventional grain. Quality specifications for different markets are similar for organic grain and conventional grain but the standards for protein in bread-making wheat are difficult to achieve.

In a survey of growers the most commonly grown cereals were winter wheat (47% of farms), spring barley (39%) and spring oats (34%) and expected yields ranged from 3.7 tonnes/ha for spring barley to 4.7 tonnes/ha for winter wheat. Weeds were cited as the most common problem in cereal crops (53% of crops), particularly perennial weeds. Lack of fertility was given as a problem in only 16% of cereal crops. Less than a quarter of crops were sown with home-saved seed and 69% of growers used higher seed rates than they would have done in conventional crops. Most farms used grass/clover leys and livestock to maintain soil fertility.

The literature review identifies a number of areas where fundamental information for the production of organic cereals is lacking; these include an understanding of weed competition, an understanding of appropriate management systems for nitrogen fixing green manures and management of nutrients in stockless systems, tactical use of composts and nutrients, interactions between rotations and soil biology, and fundamental processes involved in the ecology of cereal weeds, pests and pathogens.

The final section discusses issues for the future of organic cereal production in the UK and suggests priorities for future organic cereal research, including those relating to stockless, cereal-based rotations, cereal/legume bicropping, commercial and home-saved organic seed production and seed quality, identification of organic cereal ideotypes and mixtures, weeds, pests and diseases, effects of cultivations on soil N mineralisation, soil fungi, sources of nutrients, grain quality, and pest and disease control in stored grain.

Executive Summary

Aims and Objectives

To review present husbandry practices and research literature in order to provide information to help in future research and development in organic cereals.

Introduction

There has been a rapid expansion in the UK organic food market in recent years. The number of registered organic farmers is reported to have risen from 800 in 1997 to nearly 1600 in 1999, with a large number of farmers presently converting to organic production and applying for organic status. Cereal production is a major component of organic farming systems, cereals being grown as cash crops for premium markets, as livestock feed, and for on-farm processing into added-value products. It is estimated that 31,900 tonnes of organic cereals were produced in 1998, valued at £5.77 million. Demand is such that presently approximately 50% of the domestic market for organically-produced cereals is met by imports. This results in UK grain prices more than double those of conventionally-produced grain. Because more farms are converting to organic livestock production than to organic arable cropping, there is a severe shortage of organic feed grains.

Organic Farming Principles and Certification Schemes

Organic farming is both a philosophy and a system of agriculture that developed in response to the increasing industrialisation of agriculture. The detailed husbandry standards of organic farming are based on the enhancement and exploitation of the natural biological cycles in soil, crops and livestock. There is strong emphasis on optimising animal welfare, avoidance of pollution and improvement of the environmental infrastructure of the farm.

The sale of food as 'organic' is controlled under EU Regulation 2092/91, which sets out the minimum standards of production and defines how certification procedures must operate. Member states are required to establish a National Certifying Authority, which for the UK is the UK Register of Organic Food Standards (UKROFS), and organic farmers must be registered with a certification scheme approved by this Authority (e.g. the Soil Association, Organic Farmers and Growers, Scottish Organic Producers Association, Irish Organic Farmers and Growers Association, the Organic Food Federation, and the Biodynamic Agricultural Association). Some of the main features of the UKROFS standards are: organic farming units must be large enough to impose a valid crop rotation; a two-year conversion period is required between the last application of a prohibited substance and the sowing of the first full organic crop; the crop rotation must have a balance between fertility building crops (e.g. grass-clover ley) and exploitative crops (e.g. cereals, potatoes) and must receive regular inputs of organic matter, such as farmyard manure (FYM);

bought-in FYM must be from ethically acceptable livestock systems and must be composted; some nutrient sources are permitted but soluble mineral fertilisers are prohibited; most manufactured agrochemicals are prohibited but some natural biocides are permitted; crops must be grown from organically-produced seed; no genetically-modified material may be used; livestock diets, housing and health policies are regulated.

Methods Used in this Review

Grain quality requirements were determined from telephone interviews of buyers and processors of organic grain in the UK. Current practices in organic cereal growing were reviewed from technical information available to farmers and random telephone and postal surveys of organic cereal growers. Elm Farm, SAC and other field advisers specialising in organic farming were asked to indicate the main problems facing organic cereal growers. For the literature review the conventional scientific literature was searched electronically, requests for information were sent to organic researchers and a request for literature was displayed at the 13th International IFOAM Scientific Conference in August 2000. Visits were made to SAC, Elm Farm and ADAS trial sites.

Review of Current Practice

Quality specifications for different markets are generally the same for organic grain as for conventional grain. Buyers of organic grain indicated that quality was comparable to that of conventional samples except for milling wheat where protein levels were 1.5-2% (14% moisture basis) below those for satisfactory bread making.

Responses to the surveys were obtained from 70 growers who gave details of 108 organic cereal crops. The most commonly grown cereals were winter wheat (47% of farms), spring barley (39%) and spring oats (34%) and expected yields ranged from 3.7 tonnes/ha for spring barley to 4.7 tonnes/ha for winter wheat. Weeds were cited as the most common problem in cereal crops (53% of crops) with some growers and advisers pointing to perennial weeds as a particular problem; rotation, cultivation and high seed rate were given as the main methods of weed control. Lack of fertility was given as a problem for only 16% of cereal crops with the main source of fertility identified as rotation and to a lesser extent home-produced manures; there was little use of green manures or fertility-building crops apart from grass/clover leys. Only three of the surveyed farms had no commercial livestock. Less than a quarter of surveyed crops were sown with home-saved seed and 69% of growers used higher seed rates than they would have done in conventional crops. A major source of information to farmers on organic cereal husbandry and varieties was given as 'own experience', although 39% used the Elm Farm Organic Advisory Service for husbandry advice and 37% obtained advice on varieties from commercial sources. The cereal varieties grown were generally those on current recommended lists for conventional use.

Literature Review

The scientific literature in organic cereal production of the past 15 years was reviewed. The review was arranged in disciplinary sections which included farm surveys, crop nutrition, weeds, pests and diseases, seed, plant breeding, and environmental implications. Published surveys showed a wide range of yields for organic cereals, typically 5 to 6 tonnes/ha for winter wheat in the UK, but 9.8 tonnes/ha in one field-scale trial. Reported protein levels in wheat were almost always below those of conventional wheat. Weed competition, from both annuals and perennials, was identified as a serious threat to cereal productivity with a need for advice relating to individual weed species or groups of species with different competitive abilities. A number of papers examined the use of leguminous crops in organic rotations but there appeared to be no clear understanding of appropriate management systems for nitrogen fixing green manures, or of the management of nutrients (N, P, K and micro-nutrients) in stockless systems. Organic manure applications can increase yield and grain quality, but more information is needed on the tactical use of composts and nutrients (on and off-farm sources) for early season cereal growth and the manipulation of grain quality. There is a need for a better understanding of the interactions between rotations and soil biology in relation to nutrition and soil structure. Varietal variation in resistance to a number of seed-borne diseases has been reported and could be exploited for organic cereals; a number of permitted seed treatments have also been shown to reduce the contamination of seed by fungal spores. Crop health in organic crops depends largely on a preventative strategy. For prevention to be successful in the field, a knowledge of the fundamental processes involved in the ecology of cereal weeds, pests and pathogens is required.

Future Challenges

This section discusses a number of separate issues for the future of organic cereal production in the UK: key agronomic questions, prospects for seed production, plant breeding for organic cereals, profitability, and technology transfer. Finally, priorities for future organic cereal research are identified; these include: the identification and understanding of optimum conditions, sequences and nutrient management in stockless, cereal-based rotations; the development of guidelines for cereal/legume bicropping; the development of guidelines for commercial and home-saved organic seed production, and the understanding of factors affecting seed quality; the identification of desirable traits for organic cereal varieties and the use of conventional trials to evaluate varieties for these traits; the assessment of variety x genotype interactions and the use of a wider range of organic genetic material, including variety mixtures, in organic systems; an understanding of the way in which weeds pests and diseases affect organic cereal crops and interact with soil fertility and crop rotation; the development of direct and indirect control strategies for weeds, pests and diseases; an understanding of the effects of cultivations on soil N mineralisation and of soil fungi on nutrient uptake by organic cereals; the evaluation of sources of nutrients available to organic growers; an understanding of the factors affecting grain quality and the development of strategies for the production of

quality grain; the evaluation of methods of pest and disease control in stored grain, store hygiene and wet grain storage systems.

Acknowledgements

The authors wish to acknowledge the help and advice given by the following in the preparation of this review: Dr Bill Cormack of ADAS Terrington, and Dr Bruce Pearce, Deputy Research Director at Elm Farm Research Centre, for advice on organic cereal production and comments on the manuscript; Professor Martin Wolfe, Research Director at Elm Farm Research Centre for spending time discussing research at Wakelyns Agroforestry; Mr John Clarke of Upper Lenshaw, Rothienorman, Aberdeenshire, for comments on the survey questionnaire; the many organic farmers who gave up their time to answer questions on their organic farming methods; the processors and buyers of organic grain who spent time discussing cereal quality requirements; and the researchers at home and abroad who discussed their work with the authors and provided papers for the literature review. The funding for this review was generously provided by the Home-Grown Cereals Authority.

Aims and Objectives

The overall objective of this review is to provide information on which to base future research and development for organic cereals in the UK. There are three specific sub-objectives:

- To review present husbandry practices for the production of organic cereals for different uses and market outlets in the UK.
- To carry out a literature review of the factors which interact in organic crop production to provide qualitative and quantitative understanding of the complex interactions between soils, pests, weeds and diseases.
- To highlight key areas where lack of information or technological development hamper the production of organic grain in sufficient quantity or of acceptable quality, taking into account the present and projected size and quality requirements of the different organic cereal markets and anticipated changes in organic livestock numbers, thus identifying key areas for future research and optimal methods of technology transfer.

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1. Introduction

The market for organic food in the UK has grown rapidly in recent years and is expected to be about 1% of total food sales in 2000, among the lowest in Europe (cf. Denmark 4.5%, The Netherlands 4%, Germany 1.75%) (SAC, 2000). Although the greatest demand is for vegetable and meat products, the organic bread market alone is valued at over £20 million (Mintel, 1999). The number of registered organic farmers is reported to have risen from 800 in 1997 to nearly 1600 in 1999 (Soil Association, 1999) with a large number of farmers presently converting to organic production and applying for organic status, many of whom are in the livestock sector, especially in Scotland. In April 1999 there were 60,000ha of fully organic land in the UK with a further 180,000ha in conversion. At the same time the average size of organic farms, 116ha in England, Wales and Northern Ireland and 330ha in Scotland, is increasing (Soil Association, 1999).

The area of registered organic or in-conversion land in Scotland increased from 22,000ha to around 276,000 ha from 1997 to 2000, and the number of organic farmers with organic enterprises rose from 120 to around 540 over the same period. However, there is a major imbalance in the pattern of conversion between different land types. The vast bulk of the 276,000 hectares now registered as organic in Scotland is rough grazing and upland pasture.

It is estimated that 31,900 tonnes of organic cereals were produced in 1998, valued at £5.77 million (Soil Association, 1999). Cereal production is a major component of organic farming systems with cereals grown as cash crops for premium markets, as livestock feed, and for on-farm processing into added-value products. Demand is such that approximately 50% of the domestic market for organically-produced cereals is at present met by imports. This not only results in prices for organic malting barley and organic milling wheat which are more than double those of conventionally-produced grain, but, because more farms are converting to organic livestock production than to organic arable cropping, there is a severe shortage of organic feed grains which, at nearly £200/tonne, are much more costly than conventional grain.

The certified organic cereal area in the UK nearly doubled between 1993 and 1997 (Foster and Lampkin, 1999), an increase of about 700ha/year. The Soil Association (1999) reported an increase of 1200ha from 1998 to 1999, whilst HGCA (2000b) predict a certified organic cereal area of 40,000ha by 2002 based on the present area of in-conversion land eligible for arable area payments; this may be an overestimate which does not take into account the need for a high proportion of organic rotational land to be devoted to fertility-building grass/clover leys (Table 1.1).

Table 1.1. Estimates of organic cereal areas in the UK (ha).

	1993	1994	1995	1996	1997	1998	1999	2002
Cereal area ha (1)	2785	2955	4076	4987	5236			
Cereal area (2)						8000		40000
Cereal area (3)					6493	7649		

(1) Foster and Lampkin; 1999, (2) HGCA, 2000b; (3) Soil Association, 1999.

2. Organic Farming Principles and Certification Schemes

2.1 Principles of organic farming

Growing concerns about animal welfare, food quality and safety, including pesticide residues and disease problems associated with food, have focussed public interest on the methods employed in food production. In the UK this has led to a number of quality assurance schemes introduced variously by producer groups, processors and retailers. Organic farming systems were originally developed in response to the increasing industrialisation of the agriculture sector and in its most developed form organic farming is both a philosophy and a system of agriculture. The objectives of environmental, social and economic sustainability lie at the heart of organic farming and are among the major factors determining the acceptability or otherwise of specific production practices. The formation of the International Federation of Organic Agriculture Movements (IFOAM) in 1972 gave an international framework for the discussion and codification of internationally recognised principles for organic farming. Organic farming can be considered to be a food quality assurance scheme with the most clearly defined standards of production, which has been operating since the mid 1970's, and which is recognised at an international level (CEC, 1991). The aims of organic farming (food quality, human health, environmental, animal welfare, and socio-economic) derive more from a consumer perspective than from a producer perspective. The result is that organic food has a very strong brand image in the eyes of consumers and can thus command higher prices for retailers and farmers than conventionally produced food.

The detailed husbandry standards of organic farming are primarily based on the enhancement and exploitation of the natural biological cycles in soil (e.g. N fixation, nutrient cycling in the soil), in crops (e.g. manipulation of competitive ability of crops and populations of natural predators of crop pests) and in livestock (e.g. rumen digestion in ruminants, development of natural immunity in young animals, interruption of host/pathogen relationships). In addition, there is strong emphasis on optimising animal welfare, avoidance of pollution and improvement of the environmental infrastructure of the farm. The aim, therefore, is to work with natural processes rather than seek to dominate them, as is often the case in 'conventional' systems using soluble fertilisers and pesticides, particularly the more intensive systems, and to minimize the use of non-renewable natural resources such as the fossil fuel used for manufacture of fertilisers and pesticides (IFOAM, 1992; UKROFS, 1997).

2.2 Certification of organic farming

2.2.1 Legal framework

Within the EU, the sale of food as 'organic' is controlled under EU Regulation 2092/91 (CEC, 1991), which became operational, for plant products, in January 1993 and was supplemented by Regulation 1804/1999 to cover livestock production (CEC, 1999). This Regulation in effect defines organic farming. It sets out the minimum standards of production and defines how certification procedures must operate. In addition to organic production and processing within the EU, the Regulation also covers certification of produce imported into the EU.

Under the Regulation, each member state is required to establish a National Certifying Authority to ensure adherence to the law (in the UK, the UK Register of Organic Food Standards (UKROFS)). Organic farmers must be registered with a certification body which must be approved by the National Certifying Authority. There are six approved certification schemes in the UK (Soil Association (SA), Organic Farmers and Growers (OFG), Scottish Organic Producers Association (SOPA), Irish Organic Farmers and Growers Association (IOFGA), Organic Food Federation (which is primarily concerned with processors), and the Biodynamic Agricultural Association (BDAA). Biodynamic agriculture is a specific form of organic agriculture, first defined by the Austrian philosopher Rudolf Steiner in the 1920's (Steiner, 1974).

2.2.2 Standards for organic food production

The standards of the OFG, SOPA and SA schemes are fairly similar and, on the whole, mirror those of UKROFS. The BDAA has more wide-ranging standards. The main features of UKROFS standards are as follows (UKROFS, 1997):

- It is not necessary to convert the whole of a holding, although the unit to be converted must be large enough to impose a valid crop rotation. Parallel cropping of the same crop varieties under organic and conventional systems is prohibited.
- It is not necessary to convert the whole unit at once; a field by field conversion is possible (and may even be desirable in order that a grass-clover ley can be established in each field, in turn, to ensure that the soil fertility during the conversion phase is satisfactory).
- A two-year conversion period is required between the last application of a prohibited substance and the sowing of the first full organic crop.
- The crop rotation must have a balance between fertility building crops (e.g. grass-clover ley) and exploitative crops (e.g. cereals, potatoes), e.g. a cycle of three years of ley, followed by a succession of one year each of cereal, roots, then cereal.
- Permanent grassland is permitted.
- Regular inputs of organic matter, e.g. farmyard manure (FYM), must be made.

- Conventionally produced FYM (from ethically acceptable livestock systems) may be brought in but must be composted prior to application.
- Crops must be grown from organically-produced seed.
- No genetically modified seeds, feedingstuffs or other materials may be used.
- Fertilisers such as lime and rock phosphate, which are slowly soluble in the soil, are permitted but soluble mineral fertilisers are prohibited.
- Most manufactured agrochemicals are prohibited but some natural biocides are permitted.
- Ruminant livestock must be fed a diet which is at least 60% green forage on a daily dry matter basis (i.e. maximum 40% concentrates).
- Livestock diets must be based principally on organically produced feedstuffs but a small proportion can be of conventional origin (e.g. 10% of daily dry matter intake for beef animals)
- Feeds derived from genetically modified organisms, and solvent-extracted feeds, are prohibited. Fishmeal is prohibited in ruminant diets.
- Housed animals must be provided with bedding; totally slatted systems are prohibited.
- Livestock must have access to pasture during the growing season.
- Livestock health policy must be based on preventative management strategies; there should be no routine treatment of healthy animals with drugs, except in the case of a known farm problem. However, chemotherapy of individual sick animals is permitted, although withdrawal periods are extended. In the case of animals treated with organophosphate-based medicines, organic status is lost.
- Animals intended for breeding and/or milk production may be brought in from a conventional source but must undergo a conversion period; animals intended for meat production must have been born and reared under full organic management.

The inspection and certification scheme is operated on an annual basis. Detailed records of inputs must be kept and the farmer has to submit an annual return describing the inputs to each field/livestock enterprise.

3. Methods Used in this Review

Planning and technical meetings between partners were held in Edinburgh on 6 April, at IACR Rothamsted on 31 May, and by video conference on 3 August, 13 September and 19 October. Dick Taylor visited trials at Wakelyns Agroforestry and ADAS Terrington in July, and met staff at Invergordon distillery on 15 June.

Grain quality requirements (section 4.1) were determined from telephone interviews of the major buyers and processors of organic grain in the UK. These are listed in Appendix 1.

The sources of information listed in section 4.2.1 and the experiences of advisers involved in organic cereals (Elm Farm Research Centre, ADAS, SAC, Danish Agricultural Advisory Service) were used to provide the summary of agronomic practices for organic cereals in the UK (section 4.2.2).

To provide information on current farming practices for organic cereals in the UK (section 4.3) a number of randomly-selected farmers throughout the UK were questioned in telephone and postal surveys. An example of the questionnaire is given in Appendix 2. Growers were selected from organic producers registered with Soil Association Certification Ltd, Organic Farmers and Growers Ltd, and the Scottish Organic Producers Association Ltd. Of the 130 selected growers, 40 responded to the telephone survey and 35 to the postal questionnaires.

Elm Farm and SAC field advisers specialising in organic farming were asked by e-mail to indicate the main problems facing organic cereal growers in the UK. The views of a Danish adviser were also obtained (section 4.4).

For the literature review (section 5), the conventional scientific literature was searched electronically via Web of Science and the CABI Abstracts CD-RoM. A series of appropriate search terms were used including 'organic cereals', 'ecological cereals', 'organic crop rotations' etc. Requests for information were sent to researchers listed in the Review of Organic Farming Research in Europe (Keatinge *et al.*, 2000). Names and addresses of forty individuals/institutions working on aspects of organic cereal production were selected from the database. Letters were sent to these individuals/institutions in June 1999 and replies were received from seventeen. The scientists who responded with information are listed in Appendix 3. In addition to the circulated letters, information about the project and a request for literature was displayed at the 13th International IFOAM Scientific Conference in Basel, Switzerland in August 1999. Over 1300 people attended this conference.

4. Review of Current Practice

Areas devoted to different organic cereals are estimated by the Soil Association (1999). Wheat occupies more than half the organic cereal area in the UK, followed by oats, barley and triticale (Table 4.1).

Table 4.1. Areas of organic cereals grown in the UK.

	1997	1998
Wheat	3832	4163
Oats	1487	1949
Barley	625	1005
Triticale	260	324
Rye	182	147
Spelt	107	61
Total	6493	7649

Source: Soil Association 1998, 1999

Soil Association (1998, 1999) estimates show equal quantities of milling and feed wheat harvested, four times as much oats used for feed as milling and only about one fifth of barley being processed to malt and other products (Table 4.2.). Mintel (1999) report that the organic bread market in the UK is worth £20m per year.

Table 4.2. Quantities of organic cereals harvested in the UK.

	Tonnes
	1998
Milling wheat	9000
Feed wheat	9000
Milling oats	1600
Feed oats	6500
Processing barley	800
Feed barley	3000
Triticale	1400
Rye	600

Source: Soil Association 1999

4.1 Markets and quality

Grain specifications for different markets are generally the same for organic grain as for conventional grain. However, samples of organic grain which do not meet conventional specifications may be acceptable to buyers and processors of organic cereals, especially where there is a shortage of supply and blending can be used to achieve the required quality. Variety and crop management are key to the successful production of cereals for premium or quality markets.

4.1.1 Wheat

Millers of organic wheat require grain of the same quality as that used by conventional millers (Table 4.3). The millers questioned indicated that apart from protein level there are usually no problems with offered samples of organic grain. If possible they source supplies from the UK but the required quality is not always available and shortfalls are met by imports from Canada, the Czech Republic, Argentina, etc.. In practice UK samples with proteins down to 9.5% (14% m.c. basis) may be accepted at a discounted price. In 1999 wheat samples with 10% protein were discounted by £15/tonne, and those with 9.5% protein by £25/tonne. The flour can be blended with that from imported varieties such as Canadian Western Red, to give flour of the required standard. Varieties not currently classed as NABIM group 1 may also be accepted if quality specifications are met, e.g. Maris Widgeon. Prices for organic bread-milling wheat have been in the range £200-£250/tonne in 2000.

Table 4.3. Specifications for organic wheat markets.

	Bread-making	Biscuit	Feed
Variety (NABIM)	class 1	class 3	
Minimum grain protein %*	10.5-11	9-12	
Minimum HFN	250		
Minimum specific weight kg/hl	76	74	72
Maximum screenings (2mm)**	3	3	3
Maximum grain moisture %	15	15	15
Bold, sound grain of good visual appearance and smell			

* 14% moisture basis. **Includes small grain and admixture

The market for organic biscuit wheat is not well developed. Soft-grained varieties are used and the specifications are less difficult to achieve under organic conditions than those for bread wheat. Importantly, proteins of 9% are acceptable and a high HFN is not specified. Biscuit wheat is likely to command a small premium over a feed value of about £190/tonne.

The organic feed grain market developed in the mid to late 1990s (feed wheat price in June 1997 was £170/tonne). Now with the rapid increase in organic livestock numbers and a shortage of organic feed high yielding feed wheats are becoming an attractive option for organic growers. In August 2005 the derogation allowing 10% non-organic feed intake for livestock will end, further stimulating the demand for organic cereals and proteins. In addition, a limited demand for organic feed-quality wheat in Scotland is likely to come from grain distilling. JBB (Greater Europe) PLC have successfully completed trials to produce grain whisky from organic wheat at Invergordon, despite finding suitable raw material difficult to source. The requirements for this market are not dissimilar to those for feed, although a soft endosperm variety is specified.

4.1.2 Barley

Organic beers have been available for some years but present UK organic malting barley use is estimated at no more than 200-500 tonnes/year due to shortage of supplies. Ideally grain specifications for this market are the same as those for conventional malting barley (Table 4.4), but with the lack of available material, grain is often bought on sample. There is less emphasis placed on variety and malt may be sold on specification or performance rather than as a particular variety.

Although maltsters would hope to use 100% UK barley, the present shortfall in supply has resulted in imports from Germany, The Czech Republic and the Ukraine. There is an increasing demand for malt by distillers, for low-nitrogen malts for pot stills (single malts) and for high nitrogen malts for grain distilling. Problems with using traditional oak barrels for maturation of the spirit after the barrels have contained Bourbon which could have been made from GMO maize, appear to have been overcome by rigorous scouring and burning.

Table 4.4. Specifications for organic barley markets.

	Malting	Feed
Variety	Approved by IoB	
Grain N %	1.47-1.83	
Minimum germination %	97%	
Minimum specific weight kg/hl		63.5
Maximum screenings % (2.25mm)	6	
	% (2.5mm) 10	
Maximum admixture %	2	2
Maximum moisture %	15	15
Sound grain of good visual appearance and smell		

With the increased demand for organic feed grains, winter and spring barley varieties with their higher potential yields and energy contents, make attractive alternatives to oats .

4.1.3 Oats

Winter and spring oats can be grown organically for milling or feed. Specifications for organic milling oats are similar to those for conventional oats (Table 4.5). Millers questioned indicated that the material they receive normally meets the required specifications and that intake results show no difference between organic and conventional supplies.

Table 4.5. Specifications for organic oats markets.

Variety	Milling	Feed
Variety	Several acceptable	
Minimum specific weight kg/hl	50	50
Maximum screenings % (2.25mm)	10	
% (2mm)	6	
Maximum admixture %	2	2
Maximum moisture %	15	15
Sound grain with bright colour and sweet smell, no damage from incorrect drying		

The organic milling oats market in some areas was oversupplied a few years ago, but millers are now looking for more growers. Prices for organic milling oats have been in the range £195-£200/tonne in 2000.

4.2 Organic cereal growing

4.2.1 Sources of information

The following sources of information on the husbandry of organic cereals are available to farmers. A synthesis of this information and the experiences of a wide range of advisers involved in organic cereals (Elm Farm Research Centre, ADAS and SAC) provides the up-to-date summary of the agronomic practices for organic cereals in the UK described in Section 4.2.2.

- Organic Farming (formerly the Organic Farmer and Grower), published by the Soil Association.
- Elm Farm Research Bulletin, published by Elm Farm Research Centre.
- Focus Organic, published by the Soil Association
- Organic Farmers and Growers Newsletter, published by the Organic Farmers and Growers

- Organic Farmers and Growers Technical Leaflets.
- The Organic Farm Management Handbook, published by University of Wales and Elm Farm Research Centre.
- Books e.g. Organic Farming by N Lampkin.
- SAC, NIAB and DARD variety information.
- SAC Technical Notes.
- DARD Organic Leaflets
- Popular press articles, frequently in the form of case studies.
- Farm walks
- Elm Farm Organic Advisory Service.
- SAC Organic Farming Service.
- Organic Telephone Helplines, e.g. Soil Association, SAC
- Organic technical and discussion groups, e.g. SAC and Elm Farm Organic Advisory Service
- Internet sites.
- Commissioned reports, e.g. Weed Control in Organic Cereal Crops, Elm Farm Research Centre 1996

4.2.2 Agronomy of organic cereals

4.2.2.1 Rotations

Well designed rotations are fundamental to organic farming systems. They should achieve a balance between crops which deplete fertility, in particular nitrogen, and soil organic matter, and crops which restore fertility. For cereals the limiting plant nutrient is often nitrogen. It is normally recommended that at least half the rotation should consist of fertility-building crops such as grass/white clover leys, leguminous crops such as peas, beans, and lupins, or green manures such red clover and vetches which can be mulched and ploughed in. The amount of nitrogen added to the rotation by leguminous, nitrogen-fixing crops is difficult to quantify; crops such as peas and beans have the potential to supply 40-50 kg/ha N to the rotation while an established grass/white clover ley can supply 120-180 kg/ha/year N in the first two years and this can be moved to other parts of the rotation through livestock feeding and farm yard manure (FYM). A red clover ley can produce up to 240-380 kg/ha/year N (these figures are in broad agreement with those found by MAFF project OF 0178).

Soil organic matter is slowly depleted under annual crops which require ploughing and soil cultivation for their establishment. Grass/clover leys left in place for a number of years result in increases in soil organic matter and help to maintain soil biological activity, improve soil structure, workability and water holding

capacity, and provide a source of organic material for nitrogen mineralisation. Maximum soil organic matter increase under grass/clover leys is unlikely to exceed 0.1%/year.

Farmers converting from conventional to organic farming systems have to decide which rotations to adopt, which fertility-building crops to be included and whether the system should include livestock. Stockless, or all arable, rotations in which fertility is maintained through leguminous arable crops and green manures such as red clover, are attractive to arable farmers considering converting to organic status, but may only be feasible on soil types with good nutrient release characteristics. The costs of conversion from an all-arable conventional farm to a mixed organic farm can be high due to the cost of buying livestock (e.g. £600/ha to buy store cattle), installing fences, laying on water, replacement of arable crops which attract area payments with non-eligible crops such as grass/clover, etc.. In the first few years after conversion, stockless systems can give greater returns per ha than mixed systems due to their lower conversion costs. Following conversion, as soil fertility increases, weed populations are stabilised and knowledge of the system is acquired, yields and profitability may be expected to increase.

Cost is not the only consideration when deciding which organic system to adopt. Lack of knowledge and skills in dealing with livestock may influence growers, and farmers converting large holdings to organic production should assess the availability of markets, particularly for perishable produce such as fresh vegetables, and the likely supply of casual labour if crops requiring hand-weeding are anticipated.

Investigations into stockless organic rotations at ADAS Terrington, Elm Farm Research Centre and more recently on CWS farms, have highlighted some important features. These include the difficulty of accurately assessing net nutrient inputs, particularly from N fixation, and drawing up nutrient budgets; the importance of legumes in the rotation for cereal yield, problems with declining soil organic matter, the complexity of the relationship between weed levels and crop yields (do weeds reduce yield or do they indicate poor growing conditions?), and the importance of crop establishment in relation to final crop yield. Despite some reservations, these investigations indicate that stockless organic systems should be commercially and practically viable options for many farms in the UK, although they may be less reliable agronomically than mixed arable/livestock systems (for instance, sequences of annual crops are at greater risk from a build-up of the weed seed bank whereas leys lasting 3 to 4 years are very competitive against arable weeds). Stockless systems are most likely to be successful on easily worked grade 1 and 2 soils where organic matter levels have not been depleted by poor management, and where grass weeds and perennial weeds are at a satisfactory low level.

Stockless systems benefit from the permission given to organic farmers to use more than the normal maximum of 5% legumes in seeds mixtures for set-aside land. Fertility-building crops with no financial

return such as red clover can be included in the rotation for cutting and mulching and at the same time receive arable area payments.

Unless large amounts of organic manure are applied at some point in the rotation, the highest crop yields can be expected in the year following the fertility-building phase, that is after a grass/clover ley in a mixed system or after a leguminous crop in a stockless system. Cereals grown after a grass/clover ley give higher yields than those following non-leguminous arable crops and milling wheat is likely to achieve its highest protein level at this point in the rotation. However, where high value crops such as potatoes are included in the rotation, cereals may be taken at a later phase and have to rely on residual fertility or applied farmyard manure (FYM). Most rotations do not include more than two cereal crops, the second preferably after a legume or a crop receiving substantial amounts of organic manure. In some situations a spring cereal is taken as a second cereal after a grass/clover ley but fertility will be lower and weeds more of a problem.

4.2.2.2 Choice of crop

There is no reason why all the cereals - wheat, barley and oats, triticale, rye and spelt - cannot be grown organically in the UK. Some will suit certain situations better than others and some will require higher levels of management than others. The UK organic wheat area was estimated to be 4163ha in 1998/99 (Soil Association, 1999), approximately double that of oats and four times that of barley. Until recently the most important organic cereals were wheat and oats, with premiums paid for samples which reached milling quality. In recent years, as more livestock farmers have converted to organic systems, and feed grain has been in short supply, the range of cereals has increased. Other markets have also developed. Malted organic barley has been used for some time to produce beer, and more recently barley malt and wheat have been processed into organic whisky.

Organic growers may use different criteria to those of conventional growers when selecting which cereal crop to grow. Prime considerations include the value of the grain, the preferred time of sowing, the ability to compete with weeds, available disease resistance and ability to produce a reasonable yield and quality under difficult conditions. Winter cereals yield more and are harvested earlier but are unlikely to take up all the mineralised N made available by soil cultivations involved in autumn seedbed preparation. Where spring cereals are grown, land should not be ploughed until late winter, so avoiding the leaching of mineralised nitrogen. Spring-sown cereals may be preferred for their lower nutrient demand, and because they suffer less of a weed challenge during a short growing season and are more suitable for undersowing with grass mixtures. Seasonal soil nitrogen release patterns correspond better to the N demands of spring cereals than winter cereals. The ability to compete with weeds is greater in oats and triticale than in barley, and least in modern wheat varieties.

There is a milling demand for organically-grown wheat for bread, biscuits and for flour. The best high-protein samples have attracted prices of over £200/tonne, but prices for poorer quality samples are lower. Protein standards are particularly difficult to achieve with organically-grown bread wheat. Winter wheat is potentially the highest yielding cereal for organic situations and is often the most suitable cereal to follow a fertility-building shift in the rotation. With good management yields up to 7.5 t/ha can be achieved but yields as low as 2 t/ha are possible from poor crops. Spring wheats do not yield as well as winter varieties but are generally higher quality. In northern areas of the UK spring wheat does not mature until mid or late September when adverse weather conditions can reduce grain quality. Where winter conditions are not likely to be severe, some varieties of spring wheat, e.g. Axona, sown in November, will give higher grain protein contents than true winter varieties but yields are likely to be less and spring varieties tiller less and are less able to compete with weeds.

Organically-grown barley may be used for malting, feeding or for processing for human consumption. Yield depends on management and can range from 2.5 to 6t/ha. Contracts for malting barley are available with the market generally under supplied. There is less experience of organic winter barley than spring barley in the UK. Winter barley has the advantage that the ground is ploughed and worked when soil conditions are generally not too wet, and mineralised nitrogen is available to assist crop establishment. Disadvantages of autumn sowing are a greater risk from BYDV if the crop is established early or is sown after a ley, and a high susceptibility of many varieties to at least one commonly-occurring disease. Winter barley is more exposed to weed competition than spring barley and there is the problem of providing sufficient nitrogen for the crop in early spring. Spring barley, on the other hand, is generally less susceptible to disease. It has the disadvantage of being very sensitive to adverse soil conditions caused by cultivations in the winter or spring when conditions are wet. However, spring barley provides more opportunity for weed control cultivations before sowing because of the longer time available. This is especially true of grass weeds such as couch.

Organic oats can be grown for feed or milling for which there is an additional premium. Oats have a lower nitrogen requirement than wheat or barley and should not be grown in high fertility situations because of the risk of lodging and late ripening. High soil fertility can be exploited better by crops such as wheat, potatoes and brassicas. A crop of oats is a good competitor with weeds and this can be used to good effect following a crop that is a poor competitor, for example swedes or carrots. Oats might also follow wheat or barley. Spring oats can be undersown with a grass/clover mixture when it is usually necessary to reduce the seed rate. Winter oats are sown at about the same time as winter barley and like winter barley are susceptible to BYDV. They are less winter hardy than other winter cereals and should not be sown on exposed northerly sites. Although susceptible to weed competition in the early stages, winter oats are long-strawed and compete well with weeds. However, lodging can be a problem and highly fertile sites such as after grass/clover leys should be avoided.

Triticale is a useful crop for organic systems. It has long straw, making it competitive against weeds, good disease resistance, and a greater tolerance of drought than wheat. Furthermore, it appears to be less palatable to rabbits than other cereals. Triticale performs relatively well under conditions of low fertility which makes it more suitable as a second cereal than winter wheat. The price of triticale is competitive with other organic cereals grown as feed grain. Although only winter varieties exist it is possible to plant triticale through to the end of January/early February if soil conditions allow.

Spelt is an old cereal with new interest. It is claimed to be suitable for coeliac sufferers though it is uncertain whether there is evidence for this. Spelt is winter-sown and can perform well in severe conditions though not necessarily in poor environments. It shows good disease resistance and competes well with weeds. The harvested grain requires special milling to remove the hull and growers should confirm that they have a buyer before planting the crop. The market has been the main restriction to the production of speciality grains of this sort, and crops like spelt may be difficult to sell for a premium comparable to that from other organic cereals in some years.

Constraints imposed by crop-specific fertiliser and chemical applications on the use of crop species mixtures (mixed crops, alternate rows, alternate strips) are less of a problem in organic than conventional cropping systems. Crop mixtures may have a number of advantages in organic farming including reductions in pest and disease levels, improved weed control and provision of nitrogen where legumes are used in continuous systems. Wheat and beans do not compete for nitrogen when grown together such that higher protein levels may be achieved in wheat grown with beans than in wheat alone.

4.2.2.3 Choice of variety

Information on cereal varieties is available from various sources including NIAB, SAC, DARD, the advisory services, merchants, end-users and the trade. Detailed comparative information is contained in HGCA Recommended Lists for Cereals, the NIAB Cereal Variety Handbook, the SAC Cereal Recommended Leaflet and the DARD list of Cereal Recommended Varieties for Northern Ireland. These publications do not, however, include comparisons of varieties grown under organic conditions (although NIAB do produce an Organic Vegetable Handbook).

Variety probably has much less influence on cereal yield and profitability in organic situations than it does in conventional situations due to large variations in crop growth and yield within fields, between fields and between farms. Although organic growers may be expected to use different criteria to those used by conventional growers when selecting cereal varieties, there is evidence that varieties which do well in conventional systems also do well in organic systems. For organic systems, growers should choose varieties

with a high grain yield in the absence of fungicides and growth regulators, with high scores for disease resistance, and with long straw since this may confer good competitive ability against weeds. Other characteristics are important for specific markets, locations and farm situations. Malting and milling markets require specific varieties, good straw strength is important where a crop is to be grown after a long grass/clover ley, resistance to ear-loss is important in exposed fields, and early maturity reduces harvesting risks in northerly and upland situations.

For premium markets, selection of an appropriate variety is essential. Conventional bread-milling varieties of wheat can achieve acceptable grain quality under organic conditions. The choice of varieties for this market is limited but grain protein and Hagberg Falling Number (HFN) should be considered since these qualities can be easily lost in organic situations, the former if fertility is low, the latter if lodging occurs or the crop is infested with weeds. Similarly, variety choice might be influenced by level of screenings in malting barley, and specific weight where feed grain is intended for sale.

One variety is rarely the obvious best choice for any given situation and growers have to weigh strengths and weaknesses for different characters. For example, when comparing bread-milling winter wheat varieties, Hereward has longer straw and higher grain protein but lower HFN, and is at risk from mildew and Septoria diseases, whilst Malacca has better foliar disease resistance and HFN, but lower grain protein and specific weight, and shorter straw. (Table 4.6).

If, in future, breeders cannot guarantee their material free from genetically manipulated parents, the choice of varieties to organic growers will become very limited, encouraging the development of breeding programmes dedicated to organic varieties. It is probable that such varieties will be selected for different criteria to those for which conventional varieties are selected under conditions of high fertiliser and agrochemical inputs. Whilst some desirable characteristics are common to varieties under both systems, e.g. disease resistance and harvest index, selection criteria for varieties to be grown under organic conditions might include objectives not thought relevant to conventional systems, such as better local adaptation, natural weed resistance, resistance to a different range of pests and diseases, the ability to perform in crop mixtures, or the ability to take up soil nitrogen at times when it is most available. In the meantime limited information on varieties is available from organic cereal variety trials conducted by the certification bodies and NIAB.

Table 4.6. Characteristics of winter wheat varieties
(From NIAB Cereal Variety Handbook, 2000)

	Hereward	Malacca
Untreated yield (% of controls)	100	103

Shortness of straw	7	8
Resistance to mildew	6	7
Resistance yellow rust	7	9
Resistance brown rust	7	8
Resistance Septoria nodorum	6	7
Resistance Septoria tritici	6	6
Protein content %	13.3	12.4
Hagberg Falling Number	286	356
Specific weight kg/hl	79.8	76.2

Table 4.7. Performance of organic winter wheat varieties in ARC trial 2000

	Grain yield t/ha	Specific weight kg/hl
Maris Widgeon	4.00	74.7
Hereward	4.32	73.8
Malacca	3.12	67.8
Avalon	3.31	69.6
Mixture*	3.78	71.1

*Maris Widgeon + Malacca

There are a number of traditional varieties used in organic farming, of which the winter wheat Maris Widgeon is a good example. Maris Widgeon can give good hard-milling samples although the HFN is not as high as that of modern milling varieties. It has long straw which commands a premium for thatching if handled carefully (this may mean harvesting by binder!). Until recently there was little information to compare Maris Widgeon with modern varieties of winter wheat but trials conducted by the Arable Research Centres (HGCA project 2237) indicates a yield and specific weight comparable to modern varieties (Table 4.7). Seed of Maris Widgeon is difficult to obtain and growers are often advised to save their own.

Examples of NIAB-recommended cereal varieties suitable for organic rotations are shown in Table 4.8. Other varieties may be more suitable in specific situations. The spring wheat Axona can produce good milling quality grain and may be sown in autumn where conditions are favourable. Aberglen spring oats has better mildew resistance than Dula but a lower kernel content. Claire is a biscuit quality winter wheat with a good untreated yield, average straw length and good disease resistance except for mildew. As a spring barley for feed, Riviera has tall straw, good resistance to mildew and an excellent specific weight.

For organic growers variety mixtures offer a number of positive benefits over single varieties: buffering of environmental variables, disease and pest restriction, etc. Mixtures of winter wheat varieties in 1999/2000 trials at Wakelyns have indicated disease levels of 3 to 53% of those in pure stands.

Table 4.8. Examples of NIAB-recommended cereal varieties for organic rotations

Cereal	Market	Variety	Characteristics
Winter wheat	Bread-milling	Hereward	Longer straw and better disease resistance but lower untreated yield than other recommended varieties
Spring wheat	Bread-milling	Paragon	High untreated yield and bread-making quality, and good disease resistance
Winter oats	Milling	Kingfisher	Long straw, good disease resistance and large grain
Spring oats	Milling	Firth	High untreated yield, good mildew resistance and straw strength, but shorter than average
Winter barley	Feed	Intro	Long straw and bold grain with average yield and mildew resistance, but weak on <i>Rhynchosporium</i>
Spring barley	Malting	Chariot	Long straw, good mildew resistance, relatively early, but susceptible to <i>Rhynchosporium</i>
Triticale	Feed	Ego	Tall, strong-strawed with high yield potential and good specific weight

4.2.2.4 Establishing the crop

The aim of soil cultivations in organic systems is to provide a deep well-structured, well-drained, aerated soil to encourage deep rooting and maximum mineralisation of soil organic N and exploitation of incorporated plant nutrients. At the same time, the biological activity of the soil, particularly in the upper 15-20cm, must be maintained and weeds and trash likely to interfere with the drilling operation or carry disease to the next crop must be buried. Where there are no weed and trash considerations seedbed preparation might be achieved with shallow ploughing, or minimal cultivations and deep tine cultivation. However, because weed control and weed seed burial are of such importance in organic situations, land preparation should normally start with soil inversion by ploughing. There is some evidence that cultivating in darkness, so that weed seeds do not receive a light stimulus, reduces subsequent weed germination.

Organic winter cereals are sown later than conventional cereals in order to reduce the risk of disease infection before winter, to restrict autumn weed germination and winter weed development, and to allow time to control autumn-germinating weeds with stale seedbeds. Wheat is more tolerant of delayed sowing than are other winter cereals and a delay may be an advantage in the early spring when the availability of nitrogen is limited, and a larger overwintered crop may suffer, whereas a more backward crop will be more resilient. Late sowing in spring cereals also permits the use of false seedbeds and encourages rapid crop growth in warmer soils but exposes cereals to more pressure from diseases such as mildew and pests such as

frit fly. In practice, however, sowing depends on weather and soil conditions, and where a good, weed-free seedbed can be made in spring it is unlikely that delaying sowing will be advantageous. The inappropriate use of false seedbeds, which result in loss of moisture in dry conditions or loss of soil structure in wet conditions, does no more than delay sowing with little effect on weeds.

Crop management at sowing should aim to establish a green leaf cover quickly so that the crop competes effectively with weeds. There are a number of steps that growers can take to achieve this. Varieties which grow vigorously in the early stages are more likely to smother weeds than varieties which are less aggressive; data for early ground cover and canopy density during stem extension (Richards and Whytock 1993) are useful if available. A higher than conventional seed rate increases the plant density and the chances of early ground cover; seed rates for organic cereals may be increased by 10% or even 20% above conventional rates. Closely-spaced rows, drilling in two directions (cross drilling), and sowing seed in bands rather than in single rows all give more uniform crop plant distribution; most modern drills sow in 12.5 cm row widths or less and it is unlikely that there will be much benefit from sowing closer than this. Large seed size also confers rapid plant growth in the early stages. Growers should consider sowing in an East-West direction where possible, especially where an erect-leaved variety is being grown; there is some evidence that this may reduce weed growth in the row later in the season by increasing shading within the crop.

4.2.2.5 Soil fertility

Good soil fertility management is essential if high yields and quality are to be achieved with organic cereals. Within a rotation which includes conserved grass, field vegetables or potatoes, cereals rarely justify the use of scarce organic manures, but where they are available, spring applications of FYM to winter cereals will give worthwhile responses in yield and quality. Cereals normally rely on rotational sources of nutrients, particularly nitrogen, for example, after a grass/clover ley or after a root crop to which large amounts of FYM have been applied.

Under mixed farming systems the grass/clover ley is the main fertility-building phase of the rotation. In stockless organic systems nitrogen is accumulated in leguminous crops and the organic farmer has to include enough of these in the rotation to sustain the other arable crops. Stockless systems with one fifth of the rotation in fertility-building leguminous crops and one fifth in field beans have proved sustainable on fertile soils at ADAS Terrington (Cormack, 1997, 1999) and elsewhere. Green manures such as red clover can accumulate over 240 kg N/ha in one year when cut and mulched, and will give a financial return if grown on set-aside. Field beans, although less profitable and more risky than other arable crops are justified in a stockless rotation for their ability to provide residual nitrogen for the following crop, although this is unlikely to be more than about 50kgN/ha.

Another source of nitrogen to stockless rotations is through FYM brought onto the farm. However, the standards state that the manurial strategy should not be based on bought-in manure and so the need for this must be justified, e.g. because soil P and K levels are falling. There may, in any case, be problems in finding FYM from non-organic sources since its use from intensive non-organic livestock systems is prohibited; for example, under Soil Association standards, stocking densities for deep litter laying poultry units must not be more than 7 birds/m². Furthermore, total N application as organic manure is limited to 170 kg/ha over a holding under the UKROFS standards and to a maximum of 250 kg/ha to any one field under Soil Association standards.

Timing of organic manure application is also important. The optimum timing is during active growth when crops are making use of available nutrients. Under no circumstances should manures be applied in autumn or winter when nitrogen is likely to be lost through leaching. However, applications to winter cereals can be worthwhile in early spring to meet a shortfall in mineralised soil N. Although not always practicable, the little and often approach to spreading organic manures is the best way to avoid nutrient leaching losses.

Timing of cultivations before sowing cereal crops is important in making nitrogen available and controlling nutrient losses. The ploughing and cultivation of a grass/clover ley before sowing a winter cereal, especially if done early when the soil is warm, encourages mineralisation of more soil nitrogen than the crop can take up. Ploughing in preparation for spring cereal sowing should be early enough to allow time (4 to 6 weeks) for mineralisation to meet crop demands.

Phosphorous and potassium are depleted from organic systems as crops and livestock are sold off the farm. As far as possible, levels are maintained through the recycling of animal manures and crop residues, from external inputs of permitted products and bought-in manures, and from soil reserves. Additions from external sources normally require the consent of the certifying authority, and should not be depended upon to maintain the crop production system. Approved sources of P include rock phosphate, basic slag (no longer generally available in the UK), and calcined aluminium phosphate; approved sources of K include potassium sulphate (categorised 'restricted' and may only be used where soil index <2 and soil clay content <20%), cumulus K ('restricted' waste product from sugar beet industry containing Kali Vinesse), kainit (accepted by UKROFS but not by all certifying bodies), silvinit (contains chloride and is 'restricted'), rock potash, feldspar, keiserite and sulphate of potash-magnesium, etc.. These vary in their availability to the plant from readily to geologically. There are a number of organic 'fertilisers' on the market but their cost can only be justified for high-value horticultural crops.

4.2.2.6 Crop protection

The organic standards do not permit the use of chemical herbicides so weeds are potentially a major problem in organic cereals. The ADAS (1992) survey found weed control to be the most important crop protection problem in organic wheat production. Yield and quality reductions depend on the severity of weed competition; wheat yields have been typically reduced by 20-25% under experimental conditions; yield responses of 40-50% have been recorded after a single weeding in winter wheat. Competition from weeds is greatest in poor growing conditions and there is some evidence that in good conditions weeding may be of little benefit to cereal crops.

The organic farmer's objectives in controlling weeds may differ from those of the conventional farmer: organic farmers aim to contain rather than eradicate weed populations; they are concerned to reduce weed competition in future as well as present crops; they aim to limit weed hosts of crop pests and diseases, but at the same time maintain biodiversity, including the population of beneficial invertebrates, within the field. The basis of good weed control is weed prevention through sound crop rotation; this can include the use of appropriate catch and cover crops before spring cereal crops.

Different cereal species have different abilities to suppress weeds. Oats suppresses weeds better than barley and barley better than wheat; the short upright, spiky growth habit with few tillers of many modern wheat varieties is not suited to competing with weeds. Older varieties such as Maris Widgeon perform better in this respect.

Control strategies for weeds are not easily generalised and depend on the weeds present in a particular situation; tap-rooted weeds (e.g. poppy) need autumn control in winter cereals whilst weakly-rooted climbing or scrambling weeds (e.g. chickweed) are most effectively controlled in spring. Annuals such as mayweed may be killed with one well-timed hoeing; rhizomatous weeds need more than one weeding; a whole-farm strategy including shallow ploughing, the use of forage crops and specific measures such as roguing, inter-row cultivating and pre-drilling weed strikes, are best for wild oats. Some weeds (e.g. blackgrass) may be stimulated by mechanical weeding. To give the best opportunity for weed control, cereals in the rotation should be alternated between winter-sown and spring-sown.

Some indirect methods of weed control in cereals have already been discussed: crop rotation, fallowing, use of aggressive crop species and varieties, manipulation of sowing date, sowing density, plant arrangement and seed size. Other, more direct, methods include undersowing with grass-clover, mechanical cultivation after sowing and after crop emergence, cultivating in darkness, and the use of thermal (flame) weeders. Undersowing, in which the grass-clover mixture occupies the space between the cereal plants and competes with emerging weeds, has the benefit of contributing to the nitrogen requirements of the following crop. Where undersowing is aimed at establishing a ley rather than controlling weeds, cereal seed rates may have

to be reduced by about 5%. When undersowing with a vigorous species such as red clover, sowing the red clover later than the cereal may be required in order to reduce the competition from the clover. Cultivation in darkness, or with the cultivator enclosed in a light-proof shroud, has been shown to result in less weeds of certain species (e.g. chickweed, fat hen, annual meadow grass) the seeds of which need exposure to light in order to germinate. The effect, however, may not persist long enough to benefit either winter or spring-sown cereals in terms of grain yield (Bulson *et al.*, 1996).

Mechanical methods of weed control in cereals include harrowing before crop emergence, inter-row cultivation and non-selective harrowing after crop emergence. Inter-row hoeing is relatively uncommon on cereals in the UK; it is expensive relative to the crop value and when machines are used require the crop to be grown in wide rows (24 cm or more) to avoid problems with machine guidance. It is to be expected that as guidance systems are improved speed of operation will increase and weeding will be possible closer to the crop rows. Inter-row hoeing by hand, however, has been carried out in normal narrow rows (12.5cm) in experimental plots. Non-selective harrowing, using a fine spring-toothed harrow such as the 'harrowcomb' weeder, can be very effective in reducing weed numbers if used in suitable conditions but may not always give significant increases in yield due to crop damage and covering. Weed reductions of 0-70% have been recorded depending on crop, growth stage, weed species and numbers, soil conditions and timing. The benefits of harrowcomb weeding must outweigh crop damage if it is to be worthwhile and its main effect may be in reducing future weed problems. Harrowing is carried out in dry conditions that allow desiccation of uprooted weeds, when weeds are small (cotyledon/first leaf), preferably at about GS13 of the cereal crop and again during tillering. Where spreading weeds such as cleavers are a problem at later stages, it is claimed that the harrowcomb can be used up to ear emergence in cereals; this would seem more appropriate to silage than grain crops which could suffer ear damage and poor grain set as a result of harrowing.

Timing of harrowing is critical and determines whether weed or crop dominates the system. Attempts have been made to establish critical periods for weed competition in cereals. The critical period in winter wheat has been shown to be between 645°C days and 1223°C days at Elm Farm Research Centre, but this coincides with a period from mid-October to the end of March when soil conditions are likely to be least favourable for weed harrowing. From a practical point of view more than one harrowing may be required; the machine should be used at a relatively fast speed of 10-12 km/hour in line with the crop rows in the first instance and at an angle of 15-20° to the rows on the second occasion in order to remove some weeds from within the rows. Rotary hoes that have hundreds of closely spaced wheels that throw soil over the weeds can be used at an earlier crop growth stage (2 leaf) than the harrowcomb; they are best used on light soils when weeds are at the cotyledon stage.

A wide range of pests has the potential to cause problems in organic cereal crops. Birds remove untreated seed after sowing, rabbits graze the growing crop, slugs, leatherjackets, wireworms and frit fly damage the emerging crop. Vertebrate pests may be controlled by fencing, scaring, trapping, shooting etc. There are limited opportunities to control invertebrate pests although growers have some management options such as manipulating sowing dates for pests like frit fly, using higher seedrates to absorb losses, consolidating the seedbed to minimise wireworm, cultivating to reduce slug populations, trap crops and thermal methods. Permitted insecticidal materials include rotenone (extracted from *Derris* spp.), and pyrethrins (extracted from *Chrysanthemum cinerariaefolium*) and a range of biological materials. In extreme cases, thermal destruction of surface-feeding pests (e.g. leatherjackets) may be employed before the crop emerges.

Fungal diseases are less severe in organic cereal crops than in conventional cereals to which high levels of nitrogen fertiliser are applied; this is because of the higher dry matter content and lower herbage N content of organic crops. Control methods include resistant varieties, variety mixtures, planned rotations, manipulation of sowing dates and winter grazing. Where there is a lot of top-growth during the winter some brief sheep grazing can help reduce diseased green leaf and any weeds that happen to be present. Permitted control agents include sulphur but this is unlikely to be effective against established disease.

4.2.2.7 Harvesting and storage

As far as possible, grain harvest should be timed to avoid artificial drying. Organic crops may be at risk from the mat of weeds in the base of the crop and if lodging or brackling occurs heads will be in the weed layer and harvest difficult. To avoid sprouting and loss of quality, it may be prudent to harvest earlier rather than later.

Growers are bound by the organic standards, the Food Safety Act and the Salmonella Code. Permitted methods for maintaining hygiene in grain stores include vacuum cleaning, steam cleaning, high pressure water cleaning and washing with hyperchlorite in solution (followed by rinsing with potable water). The disinfectant JET 5 from Hortichem, which it is claimed to be active against bacteria, fungi, yeasts and algae, is approved for use by the Soil Association. It is an advantage to leave grain stores empty for 2 to 3 months after cleaning to ensure the store is pest-free, and to test for cleanliness with baitbags. Where insects such as the grain weevil and saw-toothed grain beetle are likely to be a problem it may be necessary to use a permitted insecticide such as Derris or Pyrethrum. For long term storage grain should be at 14% moisture. It is required that all equipment, including, combines, trailers, elevators should be free from contamination by non-organic crop residues. Where oil-fired driers are used growers must ensure that grain is not contaminated with combustion products. Stores should be made vermin-proof with netting, installed to exclude birds, and traps and licenced poisons used for rodents etc. Where conversion or non-organic grain is stored on the same farm, all stores must be clearly marked to avoid any confusion over the status of the

grain. Rented storage must also comply with UKROFS standards. Once in store, grain should be covered with a breathable cover such as hessian to protect it from bird droppings.

The most useful developments in longer term storage of organic grain include controlled atmosphere and to a limited extent, biological control of pests.

4.2.2.8 Seed production

EU Regulation 2092/91 states that crops raised in organic systems should be grown from organic seed, defined as seed produced from crops grown organically for at least one generation. A derogation to the regulation has allowed organic growers who cannot source organic seed to use untreated conventional seed until 31 December 2000; however, it has become apparent that very little organic seed will be available before the derogation expires. The derogation has now been extended until 31 December 2003. If seed does not become available before the end of this period farmers will be faced with using unfamiliar varieties, varieties not suitable for their conditions or, more probably, home saved seed. Seed quality could be a problem for some home-saved seed. In a small trial conducted by EFRC organically produced spring wheat seed had a lower germination and vigour than untreated conventional seed. The extra period to the end of 2003 should be used to stimulate organic seed production. The demand for organic cereal seed is expected to more than double in the five years to 2002 (Cook, 2000). At present 97% of crop varieties for which organic seed is available are vegetables and only 1% cereals, and this of only 3 cereal varieties. A major problem is that organic agriculture is likely to need small quantities of a large number of varieties of many species; this is not compatible with the objectives of most large breeding companies. Organic cereal growers, like organic potato growers, could overcome the problem by multiplying conventional seed for their own use, although seed quality could be a concern.

In response to the problem of organic seed Elm Farm Research Centre (EFRC) set up the Seeds for the Future Initiative which aims to link breeding, production and the final product. EFRC has also taken significant steps towards setting up a European Centre of Organic Plant Breeding, and has established the Organic Seed Producers Company which has the aim of producing significant quantities of organic seed in the major species and varieties used by organic farmers. Varieties available from this company for sowing in spring 2000 included the spring barleys Chariot and Hart and the spring wheat Axona. Prices are higher than for conventional seed, reflecting current values for organic grain; autumn sown wheat and oats seed is expected to cost from £435 to £460/tonne. Another company, Demeter Seeds Stormy Hall, specialises in organic vegetable and flower seed.

4.3 Survey of organic cereal crops

4.3.1 Farm data

In the survey carried out by SAC for this review, seventy five farmers were questioned, of which 40 were by telephone. Out of the total, 5 farms were still in conversion and are not included in the tables below. All others had all or some land fully converted to organic cereal production. Where there was more than one, details of the two cereal crops with the largest areas were requested for each farm. This gave records for 108 crops. Farms have been grouped by region, corresponding to those used by NIAB for regional recommendations of cereal varieties (Appendix 3). No farms were recorded in the North West region, either because respondents were still in conversion or they were unwilling to answer the questionnaire.

Farm details are given in Table 4.9. The random sample included more farms in the SW region than elsewhere. Average farm size was a little under 200 ha, but this includes farms with extensive areas of permanent grazing and it is thought that some farmers may have included unconverted or in-conversion land in the farm size. Nevertheless, the data do not suggest that organic farms are small. Average cereal area per farm ranged from 20 ha in the NE to 39 ha in the SW. The higher altitude of the SW farms reflected the inclusion of upland parts of Wales. The proportion of fertility-building crops (grass/clover plus other legumes) in the rotation was relatively constant and ranged from 49% in the SE to 59% in the SW.

Table 4.9. Averages for surveyed farms.

	No. in survey	Farm size ha	Rainfall mm	Altitude m	Cereal area ha	Grass/ clover in rotation %	Fertility building crops %
South west	32	210	866	125	39	55	4
South east	14	148	627	62	30	36	13
Central	9	145	697	70	32	44	6
North east	15	222	756	116	20	52	3
Overall	70	192	773	101	32	47	6

Farm livestock were predominantly beef cattle and sheep, with relatively similar proportions of each in all regions except the SE where pigs and/or poultry were found on 36% of farms (Table 4.10).

The overall distribution of soil types did not indicate that organic farms are found mainly on lighter or heavier soils, although there were relatively more heavy soils in the SW than in other regions (Table 4.11).

The number of farms in each region growing different cereals is shown in Table 4.12. Winter wheat was grown on more than half the farms surveyed in the SW, SE and Central regions, on one farm in Tyneside but not at all in Scotland. Spring barley was most popular in the Central and NE regions and spring oats in Scotland. Winter oats was popular in the SW. Winter barley was not widely grown. Winter wheat had the greatest area on surveyed farms with spring oats second and spring barley third (Table 4.13).

Table 4.10. Animals kept on surveyed farms (numbers of farms).

	Dairy	Beef	Sheep	Pigs	Poultry	Goats	Other*
S.W. (32)	12	21	18	8	3	0	3
S.E. (14)	4	4	10	5	5	1	1
Central (9)	3	7	5	2	3	0	1
N.E. (15)	2	11	8	3	3	1	1
Overall %	30	61	59	26	20	3	9

*Mainly horses

Table 4.11. Occurrence of soil types (numbers of farms).

	Sand	Sandy loam	Loam	Silt loam	Clay loam	Silt	Clay	Peat/fen	Other*
S.W. (32)	2	6	12	1	16	1	7	1	12
S.E. (14)	4	7	3	1	3	0	2	0	2
Central (9)	1	2	2	1	0	1	3	0	1
N.E. (15)	0	6	5	1	6	0	1	0	1
Overall %	10	30	31	6	36	3	19	1	23

*Mainly brash and green sand

Table 4.12. Occurrence of cereal crops on surveyed farms (numbers of farms).

Region	Winter wheat	Spring wheat	Winter barley	Spring barley	Winter oats	Spring oats	Triticale	Rye
S.W. (32)	19	10	3	11	9	9	7	0
S.E. (14)	8	3	0	4	2	5	4	1
Central (9)	5	1	1	5	1	2	2	0
N.E. (15)	1	0	0	7	1	8	0	2
Overall %	47	20	6	39	19	34	19	4

A substantial proportion of growers bought in nutrients (Table 4.14). Less bought in potash than phosphate, only one bought in organic wastes and only two proprietary organic fertilisers. Seaweed products were used on a number of crops. Two out of five growers gave priority to cereals when deciding which crops should receive home-produced organic manures; grazed grass had the lowest priority (Table 4.15).

Table 4.13. Area of cereal crops (percent of total cereal area on surveyed farms).

	Winter wheat	Spring wheat	Winter barley	Spring barley	Winter oats	Spring oats	Triticale	Rye
S.W. (32)	41	12	7	13	5	11	12	0
S.E. (14)	50	4	0	6	7	17	9	8
Central (9)	55	24	6	9	1	2	2	0
N.E. (15)	4	0	0	36	4	54	0	2
Overall %	40	10	4	14	4	17	9	2

Table 4.14. Bought-in nutrients (numbers of farms).

	Lime	Phosphate	Potash	Organic manure	Organic waste	Organic fertiliser	Other *	None
S.W. (32)	18	13	7	5	1	0	4	4
S.E. (14)	5	7	4	3	0	0	5	5
Central (9)	4	2	1	2	0	0	1	1
N.E. (15)	11	6	3	6	0	2	4	0
Overall %	54	40	21	23	1	3	20	17

*Mainly seaweed products

Table 4.15. Priority crops for home-produced organic manures (numbers of farms).

	Cereals	Roots	Grass grazed	Grass cut	Vegetables
S.W. (32)	14	6	3	13	4
S.E. (14)	6	4	1	5	3
Central (9)	3	3	3	4	3
N.E. (15)	5	9	0	3	4
Overall %	40	31	10	36	20

Some two thirds of organic farmers relied on their own experience in managing cereal crops, whilst nearly 40% used the Elm Farm Organic Advisory Service. Private consultants were not a major source of advice; ADAS and SAC were used more in the Central and NE regions than in the SE and SW (Table 4.16). Other advice was taken from merchants, farm walks, other sector body consultants, and published sources.

Table 4.16. Sources of advice on organic cereal production (numbers of farms).

	ADAS/ SAC	Press articles	Elm Farm Advisory Service	Private consultant	Own experience	Friends/ neighbours	Other *
S.W. (32)	0	8	12	4	26	11	4
S.E. (14)	1	3	10	0	5	3	3
Central (9)	2	3	5	0	5	1	4
N.E. (15)	8	4	0	2	11	3	0
Overall %	16	26	39	9	67	26	16

*Mainly merchants.

4.3.2 Crop data

The findings from the 108 questionnaires from individual crops were separated for crop type. There were only two winter barley crops and a single rye crop, grown for seed in Aberdeenshire. Percentages may not add to 100 since many crops fell into more than one category (e.g. barley intended for malting with some retained for feed) and some questions were not answered.

Table 4.17 shows that winter and spring wheats were mostly aimed at the milling market (72 % and 60% of crops respectively). Nearly 40% of the spring barley crops would be offered for malting with nearly 60% retained for feed; about half the oats were intended for milling.

Table 4.17. Cereal markets for surveyed crops (number of crops).

	Kept for feed	Sold for feed	Sold for malting	Sold for milling	Other*
W wheat (32)	7	9	0	23	2
S wheat (10)	3	2	0	6	2
W barley (2)	1	1	1	0	0
S barley (23)	13	2	9	0	1
W oats (8)	5	2	0	4	0
S oats (23)	10	3	0	12	1
Triticale (9)	6	4	1	0	0
Rye (1)	0	0	0	0	1

*Straw for thatching (2 crops), own mill (3 crops), seed (2 crops).

Weed control was based mainly on rotation (72%) and high seed rate (49%) with a high proportion of crops also being harrowed (e.g. harrowcomb) (59%) to control weeds (Table 4.18). Undersowing, narrow row spacing (although most drills now use 'narrow' rows), cross drilling and directional drilling (e.g. east-west) were not as widely used. Some triticale growers thought of this crop as good at smothering weeds.

Table 4.18. Methods of weed control in surveyed crops (number of crops).

	Rotation	Aggressive variety	High seed rate	Under-sowing	Narrow rows	Cross drill	Direction of drilling	Harrow
W wheat (32)	26	11	17	2	5	0	0	26
S wheat (10)	7	2	7	2	3	2	1	6
W barley (2)	1	0	2	0	0	0	0	1
S barley (23)	15	9	6	7	1	1	0	13
W oats (8)	5	2	5	0	1	0	0	3
S oats (23)	18	8	9	7	4	3	1	10
Triticale (9)	6	6	7	1	1	1	0	5
Rye (1)	0	1	0	0	0	0	0	0
Overall %	72	36	49	18	14	6	2	59

Crop rotation was also regarded as the main provider of nitrogen to organic cereal crops (Table 4.19). A number also received home-produced organic manures but few crops justified the cost of bought-in organic manures or benefitted from green manures in the rotation. Other methods of obtaining fertility included residual soil N from outdoor pigs, and heavy manure applications to previous crops such as potatoes.

Table 4.19. Methods of providing N fertility in cereal crops (number of crops).

	Rotation	Home produced organic manure	Bought-in organic manure	Green manures	Other*
W wheat (32)	31	16	2	7	2
S wheat (10)	9	5	3	1	0
W barley (2)	2	1	0	0	0
S barley (23)	19	13	2	2	1
W oats (8)	7	3	0	0	0
S oats (23)	20	9	2	2	1
Triticale (9)	9	5	0	1	1
Rye (1)	0	0	1	0	0
Overall %	90	48	9	12	5

*Mainly outdoor pigs.

Little seed was home-saved, the majority of surveyed crops being sown with bought-in 're-cleaned only' seed, and only about one fifth of seed being bought from organic sources (Table 4.20). Seed source did not appear to affect estimated crop yield (see later).

Table 4.20. Seed source for surveyed crops (number of crops).

	Home saved	Bought-in organic	Bought-in non-organic
W wheat (32)	8	9	18
S wheat (10)	0	0	10
W barley (2)	0	0	2
S barley (23)	7	6	11
W oats (8)	2	0	6
S oats (23)	7	5	12
Triticale (9)	2	1	8
Rye (1)	0	1	0
Overall %	24	21	62

Only two (undersown) spring crops were sown at a below-average seed rate. In nearly 70% of crops comparatively high seed rates were used (Table 4.21). Seed rate had a significant influence on yield (see later).

Table 4.21. Seed rate of surveyed crops in comparison to 'average seed rate' (number of crops).

	Below average	Average	Above average
W wheat (32)	0	8	24
S wheat (10)	0	1	9
W barley (2)	0	0	2
S barley (23)	1	11	11
W oats (8)	0	3	5
S oats (23)	1	5	16
Triticale (9)	0	1	8
Rye (1)	0	1	0
Overall %	2	28	69

An important part of the survey was to identify problems in growing organic cereals. Apart from the one crop of rye the most common problem was controlling weeds (Table 4.22). In winter wheat achieving quality (for milling) was mentioned by 19% of growers and in spring barley, pests, particularly rabbits, were a problem in 35% of crops. Lack of fertility was cited as a problem in about 20% of spring barley, triticale and spring oats crops, these being least likely to follow leys and other fertility building phases of the rotation (Table 4.23).

Table 4.22. Perceived problems of growing organic cereal crops (number of crops).

	Unsuitable varieties	Lack of fertility	Weeds	Achieving quality	Disease	Pests
W wheat (32)	5	3	24	6	6	3
S wheat (10)	1	1	5	1	1	2
W barley (2)	0	0	2	0	0	0
S barley (23)	2	5	12	2	3	8
W oats (8)	1	1	2	1	0	0
S oats (23)	5	4	9	3	2	1
Triticale (9)	1	2	3	1	1	1
Rye (1)	0	1	0	0	0	0
Overall %	14	16	53	13	12	14

Table 4.23. Previous crops in surveyed cereal crop (number of crops).

	Estimated fertility level from previous crop*			
	High	High/moderate	Low/moderate	Low
W wheat (32)	23	4	4	0
S wheat (10)	3	4	1	2
W barley (2)	0	0	0	2
S barley (23)	9	4	4	5
W oats (8)	3	0	2	3
S oats (23)	7	2	5	9
Triticale (9)	2	2	1	4
Rye (1)	0	0	0	0
Overall %	44	15	16	23

*High: after a grass ley. High/moderate: after beans, set-aside etc.
Low/moderate: after roots, potatoes. Low: after cereals.

When choosing varieties, only about one in five growers used the official recommended leaflets and 39% relied on their own experience to choose a variety (Table 4.24). Over one third of farmers chose a variety on the advice of merchants or buyers, or because that was the only untreated seed available. Cereal varieties in surveyed fields are listed in Table 4.25. In some cases more than one variety was being grown; in others the variety name could not be recalled.

Table 4.24. Source of variety advice (number of crops).

	NIAB/SAC	Press article s	Elm Farm	Private consultant	Own experience	Friends/ neighbours	Other*
W wheat (32)	6	4	6	3	14	2	11
S wheat (10)	3	2	1	2	2	0	5
W barley (2)	0	0	0	1	1	0	1
S barley (23)	6	1	2	2	7	1	9
W oats (8)	2	1	2	1	1	0	2
S oats (23)	2	0	1	3	13	0	9
Triticale (9)	2	1	1	1	4	1	3
Rye (1)	0	0	0	0	0	0	0
Overall %	19	8	12	12	39	4	37

*Mainly merchants, but also available seed and buyers.

Table 4.25. Varieties in surveyed crops

W wheat (31)	Hereward (10), Shamrock (6), Maris Widgeon (5), Spark (3), Rialto (3), Axona (3), Malacca (2), Abbot (2), Claire (2), N.59, Hussar, Eclipse.
S wheat (10)	Chablis (4), Axona (2), Avans, Paragon.
W barley (2)	Fighter, Regina.
S barley (23)	Chariot (9), Hart (3), Optic (2), Chalice (2), Dandy (2), Riviera, Maresi, Plumage Archer.
W oats (8)	Gerald (3), Jalna (2), Aintree, Solva, Dunkeld.
S oats (23)	Valiant (4), Melys (3), Amigo (3), Drummer (2), Revisor (2), Dula (2), Banquo, Aberglen, Winston, naked variety.
Triticale (9)	Purdy (3), Trinidad 2, Taurus (2), Fidelio.

4.3.3 Crop yields

Growers' estimated grain yields were examined in relation to location and agronomic factors in stepwise regression analyses. Differences between farms accounted for 35% of the variation in estimated yields. There were no significant differences between regions nor was there any consistent effect of altitude, average annual rainfall, amount of grass/clover in the rotation or amount of other fertility-building crops in the rotation (but there was evidence of an inverse relationship between farm size and estimated yield). There were significant yield differences between cereals; winter cereals were higher yielding than spring-sown crops with winter wheat expected to yield more than the other winter cereals (Table 4.26). Previous crop had a significant effect on estimated yields which were higher after grass/clover leys and roots/potatoes, than after other legumes/set-aside and cereals (Table 4.27). There was no significant effect of seed source on grain yield (Table 4.28). Expected grain yields from different seed rates were significantly different although there was no real difference between the average and higher than average rates (Table 4.29).

Table 4.26. Estimated cereal yields.

	Estimated grain yield t/ha
W wheat (32)	4.7
S wheat (10)	4.1
W barley (2)	4.6
S barley (23)	3.7
W oats (8)	4.6
S oats (23)	4.1
Triticale (9)	4.4

Table 4.27. Effect of previous crop on estimated grain yield.

	Estimated grain yield t/ha
Ley	4.4
Legume	4.1
Roots	4.3
Cereal	4.0

Table 4.28. Effect of seed source on estimated grain yield.

	Estimated grain yield t/ha
Home saved	4.5
Bought-in organic	4.1
Bought-in non organic	4.3

Table 4.29. Effect of seed rate on estimated grain yield.

	Estimated grain yield t/ha
Below average	2.8
Average	4.4
Above average	4.3

4.4 Problem areas identified by organic farming advisers

The following areas, where information on organic cereal production is lacking, were highlighted by field advisers.

- Weed control, particularly techniques for mechanical control in growing crops and the problems associated with perennial weeds such as docks, creeping thistle and couch. Wild oats was also regarded as a difficult weed to control in organic systems, whereas opinions varied on the size of the problem caused by aggressive annual weeds such as cleavers and chickweed.
- Crop nutrition and the lack of reliable data with which to construct nutrient budgets. There was a lack of information on the ability of fertility-building crops and of bicropping systems (e.g. sowing a cereal crop into an established clover sward) to supply nutrients to cereal crops.
- Undersowing of cereals with grass/clover mixtures. There are no clear guidelines on seed rates, soil fertility, cereal variety, etc., all of which can influence the balance between cereal, weeds and the undersown mixture.
- Cereal seed rates. High seed rates are recommended but organic cereal seed is expensive. There is insufficient information about conditions in which lower seed rates can be safely used.
- Variety selection. There is a lack of comparative information on cereal varieties grown under organic conditions. Desirable agronomic characteristics for organic cereal varieties may differ from those of conventional varieties. Characteristics such as early establishment and ground cover are likely to be important in organic situations.

- Seed, in particular the problems associated with home-saved seed. Guidelines for the production of good quality, disease-free organic seed are required.
- Pests, particularly control methods for slugs and leatherjackets.

5 Literature Review

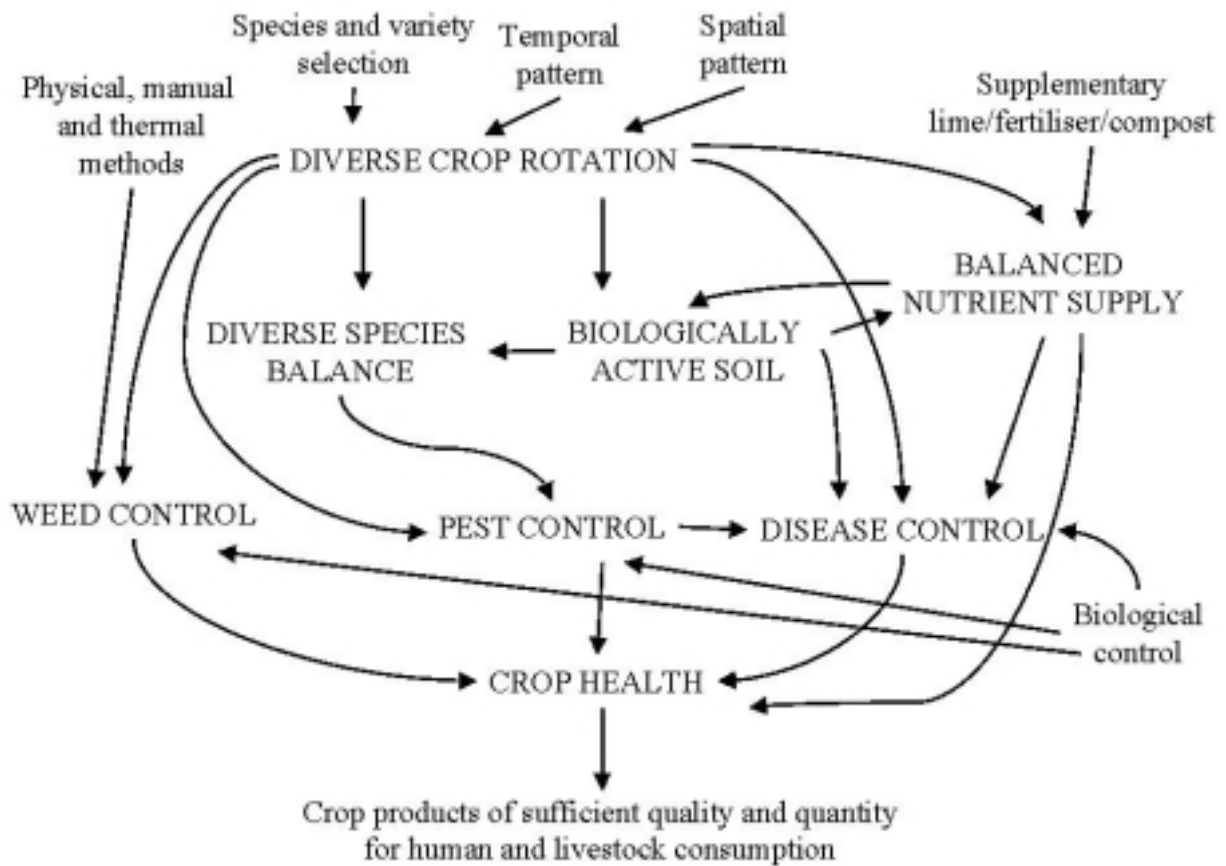
5.1 Introduction

The scientific literature in organic cereal crop production of the past 15 years was reviewed. The papers were largely of European origin, and included literature published in French and German. Published research work covered a wide breadth, e.g. on-farm surveys of current practice; farming systems trials established to compare organic, integrated and conventional production; detailed process-based studies of particular issues, e.g. nutrient supply and crop protection. Researchers carrying out work in organic cereal production throughout Europe also provided details of current projects, which may not yet be published in the scientific literature. A table of ongoing and recently completed research relating to the production of organic cereals listed in MAAF project OF0171 "A review of current European research on organic farming" (Keatinge, 1999) is presented in Appendix 5.

It is clear from the literature that it is not possible to consider organic cereal production in isolation. Contrary to conventional crop production, where crop management factors can be largely optimised individually for single crops or enterprises, organic farming systems are managed as a single unit ('an organism', Steiner, 1970). Central to crop production in organic agriculture is the design of a sound crop rotation which minimises the propagation of disease and ensures N supply through the use of N fixing crops (Askegaard *et al.*, 1999); cereal production may be one component of this rotation in both mixed and stockless systems. The crop sequence (including species and variety choice) in part depends on the balance of enterprises on the farm and will be constrained by the soil type and climatic conditions (Millington *et al.*, 1990). Organic agriculture therefore concentrates primarily on structural adjustments to the whole farm and farming system, and focuses on the protection of crop health rather than the treatment of disease (Woodward and Lampkin, 1990). Tactical management practices, e.g. manure management and cultivations, then interact with this structure to determine the productive success of the whole rotation. External inputs and direct methods of intervention are adjuncts to this management of internal features (Woodward and Lampkin, 1990). The interaction of structural and tactical management together dictate the extent to which objectives of maintenance of soil fertility and the control of weeds, pests and diseases is achieved in practice (Figure 5.1). Successful cereal production in organic farming systems cannot therefore be considered separately from the management of the whole rotation, and indeed the whole farm system. While this review attempts to draw out the components of structural and tactical management which impact directly on cereal production, the overriding context of the whole farm system in terms of economic and environmental resources, must be considered (Kho, 2000).

Research work in organic cereal production often therefore overlaps a number of scientific disciplines and attempts to integrate across a range of scales from process to field, farm and landscape. The scientific literature is reviewed below in disciplinary sections. However, overlap between sections will occur, since on an organic farm there is not one method of weed control or nitrogen supply: leys, green manures and

Figure 5.1. The interaction of structural and tactical components of organic crop production systems (from Stockdale *et al.*, 2000). © Academic Press 2000. Reproduced with kind permission.



appropriate cultivations interact to serve both these functions and others. Attention will be drawn to links between sections which arise because of interactions between management practices. Many of the reviewed papers included the results of surveys of current organic farming practice and crop yields, often compared to conventional crops and yields, and indicated some of the key problems for organic cereal production in terms of crop nutrition, weeds, pests or disease.

5.2 Organic farming surveys

5.2.1 Crop yields and quality

The earliest on-farm comparison between organic (at the time called bio-dynamic) and conventional cereal yields was carried out in the 1930's in Germany, when bio-dynamic farms significantly out-yielded the conventional comparison (Stanhill, 1990). However, yields have increased rapidly in conventional farming systems since 1945 with increasing intensity of production practice and a more recent comparison in the same region of Germany showed that organic farms had cereal yields about 70% of those in conventional production (Stanhill, 1990). In Denmark, winter cereals on organic farms yielded 68% of those of those on conventional farms and spring cereals 77% (Halberg and Kristensen, 1997). Comparisons with conventional production can be limited due to the use of different varieties and to the different proportions of milling and feed wheats in the rotation (Halberg and Kristensen, 1997). Estimates of average yields of organic winter wheat in the UK around 5.5 t/ha are common. However, cereal yields are highly variable depending on position in the rotation, site and season. In the UK, Woodward and Lampkin (1990) suggest that yields of winter wheat are typically 4-6 t/ha, with some yields over 7 t/ha. Unwin *et al.* (1990) measured a yield range of 3.8-6.8 t/ha for organic winter wheat.

Table 5.1. Average cereal yields measured in on-farm surveys

Winter wheat	5.3 t/ha, UK (Woodward and Lampkin, 1990) 5.5 t/ha, UK (Unwin <i>et al.</i> , 1990) 5.6 t/ha, UK (Dover and East, 1990) 3.3 t/ha, Baden Württemberg, Germany (Woodward and Lampkin, 1990) 3.6 t/ha, Hessen, Germany (Von Fragstein, 1996)
Spring wheat	2.8 t/ha, Baden Württemberg, Germany (Woodward and Lampkin, 1990)
Winter barley	3.5 t/ha, Baden Württemberg, Germany (Woodward and Lampkin, 1990)
Spring barley	2.6 t/ha, Baden Württemberg, Germany (Woodward and Lampkin, 1990)
Winter rye	3.0 t/ha, Hessen, Germany (Von Fragstein, 1996) 3.2 t/ha, Baden Württemberg, Germany (Woodward and Lampkin, 1990)
Oats	3.2 t/ha, Baden Württemberg, Germany (Woodward and Lampkin, 1990)

In trials with farming systems, organic cereals yielded 75% of the conventional comparison in Finland (Poutala *et al.*, 1994), 67% in stockless rotations and 80% in rotations including forage in Norway (Eltun, 1996), and 60% of the conventional comparison in Sweden (Helander, 1997). In farm-scale trials of stockless rotations in the UK winter wheat has yielded 6.3-9.8 t/ha on Grade I/II land at Terrington

(Cormack, 1997) and averaged 5.2 t/ha on Grade II/III land in Leicestershire (Leake, 1996). Bread-making winter wheat varieties yielded 3.2-4.3 t/ha in trials in the Cotswolds (Gooding *et al.*, 1998).

Protein contents of organic wheat are almost always lower than conventionally grown wheat (Starling and Richards, 1993). Gooding *et al.* (1997) in variety trials of bread-making varieties of winter wheat measured crude protein between 8.4 and 9.6% and Hagberg Falling Numbers between 200 and 320. However, specific weights were not a major constraint to marketing bread-making varieties (Gooding *et al.*, 1999). Spring wheats often had higher protein levels but these were still below the 10.5% crude protein target for milling (Cormack, 1997). Trials with winter and spring wheat in Germany (Landessorten- und Anbautechnische Versuche, 1999) achieved protein levels between 10.2 and 12%. Eltun (1996) could not find any difference between cadmium levels, mycotoxins or pesticide residues in wheat harvested from the farming systems comparison trial in Norway.

5.2.2 Main problems identified

Cook (1997) carried out a survey of 14 organic farms in the UK and found that losses due to disease were low. However, there was a higher incidence of foliar disease than on treated conventional comparisons with *Septoria tritici* the most common severe foliar disease. Ear disease incidence and severity were low and stem base diseases were less severe in organic cereals than in conventional comparisons. Weed competition was the most consistent and potentially damaging crop protection problem.

In farm-scale trials of stockless rotations in the UK, Cormack (1997) found that populations of *Cirsium arvense* and *Agropyron repens* were increasing. Leake (1996) noted that under organic conditions populations of *Avena fatua* were increasing and that perennial weeds might also be reaching levels that would reduce crop yields in the near future.

Weed species identified in on-farm surveys are listed in Table 5.2.

Table 5.2 Weed species identified in on-farm surveys
(listed in order of frequency of occurrence in each survey)

Unwin <i>et al.</i> (1990)	UK	<i>Polygonum</i> spp. <i>Sinapis arvensis</i> <i>Poa trivialis</i>	
Von Fragstein (1996)	Germany	<i>Cirsium arvense</i> <i>Agropyron repens</i> <i>Alopecurus myosuroides</i>	
Eisele (1998)	Germany	<i>Cirsium arvense</i> <i>Vicia hirsuta</i> <i>Agropyron repens</i>	
Cook (1997)	UK	<i>Stellaria media</i> <i>Poa annua</i> <i>Veronica persica</i> <i>Matricaria</i> spp. <i>Rumex</i> spp.	in some cases likely to cause yield loss in many cases likely to cause yield loss

5.2 Crop nutrition

5.3.1 Nitrogen

The inclusion of crops within the rotation that are able to fix nitrogen through a symbiotic relationship with nodulating nitrogen-fixing bacteria enables organic farming systems to be self-sufficient in nitrogen (N). In mixed farming systems, medium to long-term grass-clover leys are included in the rotation. These are utilised for fodder, fix significant amounts of N, and act to restore soil structure and maintain soil organic matter levels (Younie *et al.*, 1996). In stockless systems, however, it is often not financially feasible to include a long-term fertility-building phase in the rotation. In such systems short/medium term green manures are used instead and these may be cut and mulched or incorporated directly into the soil (Poutala *et al.*, 1994). *Trifolium*, *Medicago* and *Vicia* species are used widely and their incorporation has been shown to increase the yield of a following crop (Thorup-Kristensen, 1994; Stopes *et al.*, 1995; Ogren *et al.*, 1998). While N supply is a critical factor in increasing following crop yields, additional yield increases may also be seen that cannot be entirely attributed to N supply (e.g. Campiglia *et al.*, 1992). These may reflect an improvement of soil structure or disruption in the transmission of weeds, pests or disease through the rotation.

White (1987) estimates that nodulated crops fix c. 200 kg/ha/year N in temperate regions. However, the actual amount fixed at any site in any year is dependent on soil and climatic conditions and the choice of variety or cultivar (e.g. Ledgard and Steele, 1992). In the UK, a productive grass/white clover ley is likely to fix between 100 and 200 kg/ha/year N (Whitehead, 1995). In grain crops much of the fixed N is removed in grain and returns of crop residues contribute little to the following crop (Sprent and t'Mannetje, 1996). In forage crops, the amounts of N fixed are also affected by the balance between cutting and grazing, stocking densities and manure and slurry applications (Ledgard and Steele, 1992). Recently, a number of simple models have been published for predicting nitrogen fixation in leguminous swards (e.g. Watson and Goss, 1997; Korsath and Eltun, 2000). These models require refinement and validation under different conditions to fully take into account the impact of the management factors mentioned above. Good estimation of the pattern of N release from grass-legume residues during the first and subsequent seasons after incorporation will improve the management of organic cereals.

The management of N-fixing pre-crops is critical for the success of cash crops within the rotation (Temple *et al.*, 1994). However, there has been little work on the most appropriate management systems for N-fixing green manures. Stopes *et al.* (1995) showed that there was no increased yield benefit from a 2 year compared to a one year red-clover ley when they were cut and mulched and crop height was not allowed to exceed 40 cm. N fixation is reduced where crops are cut and mulched compared to removing the cut material, as the mulched crop supplies N and promotes grass growth at the expense of clover (Schnitt and Dewes, 1997). Losses of N from cut and mulched materials, particularly through ammonia volatilisation may be significant but no measurements of such losses have been made. Henriksen *et al.* (2000) showed considerable losses of N from standing clover biomass overwinter, but this was not coupled to any change in soil mineral N and may indicate gaseous losses from frost-damaged foliage. Large leaching losses of N have been measured following the cultivation of grass-clover leys (Watson *et al.*, 1993; Eriksen *et al.*, 1999). Stopes *et al.* (1995) found that c.33% of the N accumulated above-ground in cut and mulched green manures was lost by leaching after they had been incorporated in the autumn. Spring incorporation of green manures or leys reduces the losses of N by leaching (Philipps *et al.*, 1995; Watson *et al.*, 1993). However, this restricts crop choice and Henriksen *et al.* (2000) found that the effect on subsequent growth of spring wheat was better from autumn than spring incorporation of clovers, despite reducing N leaching. Incorporation of clover with straw can be used to partially manipulate the rate of N release (Henriksen *et al.*, 1999).

Spring cereals are widely used, in organic as well as conventional agriculture, as a nurse crop for the establishment of a subsequent ley (Lockhart and Wiseman, 1983). Henriksen *et al.* (1999) demonstrated that the reduction in yield of the nurse crop (c. 0.6 t/ha) was more than compensated for by an increase of 1.35 t/ha in a following spring wheat. Such an undersowing approach to the cultivation of green manures

may be critical where green manure crops are not eligible for set-aside payments. As well as rotational use of N fixing crops, it has been demonstrated that a permanent understorey of clover can be maintained into which a cereal crop is drilled, known as clover-cereal bicropping (e.g. Clements *et al.*, 1996). In Finland systems have been developed for cereals and clover in parallel drills, with the clover cut and mulched to the neighbouring cereal during crop growth (Schafer *et al.*, 2000). However, further development is required in this system, as some damage to the crop occurs when it is buried beneath the mulch material.

Non-leguminous green manures can also be used to help maintain fertility, particularly where they maintain ground cover over winter and conserve nitrogen which would otherwise be leached. Crops such as rye (*Secale cereale*), fodder radish (*Raphanus sativus*) and mustard (*Sinapis alba*) are often used for this purpose, whereas legumes are less effective as catch crops (Thorup-Kristensen, 1993; Rayns and Lenartsson, 1995).

Unwin *et al.* (1990) observed that organic cereals in the UK made slow growth in early spring. Helander (1997) also observed that cereal yields in Sweden were critically limited by N availability particularly in the early growing season. David *et al.* (1999) confirmed that the duration and intensity of temporary N deficiencies has a direct impact on grain number and final yield in organic, as in conventional, cereal production. Tactical use of on-farm sources of N, such as animal manures, can very effectively increase yields and grain protein depending on the timing of applications (David *et al.*, 1999; Stein-Bachinger and Werner, 1997; Nicholson *et al.*, 1999). There is a high degree of variability in the efficiency of utilisation of N from organic sources (0-60%) and the dependence of this efficiency on climate, soil and rotation means that it may be difficult to predict or control (David *et al.*, 1999). Use of organic manures in rotations has also been shown to confer yield benefits not totally matched by the use of mineral fertiliser (Raupp, 1996). Increasing attention to the management of manures in conventional farming systems means that the suitability of application equipment for use on growing crops and its evenness of spread are increasing (Nicholson *et al.*, 1999). However, little work has been done so far to adapt guidelines for use of manures in conventional agriculture for organic production (but these are in preparation as part of MAFF contract OF0145), or to identify the most suitable timing and rates of use of green-waste composts for cereal production.

5.3.2 Other nutrients

Unlike N, no other nutrient can be fixed from the atmosphere, though small and often sufficient amounts of other nutrients are supplied to the soil through atmospheric deposition and/or weathering of parent materials. Phosphorus (P), potassium (K), sulphur (S) and micronutrient balances range from deficit to surplus in organic farming systems (Nolte and Werner, 1994; Nguyen *et al.*, 1995; Fagerberg *et al.*, 1996; Wieser *et al.*, 1996). This depends on farm management and the balance of imports (livestock feed, straw

for bedding, fertilising materials, deposition) and exports (crop and animal products, losses to the environment) in organic farming systems. Balanced budgets are often more easily achieved in mixed farming systems than stockless systems.

Good rooting depth and extent are critical for maximising the use of available reserves of soil nutrients, particularly those which are less mobile. Good establishment is vital and preparation of a good seedbed to allow rapid root growth and development essential (Askegaard *et al.*, 1999). Arbuscular mycorrhizal fungi (AMF) are non-pathogenic symbiotic fungi, which infect the roots of 95% of crop plants, including cereals. AMF associations increase the root surface area very significantly and therefore improve the uptake of water and nutrients; they may also play an important role in stabilising soil structure (Bethlenfalvay and Barea, 1994). AMF colonisation is suppressed by high availability of phosphorus in soils (Dann *et al.*, 1996; Kurlle and Pflieger, 1996). The use of slowly soluble rock P had no effect on AMF colonisation (Ryan *et al.*, 1994) but also little effect on crop P nutrition in the short-term. The critical importance of AMF in linking soil and plant processes in low-input and organic farming systems is well known (e.g. Douds *et al.*, 1993) and AMF inoculum taken from organic farms was more effective than that isolated from conventionally managed soils (Scullion *et al.*, 1998). However, it is not clear how cropping systems can be managed to increase the effectiveness of such plant-fungal symbioses.

Although significant amounts of potassium (K) are required for crop growth, most of this K is returned to the soil when straw is returned either directly following harvest, or indirectly when it is used as animal bedding then returned in manure, or where reciprocal arrangements for the cultivation of, for example, mushrooms return the resulting compost. Some UK soils are able to supply sufficient K for the reduced yields in organic farming through weathering of soil parent materials (Goulding and Loveland, 1986). Tactical use of manure within the rotation can be critical for recycling nutrients to crops, which most need P and K. Within a mixed rotation, manure use is likely to be targeted to leys cut for silage. Silage effluent may also be a useful K fertiliser within organic systems. However, in stockless systems the management of K may be difficult. There has been little work published on P or K dynamics within organic farming systems and none on micronutrient limitations.

The lower yields and reduced grain protein of organic wheat relative to conventional crops means that currently there is no problem of sulphur (S) deficiency in organic wheat. N:S ratios are typically 12-13 or 15-16 depending on yield level (Hagel and Schnug, 1997). Even where tactical management is targeted to achieve an increase in grain protein, it is likely that the materials used (manures and other organic materials) will contain sufficient S to balance the N addition.

5.4 Weeds

The aim of weed management strategies in organic farming systems is to maintain weeds at a manageable level by structural measures (rotation design, variety choice, sowing date) to ensure that direct control measures can succeed in preventing crop losses. Organic farmers seek to balance the benefits of environmental diversity introduced by weed species (deep rooted weeds may recycle nutrients from depth, weeds act as shelter for natural enemies or trap plants for pests) and yield penalties incurred by competition for resources between crops and weeds (Millington *et al.*, 1990). Crop-weed interactions are well known to be overwhelmingly site and season specific (Welsh *et al.*, 1999), with the degree of competition between crop and weeds dependent on plant factors such as species, density of crop and weed, and environmental/management factors including temperature, tillage and pests (Altieri, 1995).

Early sowing of winter cereals increases weed populations significantly (Leake, 1996; Cosser *et al.*, 1996), so that in the UK drilling after mid-October is optimum (depending on weather conditions) to maximise crop and minimise weed competitiveness. Increasing seed rate (to 450–500 seeds/m², c. 250 kg/ha) reduced pre-harvest weed populations (Samuel and Guest, 1990; Dover and East, 1990); however, there was not always a resulting increase in yield.

Rapid crop establishment and strong early growth are critical to ensuring crop competition is strong (Rasmussen *et al.*, 1999). Crop varieties can be selected to ensure good early competitiveness against weeds. When grown organically, barley seems to compete with weeds mostly for below ground resources (Bertholdsson and Jonsson, 1994), while in oats competition for light seems more important. Such knowledge may be important to allow the ‘best’ varieties to be selected. Wheat varieties with planophile rather than erectophile leaves have been shown to increase ground shading during growth and can significantly reduce weed biomass and seed yield (Eisele and Köpke, 1997). ‘Older’ varieties of wheat in the UK, such as Maris Widgeon, consistently increase early dry matter accumulation, increase height of the canopy and reduce the penetration of photosynthetically active radiation into the canopy (Cosser *et al.*, 1997). The introduction of dwarfing genes and reduced plant heights (Cosser *et al.*, 1995) coincided with increased blackgrass populations and seed yields. However, experiments over several seasons comparing modern varieties with Maris Widgeon showed its growth habit did not always reduce weed numbers or the weed seedbank, and sometimes increases were seen. In the same experiments, early sowing always increased the weed burden (Cosser *et al.*, 1997). Sowing date, rather than variety selection, seems more critical in optimising competition between cereals and weeds.

Intersowing wheat crops with subterranean clover (a living mulch) in Italy has been shown to remove weed biomass (Barberi *et al.*, 1998). Lambin *et al.* (1994) also showed in France that intersowing wheat with clover reduced weed problems after harvest. However, Eisele (1998) has shown that *Vicia hirsuta* can be a significant weed problem reducing yields in organic cereals. Care is therefore needed in establishing

intercrops to minimise competition with the cereal crop. The presence of grass-clover leys in the rotation also retarded the growth of weed populations on farms converting to organic production (Davies *et al.*, 1997). Forage and green manure crops can be used successfully to reduce the available regeneration niches within the rotation for weed species, while seed predation continues. However, it is important that crop rotations disrupt the regeneration niches by using different planting dates, growth periods and dissimilar management practices (Liebman and Davis, 2000).

The allelopathic effects of a number of species have been studied widely. Rye residues are known to reduce the germination and inhibit the growth of some weed species (Przepiorkowski and Gorski, 1994). This may be due to the presence and exudation of hydroxamic acids (Perez and Ormeno-Nunez, 1993) and/or β -phenyllactic acid, β -hydroxybutyric acid and benzoxazolinone compounds (Liebman and Davis, 2000). Triticale has also been shown to have some allelopathic effects (Jaskulski, 1997). Some weed species (e.g. *Ranunculus* spp., *Amaranthus* spp., *Stellaria* spp) have also been shown to exert some allelopathic effects on crop and other weed species, linked to high levels of phenols (Bansal, 1997; Inderjit and Dakshini, 1998). Such effects may be manipulated, if they are understood, through appropriate timings between cultivation and sowing and possibly through the selection of allelopathic varieties (Olofsdotter, 1999). The presence of organic residues on the soil surface might also enhance the activity of indigenous fungal seed pathogens (Liebman and Davis, 2000).

Seedbed preparation is critical, as discussed earlier, and stale seedbed techniques are used widely. However, soil moisture after harvest is critical for weed emergence in the stale seedbed (Bond and Baker, 1990) and stale seedbed techniques are often found to have only limited efficacy (Leake, 1996). Preparation of seedbeds in the dark can have some effect in reducing the germination of weed seeds which have a strong photoblastic response (Welsh *et al.*, 1999). For high value crops precision drilling and inter-row hoeing may be cost-effective strategies, but they are unlikely to be worthwhile for cereals (Lambin *et al.*, 1993; Leake, 1996). Critical weed-free periods can be defined, so that weed control measures can be targeted appropriately (Welsh *et al.*, 1999). However, more work is needed to develop advice, which relates to individual weed species or groups of species, with different competitive abilities (Welsh *et al.*, 1999). The effectiveness of different mechanical weeding strategies is related to both the crop and the soil conditions when they are used (Pedersen, 1990). The effectiveness of covering weed seedlings with soil during cultivations depends on the size of the weed seed, with larger seed requiring a greater coverage of soil (Baerveldt and Ascard, 1999). Brush weeding which also bends weeds before covering them is most effective. Spring-tine harrow weeding is widely used in cereals between tillering and the onset of stem extension; this has been shown to reduce weed biomass without any impact on yield (Samuel and Guest, 1990). However, harrowcomb weeding at times when weed densities are not likely to reduce crop yields has been shown to reduce crop yields (Leake 1996). Spring-tine harrow weeding can also be effective when

used in the autumn (Rasmussen *et al.*, 1999; Welsh *et al.*, 1999) depending on soil conditions. The presence of a catch crop can reduce weed control possibilities and where weed problems are severe, weed control may take priority (Askegaard *et al.*, 1999).

Where winter cereals have accumulated significant dry matter over winter, and before the onset of stem elongation, they may be used as an 'early bite' for the grazing of sheep while grass growth is still scarce. This has the potential to benefit the cereal crop by removing damaged tissues that may act as loci for disease, by providing a small amount of available N in excreta for crop growth, and by reducing seed return from some erect weed species (Gooding *et al.*, 1998). Benefits were seen from grazing in reducing weed biomass without any loss in cereal yield. However, risks of soil damage due to poaching may reduce the opportunities for such a practice to be used in the UK.

Samuel and Guest (1990) showed that there were many more species of weeds in organic than conventional cereal fields, with most at very low densities so they did not cause any yield limitation. Ammer *et al.* (1994) showed that annual weeds were able to complete their full development cycle within organic cereal fields, while they were restricted to margins and other refugia in conventional production. Overall, organic farming seems to have a neutral to beneficial effect on rare arable weeds (Albrecht and Mattheis, 1998). The presence of weed species may act as a bridge for AMF through the rotation (Kurlle and Pflieger, 1996). Organic cereal fields have been shown to support a larger number and greater diversity of arthropod fauna and this has been linked to the presence of an increased diversity of weeds (Hald, 1999). Moreby (1996) also showed that both weed seeds and arthropod species were important sources of 'chick food' for bird species on organic farms.

Weed management in organic systems is best achieved through a combination of these strategic and tactical approaches. However, such a balance requires an increased understanding of crop-weed ecology, particularly with reference to the management of weed species with contrasting growth habits and competitive abilities.

5.5 Pests and diseases

McKinlay (1998) reviewed work on pests and diseases in organic crops. He noted that research input in crop protection which is largely done to benefit conventional agriculture can also benefit organic agriculture e.g. studies on insect pheromones, within-field/within-farm diversification studies such as beetle banks, flowering strips, etc. Three of the reviewed papers dealt with the effects of such refugia on beneficial invertebrates: Carmona and Landis (1999) re refuge strips; Pfiffner and Luka (2000) re undisturbed semi-

natural habitats and extensively managed field margins; and Wratten and Thomas (1990) re beetle banks. Perhaps not unexpectedly, such refugia have been shown to increase the activity of beneficial invertebrates like carabid ground beetles compared with adjacent cropping areas. The most interesting conclusion was drawn by Carmona and Landis (1999): although refugia may lead to increased beneficial invertebrate activity, they do not lead necessarily to increased activity of these invertebrates in adjacent cropping areas. It follows that these natural enemies of crop pests may not be “beneficial” as they do not contribute greatly to pest management. The aim of research should therefore be twofold: to promote cropping systems (including their surroundings) which encourage natural enemies into the crop and, at the same time, diminish pest activity (Ravn and Holm, 1997); and to demonstrate unequivocally that increasing natural enemy activity in the crop leads to decreasing crop pest activity.

McKinlay (1998) drew a number of conclusions from his review. Firstly, more research effort would be needed by experiment rather than by survey, i.e. innovative experimentation in organic farming is to be preferred to comparisons of different farming systems. Amongst the papers reviewed were two which compared the effects of conventional farming and organic farming on invertebrate natural enemies and plant disease severity: Pfiffner and Niggli (1996) and Bruggen (1995), respectively. Results from such comparisons cannot be readily applied. Much more useful would be research into the causes of any interesting differences which may occur between farming systems. The output from this type of research could then be transferred to the benefit of other farming systems (Schuhbeck *et al.*, 1995).

The second conclusion was that more research effort was needed into disease management. The majority of papers reviewed were on this topic. Amongst the subjects covered were: variety and species mixtures for disease management (Dover and East, 1990; Finckh and Mundt, 1992a; Finckh and Mundt, 1992b; Finckh and Mundt, 1993; Finckh and Mundt, 1996; Finckh *et al.*, 1999; Limpert *et al.*, 1996; Wolfe, 1990; Wolfe *et al.*, 1991); surveys of foliar and grain diseases of organically grown wheat (Guest *et al.*, 1990; Higginbotham, 1996; Holm, 1994; Thompson *et al.*, 1993); cultural and biological control (Altieri, 1995; Fokkema, 1996); seed quality criteria in organically grown wheat (Dornbusch *et al.*, 1992); and effect of farming system on the incidence of *Fusarium* foot rot in barley (Knudsen *et al.*, 1999) and on *Fusarium* toxins in wheat (Birzele *et al.*, 1998).

Varietal blends appear generally to reduce the severity of disease, particularly foliar diseases, e.g. mildew on wheat and barley, and yellow rust and leaf rust on wheat (Wolfe, 1990). Although varietal mixtures have no effect on soil-borne diseases, splash-dispersed pathogens such as *Septoria* and *Rhynchosporium* spp. can be managed effectively by mixtures (Wolfe, 1990). Mixtures involving different species of plants, while having a good suppressive effect on weeds, can exacerbate foliar diseases, e.g. a wheat-bean mixture led to a reduction in weed biomass compared to monocropped wheat or beans, but the severity of wheat mildew

increased with increasing bean density (Bulson *et al.*, 1997). Species mixtures have therefore to be used with caution. From the disease management perspective, the principles that underlie mixtures whether of varieties or species are the diversification of resistance and the limitation of exposure to the pathogen (Wolfe *et al.*, 1993). The use of such mixtures is a promising approach to the management of diseases in organic cereal production.

The cultural and biological control of plant diseases is discussed by Altieri (1995). Amongst cultural approaches to disease management are: varietal diversification schemes (Bayles *et al.*, 1990); time of sowing (e.g. early *v.* late); method of sowing (e.g. row spacing, depth of sowing); rotation; undersowing, e.g. wheat or barley with legumes can reduce the severity of take-all; elimination of alternative hosts; deep ploughing of crop refuse; and use of barrier crops. Many of these approaches have not been studied within an organic cereal production system.

Plant diseases can be managed biologically by the use of fungal antagonists such as *Trichoderma* spp. and mycorrhizae and also by green manures and soil amendments (Altieri, 1995). Fokkema (1996) listed the strategies for the biological control of fungal diseases as: microbial protection of host against infection; microbial reduction of pathogen sporulation; and microbial interference with pathogen survival. Knudsen *et al.* (1999) introduced a note of caution regarding the use of microbes for disease management: they found that the increased microbial biomass and activity of soils managed organically did not necessarily lead to increased disease suppression. Despite much research on the biological control of plant diseases, the number of products available is limited (Fokkema, 1996). As McKinlay (1998) suggests, one useful area of research may be to investigate the potential of natural populations of phylloplane microbes (as distinct from artificial populations of phylloplane microbes introduced by, for instance, spraying) to be antagonists of disease-causing pathogens; a similar study of the naturally-occurring populations of microbes in the soil would also perhaps suggest ways of managing their numbers and activity to the detriment of soil-borne plant pathogens.

The quality of seed grain in organic cereal production can be reduced by diseases. Dornbusch *et al.* (1992) found bunt, *Septoria* and *Fusarium* spp. present on seed lots. However, the concentration of deoxynivalenol (DON), the toxin from *Fusarium* spp., in organically produced wheat was not found to be greater than the DON concentration in wheat produced by integrated management (Birzele *et al.*, 1998). Von Spiess and Dutschke (1991) report on a range of natural seed treatments for the control of bunt. These research efforts need to be extended in order to lead to management protocols for the production of cereal seed grain in organic agricultural systems.

McKinlay's (1998) third conclusion was that more research effort was needed into microbial agents for pest and disease management (e.g. *Bacillus thuringiensis* for pest management) and into botanical insecticides (e.g. azadirachtin, the chemical active in neem tree extracts).

The fourth conclusion related to host plant resistance. Ellis (1990) reviewed host plant resistance to pests in organic agriculture and concluded that this type of resistance offers an inexpensive, long-lasting and environmentally acceptable method of plant protection to organic growers. McKinlay (1998), however, pointed out that plant breeding for organic production is aimed at a relatively small market and is unlikely to receive priority. Nevertheless, sources of resistance, if not artificially bred then naturally occurring, must continue to be sought both within varieties and across crop species for the benefit of organic agriculture, e.g. the relative resistances of different varieties of cereals to plant pathogens are essential to the success of the varietal diversification schemes of the United Kingdom Cereal Pathogen Virulence Survey as a disease management measure (Bayles *et al.*, 1990).

McKinlay (1998) emphasised the importance of further studies on polyculture (i.e. intercropping and undersowing). Polyculture is a promising technique for crop pest management in organic agriculture with studies generally showing reduced pest incidence and increased natural enemy activity. The weak link in all such studies is an unequivocal demonstration of increasing natural enemy activity causing decreasing crop pest population densities (McKinlay, 1998).

The penultimate conclusion invoked continuing effort to be expended on infochemical studies of insect herbivore-insect parasitoid/predator and insect herbivore-host plant interactions. Two papers examined the effect of cereal plant allelochemicals on aphid activity: Corcuera *et al.* (1992) and Leszczynski *et al.* (1995). Such studies make important contributions to the understanding of the biology of the target system, whether the insect-plant system or the insect-natural enemy system. Only by developing such understanding can the overall cropping system be manipulated to the detriment of the crop pest.

The final conclusion advocated an increased research effort into plant defence systems against pest and pathogen attack, e.g. systemic acquired resistance and its association with nitrogen fertilisation. Phelan (1997) concluded that the mineral balance of crop plants determines their susceptibility to insect pest infestation. The study of plants' defence systems is an area of research which is currently expanding and will lead eventually to novel developments in the application of crop protection practices to organically grown cereal crops.

To maintain crop health in organic agriculture requires the successful implementation of a largely preventative strategy as curative measures are not so effective or so abundant as they are in conventional

agriculture (McKinlay and McCreath, 1995). For prevention to be successful in the field requires an in-depth knowledge of the ecology of the agroecosystem (Atkinson and McKinlay, 1997), i.e. research is needed on the fundamental processes involved in the ecology of cereal weeds, pests and pathogens.

5.6 Seed

There are almost no cereal varieties available with resistance to seed diseases such as bunt (*Tilletia caries*), smut (*Ustilago nuda*), *Septoria nodorum*, blackpoint (*Alternaria alternata*) or *Fusarium*. However, there appears to be a wide variation among cultivars in susceptibility to blackpoint (Thompson *et al.*, 1993), *Septoria* (Dornbusch *et al.*, 1992), bunt and smut (Spiess, 1999). There is, therefore, the potential to use resistance to seed disease as a target trait for breeding. Bunt contamination of seed caused the rejection of 25-30% of organic seed lots in Germany during the early 1980's (Spiess, 1999). However, a wide range of treatments including warm and hot water treatment, milk powder and other flours, and plant extracts such as garlic, horseradish and mustard are now available and have been shown to significantly reduce the contamination of seed lots by fungal spores (Spiess and Dutschke, 1991).

5.7 Plant breeding

The development of new cereal varieties since 1945 has been associated with a gradual increase in the intensity of production systems and hence the conditions under which varieties are evaluated. However, there is no evidence that 'older' varieties are necessarily better for cultivation under organic conditions as some changes in morphology will also benefit organic cultivation, e.g. increase of harvest index. Le Gouis *et al.* (2000) showed that some modern varieties performed as well or better than older varieties under conditions of low N supply. However, Foulkes *et al.* (1998) showed that the introduction of new varieties bred under conditions of high N seemed to be associated with a declining ability of the crop to effectively use N supplied from the soil. Cosser *et al.* (1997) tested varieties under organic conditions at one site in the UK and showed that the yield potential of the varieties was not related to the average cultivar yields in national testing schemes in the same year. This may be partly due to differences in site conditions, but it suggests that yield potential needs to be assessed under organic management. However, grain quality information obtained from national list trials did relate strongly to data collected under organic conditions (Cosser *et al.*, 1997). Richards and Heppel (1990) suggest that key characteristics of varieties suitable for organic production can be largely obtained from conventional variety trials: high untreated yield potential, high quality for market, and good resistance to local disease. They added an assessment of the speed of ground cover after drilling to these routine assessments in order to identify varieties that would rapidly compete with weeds. These characteristics are also being measured on the 2000 organic variety trials carried out by NIAB (Fenwick, 2000). Karutz (1999) identified the following goals for ecological plant breeding:

- formulation of location-specific breeding goals

- site-orientated action, including the effect of location in the selection processes
- inclusion of comparisons and studies between locations, rather than simple averaging of locations
- considering the place of the crop within the whole rotation and farm context.

5.8 Environmental implications

Organic farming systems have been shown to have the potential to deliver benefits in terms of improved soil quality, environmental protection, enhancement of biodiversity, reduced energy use, reduced CO₂ emissions, reduction of reliance on external inputs and greater sustainability of resource use (Stolze *et al.*, 2000; Stockdale *et al.*, 2000).

6. Future Challenges

6.1 Key agronomic questions

Successful management of organic cereals depends on working with natural processes and involves decisions which affect many components of the production system. For example, time of sowing must balance weed development, soil nitrogen mineralisation, seed bed conditions and risks from pests and diseases. In general, early sowing of organic cereals in the autumn is not advised but delayed sowing can result in below-optimum plant populations and the inability of the crop to compete with weeds. The timing of ploughing, cultivating and sowing a cereal crop influences the amount of mineralised soil nitrogen available at different stages of cereal crop development, and therefore components of yield (including grain size) and grain protein. Optimum timings are likely to depend on the previous crop (old or new grass/clover ley, grain legume, cereal, root crop to which organic manures have been applied, etc.), and will have consequences for weed, pest and disease control. A better understanding of the effects of timing of seedbed preparation and sowing on nitrogen uptake by cereal crops and the consequences for crop protection, grain yield and quality are required.

Seed rates for organic cereals are generally higher than those for conventional cereals. Where seed is expensive there is pressure to reduce seed rates. The risks of low cereal seed rates under organic conditions are not well understood, and will depend on factors such as sowing pattern, seed vigour and size, seed treatment, sowing date, seed bed conditions, and their interactions.

The main crop protection challenge in organic cereals is weed control. Although weeds are best regarded as a rotational problem, effective weed control in established cereals can often be achieved by harrowing, but only for annual weeds. Perennial weeds are an increasing problem, with hand roguing the only tactical method of control available. There is a considerable need to look at the way all husbandry factors (variety, sowing date, seed rate, nitrogen supply, cultivation, etc.) interact in controlling weeds of different competitive abilities. Effective control strategies for perennial weeds could include crop rotation, inter-row hoeing, winter management (e.g. grazing), undersowing with different species, roguing, and the interactions of these factors with pre-sowing and post-harvest cultivation methods.

Nitrogen supply to arable crops in mixed farming systems can be shown to be adequate, but it is a concern in stockless rotations and where grain with a high protein content is required. Stockless rotations often include legumes with no sale income. For example, mulched red clover produces a return on set-aside but there is no certainty that this will always be an option; frequent cropping of red clover (one year in five?) can result in a build-up of stem nematodes, and systems which produce large amounts of nitrogen at one point in the rotation may leak N. Nitrogen fixation and losses from differently managed fertility-building

crops need to be quantified (note MAFF contract OF0178: Improving nitrogen use and performance of arable crops on organic farms using an expert group approach). Nitrogen supplies need to be more tailored to the requirements of organic cereals if they are to achieve high yields of good quality grain. How to achieve this is a major challenge which is likely to involve different nitrogen-fixing crops and incorporation methods, intercropping with legumes (bi-cropping), methods to promote nitrogen mineralisation during crop growth, and the interactions of these with soil types and organic manures and composts or other external nitrogen sources.

Whilst crop management for high grain protein and gluten quality are important in organic bread-making wheat (note HGCA project 2237: Agronomic guidelines for the production of organic wheat), management for low grain nitrogen content is important for organic malting barley and management for large grain size and high specific weight is important in all cereals. The influence of rotation and husbandry on all quality parameters deserves investigation.

Apart from soil reserves, P and K must be added to organic systems from permitted sources (including organic manure, and feedingstuffs), although routine inputs of some materials (e.g. potassium sulphate) are not compatible with organic farming principles. Many organic cereal crops are produced on soils with low P and K indices; the extent to which this reduces yield and quality and influences other components of the system is not known (note MAFF contract OF0114: Optimisation of P and K management in organic farming systems). As the length of time over which land has been farmed organically increases, limitations imposed by other nutrients (e.g. sulphur and micronutrients) may become important. For organic systems to become fully self-sustaining for nutrients, they will have to recycle nutrients from (treated or composted) domestic waste or sewage. The use of sewage sludge is not permitted by the organic standards at present.

Diseases in organic cereals do not appear to present severe problems, especially with low nitrogen fertility; adequate routine control appears possible through resistant varieties and variety mixtures, although little can be done about sudden outbreaks. Pests can affect organic cereals as much as conventional crops, and localised attacks from slugs, leatherjackets, birds (especially with untreated seed), aphids and rabbits have only a limited range of control measures.

Agronomic research on organic cereals has concentrated mainly on winter wheat. However, spring cereals, which are often grown later in the rotation, have advantages such as more opportunities for weed control and less risk of N leaching. Agronomic problems associated with spring cereals need to be addressed. A number of other cereals (winter barley, winter oats, triticale, rye, spelt, durum) could also offer specific benefits to growers (competitiveness with weeds, ability to scavenge for nutrients, allelopathic effects, grain quality, etc.) and should be evaluated under organic conditions.

6.2 Supply of seed

The derogation to EU Regulation 2092/91, allowing the use of non-organic seed when organically-produced seed is not available, ends on 31 December 2003. It is probable that supplies of organically-produced seed will be unable to meet demand. Whilst organic seed production is being encouraged by the organic advisory services, there is not a sufficient interest from plant breeders or the seed trade. Seed for organic varieties takes up only a small proportion of the total seed market and organic producers are likely to need small quantities of a large number of varieties; this is not compatible with the objectives of most large breeding companies which look to collect royalty payments on large tonnages of their varieties.

HGCA (2000b) projections indicate 40,000 ha of organic cereals by 2002, up from 8000 in 1998; this is based on the amount of arable land undergoing conversion and an estimate of how that land will be allocated to arable crops. At a seed rate of 200 kg/ha this would equate to 8000 tonnes seed for which an area of 1300 ha would be needed under conventional conditions and possibly 2000 ha under organic conditions given lower yields and higher seed rates. However, these figures may not take into account the high proportion of organic rotational land which is devoted to fertility-building crops (see section 1). Using average growth rates in organic cereal land area (17.8% p.a.) Cook (2000) estimates that 646 ha will be required to produce 2583 tonnes of organic cereal seed in 2002, rising to 1058 ha and 4222 tonnes in 2005, but points out that these may be underestimates. Between these two figures the actual requirements might be 1000 ha in 2002. This area will be divided largely between the three cereal species (wheat, oats and barley) and it may be further divided between winter and spring sown varieties.

When assessing breeder interest it is worth looking at the whole market. In 2000 British seed areas were approximately 58,000 ha of winter wheat, 1400 ha of spring wheat, 2900 ha of winter oats, 1133 ha of spring oats and 21,000 ha of spring barley. This would indicate that a breeder of spring wheat might be tempted to enter the organic market and could add substantially to his market share, whereas a winter wheat breeder would probably consider it a waste of time, unless he produced a variety that had particular merit for organic systems. Similarly oat breeders might be interested in producing seed for relatively small or niche organic markets. Currently conventional spring barley is being driven mainly by malting quality although there are some high yielding feed varieties being evaluated; spring barley is probably in a similar situation to winter wheat when it comes to assessing breeders' perceptions.

Seed production involves both plant breeders and the seed trade with some companies performing both functions. Breeders and the seed trade have different interests and may take different views on the benefits of moving into organic seed production. It will be important in future to try to satisfy the interests of all sectors in the seed chain if seed demands are to be met.

The estimates of seed requirements include a proportion that will be farm-saved although it is unlikely that growers will farm-save exclusively. Of surveyed crops, less than a quarter were sown with home-saved seed. The conventional policy is to buy in certified seed to produce farm-saved seed the following year, but after 2003, organic growers may be forced to farm save a high proportion of cereal seed. This will not find favour with the seed trade who have always regarded farm-saving with disfavour and now feel under additional pressure as seed sales are well down on two years ago.

The seed trade may also view multiplication under organic conditions as a major problem for two reasons: firstly, high value seed in the early stages of multiplication can be sown as low as 20 kg/ha giving colossal multiplication rates; and secondly normal seed crops are grown for high yield. Both these factors mean that a seed merchant will need to buy more tonnes of early generation (i.e. expensive) seed in order to produce 100 tonnes of commercial grade organic seed. Merchants normally carry the risk of what they produce not finding a market either because of over production in a high yielding season or because the variety is no longer in demand. The extra costs associated with organic production increase merchants' risks whilst undersupply in the market will reduce the risks of unsold stock. This latter risk could be tackled if organic seed was multiplied on a contractual rather than a speculative basis. Although the seed trade in general may be against organic production, one or more of the smaller merchants might be able to build up a specialised business.

Cereal breeders are in a different position. There is a levy on home-saving and as the proportion of home-saving goes up so does the amount of levy. If organic production increases seed rates, especially during the multiplication phase, then breeders will sell more seed.

For the seed grower organic seed production will carry risks associated with failure to meet certification standards in crops where crop protection measures are limited. A better understanding of the influence of husbandry factors (seed rate, seed treatment, etc.) which influence quality in organic seed (disease, vigour, germination, etc.) is required for certified seed production.

6.3 Plant breeding

At present few, if any, varieties are selected specifically for organic systems, although some may be promoted as suitable for organic production. The possibility of breeding varieties specifically for organic systems was discussed with a number of plant breeders at the Cereals 2000 event. Many had no plans for breeding or selection of cereal varieties for their specific suitability to organic farming systems. They did not anticipate that there would ever be a sufficient market (i.e. about 10,000 tonnes seed) to make it worth breeding a specifically targeted variety. However, it might be economic to maintain an existing variety, targeted at organic cereal growers, as in this case the market would need to be only 1000 tonnes per annum. Breeders did identify the possibility of screening new varieties under organic conditions in 'organic national list trials', as a concurrent screening to the National List trials for conventional systems. This would increase the number of varieties considered under organic conditions by up to 40-fold, but at much less cost than a specific breeding programme; such a programme could have value in other low-input systems.

Breeders suggested that cereal varieties suited to cultivation in organic systems would:

- have good all round disease resistance
- have good grain quality
- have good resistance to ear disease
- develop good ground cover to rapidly compete with weeds
- have a growth habit which discourages weed competition throughout the growing season
- be tolerant of late-sowing
- have extensive rooting systems
- have high N use efficiency for slow-release sources e.g. manures

All the breeders were able to identify examples of their current varieties which they felt showed some of these characteristics and hence showed promise within organic systems.

The variety trials conducted by Elm Farm Research Centre and by NIAB will provide valuable information to organic cereal producers. Not only should these trials cover as many organic cereal growing areas of the UK as possible, but they should also test a range of varieties and variety mixtures from the UK and abroad.

6.4 Profitability

HGCA (2000b) estimate that organic cereal production in the UK will increase from 30,000 tonnes in 1998 to 160,000 tonnes in 2002. Even if output is only half that amount or 80,000 tonnes (see section 1) this represents a 2.5 fold increase on the Soil Association's 1998 estimate. Such an increase might be expected to have a profound effect on prices of organic cereals but HGCA (2000a) point out that many EU countries have a higher proportion of land in organic production than the UK and are still net importers of organic

cereals, with prices showing premiums similar to those in the UK. In Germany, where 2.4% of land is devoted to organic production compared to 1.8% in the UK, the price of organic milling wheat has fallen from about £300/tonne in 1993 to under £200/tonne at present, during which time it has fluctuated between 2 and 3 times that of conventional milling wheat.

Table 6.1. Gross margins and prices of organic cereals

Crop	Market	Organic yield t/ha (1)	Organic price £/t (2)	Organic gross margin £/ha (3)	Conventional gross margin £/ha (4)	Organic breakeven price £/t (5)
W wheat	feed	4.7	175	959	540	86
S wheat	bread	4.1	185	885	592	114
W barley	feed	4.6	170	928	455	67
S barley	malt	3.7	200	881	525	104
W oats	mill	4.6	170	922	430	63
S oats	mill	4.1	170	823	445	78
Triticale	feed	4.4	170	873	475	80

(1) Yields from surveyed crops. (2) Estimated prices 10 October 2000. (3) Gross margins calculated using costs from the Organic Farm Management Handbook (1999). (4) Gross margins derived from Nix (1999); yields of wheat not reduced for milling. (5) Organic cereal price required to equal conventional gross margin.

The UK price for organic bread wheat (October 2000) is £180-195 per tonne, depending on protein content, about 2½ times that of conventional bread wheat. If, as HGCA (2000a) predicts, the UK remains in deficit for organic cereals for the foreseeable future, growers can continue to expect premiums, although these will depend on import replacement price and domestic supply. Despite relatively low yields, high grain prices give gross margins for organic cereals which are 50-100% above those for conventional cereals. Using the yields from crops surveyed in section 4 of this review, it is calculated (Table 6.1) that organic grain prices would have to fall to between £63 and £114 per tonne for organic cereals to give gross margins no greater than those of conventional cereal crops.

6.5 Technology transfer

From the perspective of an organic farming adviser, one of the most commonly recurring characteristics of farmers who are considering converting to organic farming is apprehensiveness (David Younie, personal communication). The extent of the change in approach which they are contemplating is so great that they find it difficult to conceive how it could possibly work in practice. There is a considerable challenge, therefore, in conveying effectively the information that is available on organic cereal agronomy.

The range of technology transfer techniques used in conventional agriculture are also applicable in organic cereal production, although perhaps the emphasis should be directed slightly differently. There is a role for technical leaflets, web-based information, technical seminars/conferences, farmer training courses, discussion groups and demonstrations, including demonstration farms. These approaches are all being provided to some extent at present, primarily by Elm Farm Research Centre and the Soil Association in England and by SAC in Scotland. However, there is clearly a need for more resources to be directed to technology transfer, in virtually all of these areas.

6.5.1 Technical publications

There is a dearth of good farmer leaflets on organic cereal production. This stems partly from the relative paucity of research activity and information, and partly from the (until recently) relatively small size of the organic sector. The rapid development in organic farming which has taken place in the late 1990's and the pressure this has placed on advisory organisations has limited their ability to respond quickly in terms of developing new advisory material. In the survey (Section 4.3) the most commonly cited source of husbandry and variety information was 'own experience'. There is a major role for HGCA here in publication of organic farming technical leaflets.

6.5.2 Technical seminars/conferences

Technical meetings have the attraction of being able to convey large amounts of targeted information in a short period of time. There is an additional attraction in that they allow for a lot of personal interaction between delegates, which in itself is an effective means of technology transfer. The same is true at a local level of Discussion Groups. Clearly these have much potential, given the survey results which indicate that there is a lot of farmer to farmer transfer of information. One-day participative training courses are also a very effective technology transfer technique but are costly to prepare and run. SAC has run approximately 20 such courses during 1999-2000, supported by the EU and local enterprise companies as well as by the participants themselves. However, much of this activity until now has been at a general level, covering certification requirements, etc. It is now time to move towards more specific technically oriented meetings/groups/courses. At the very least there is scope for a series of regional conferences/seminars on organic cereal production. Here again there is a role for HGCA.

6.5.3 Technical demonstrations

Notwithstanding the undoubted need for publications, technical meetings and training courses, the approach which probably has the biggest potential impact in terms of technology transfer in organic farming is through technical demonstrations, either in the form of *ad hoc* farm walks, open days at research sites, or the establishment of a network of demonstration farms. Institution farms can be used but commercial farms probably have the greatest potential for convincing apprehensive farmers about the feasibility of profitable organic cereal production. Programmes of organic farm walks are organised by SAC, EFRC and the Soil Association, although at present the range of activities is limited by the number of fully converted farms on which to stage demonstrations, the number of organic cereal research sites, and funding.

6.6 Research priorities

UKROFS (1998) identified a number of priority areas for research. The following relate to cereals: efficiency of manure use, factors influencing root development, strategies for the control of broad-leaved and difficult weeds, registration of permitted crop protection substances, pest control, seed production, stockless rotations and multiple cropping. Cereals research listed in MAFF project OFO171 "A review of current European research on organic farming" appears in Appendix 5.

Research priorities identified in the present report are listed below (ranked ** and * for highest and second highest priority respectively).

6.6.1 Cereal systems

6.6.1.1 Stockless, cereal-based rotations

Research issues

- Identification of optimum edaphic and climatic conditions for stockless systems
- Understanding the effects of length and order of cropping sequence on soil nitrogen availability, and weed, pest and disease incidence in stockless systems **
- Understanding the management of soil phosphorus, potassium and micro-nutrients in stockless systems*

6.6.1.2 Species mixtures

Research issues

- Development of guidelines for cereal/legume bicropping *

6.6.2 Seed production

Research issues

- Development of guidelines for the production of organic cereal seed to meet certification standards *
- Development of guidelines for the production of home-saved cereal seed with minimal seed disease and weed seed contamination
- Understanding of the factors affecting organic seed viability and vigour and the importance of these to organic cereal growers **
- Assessment of the financial implications and risks of organic seed production

6.6.3 Plant breeding and variety testing

Research issues:

- Identification of desirable traits for organic cereal varieties (e.g. disease resistance, competitiveness, ability to exploit the soil profile for nutrients and water) *
- Use of conventional cereal trials to evaluate varieties for organic systems *
- Assessment of the importance of the genotype x environment interaction for organic cereal varieties
- Assessment of opportunities for broadening the genetic base for organic cereal variety improvement
- Formulation of strategies for optimising cereal variety mixtures *

6.6.4 Crop protection

Research issues

- Quantification of losses to weeds, pests and diseases in organic cereal crops *
- Understanding of cereal disease incidence x soil fertility interactions
- Understanding of population dynamics of annual and perennial weeds in organic rotations which include cereals **
- Development of indirect strategies for the suppression of weeds, pests and diseases in organic rotations which include cereals *
- Identification of direct control methods for weeds, diseases and pests (notably slugs, leatherjackets and aphids) in organic cereals *

6.6.5 Soil fertility

Research issues

- Understanding the effects of soil management (timing x frequency x intensity of cultivation) on soil N mineralisation in relation to organic cereal crops **
- Understanding the effects of crop sequence x soil biological interactions on nutrient uptake by organic cereals

- Understanding the effects of low soil phosphorus and potassium levels on the growth and yield of organic cereal crops
- Evaluation of sources of phosphorus, potassium and micro-nutrients for organic cereals *

6.6.6 Cereal grain quality

Research issues

- Understanding the factors affecting grain quality in organic cereals *
- Development of production strategies for quality cereal grain (note HGCA project 2237) *

6.6.7 Grain storage

Research issues

- Evaluation of permitted and novel methods for the direct control of pests and diseases in stored organic grain (e.g. pheromones, repellents, irritants, fumigants)
- Evaluation of strategies for grain store hygiene
- Evaluation of wet grain storage in organic systems (e.g. crimping of ensiled grain)

References

- ADAS (1992). ADAS Organic wheat survey. *New Farmer and Grower* 34, 31-33.
- Albrecht, H. and Mattheis, A. (1998). The effects of organic and integrated farming on rare arable weeds on the Forschungsverbund Agrarokosysteme Munchen (FAM) research station in southern Bavaria. *Biological Conservation* 86, 347-356.
- Altieri, M. A. (1995). *Agroecology. The Science of Sustainable Agriculture*. Westview Press.
- Atkinson, D. and McKinlay, R. G. (1997). Crop protection and its integration within sustainable farming systems. *Agriculture, Ecosystems and Environment* 64, 87-93.
- Ammer, U., H. Utschick, and Woll, T. (1994). The importance of various kinds of field margin for the occurrence and phenology of weeds under conventional and organic farming conditions. *Forstwissenschaftliches Centralblatt* 113, 325-344.
- Askegaard, M., Rasmussen, I.A. and Olesen, J.E. (1999). Agronomic considerations and dilemmas in the Danish crop rotation experiment. In *Designing and Testing Crop Rotations for Organic Farming* (eds J. E. Olesen, R. Eltun, M. J. Gooding, E. S. Jensen & U. Kopke), DARCOF Report No. 1, 63-69.
- Baerveldt, S. and Ascard, J. (1999). Effect of soil cover on weeds. *Biological Agriculture and Horticulture* 17, 101-111.
- Bansal, G.L. (1997). Allelopathic effect of buttercups on wheat varieties. *Allelopathy Journal* 4, 139-142.
- Bàrberi, P., Caporali, F., Campiglia, E. and Mancinelli, R. (1998) Weed community composition in a mixed farming system in Central Italy. Proceedings of a workshop on *Mixed Farming Systems in Europe*, Dronten, 25-28 May (eds H. Van Keulen, E.A. Lantinga, and H.H. Van Laar), A.P. Minderhoudhoeve-reeks nr. 2, Landbouwniversiteit, Wageningen. pp.71-77.
- Bayles, R. A., Channel, M.H. and Stigwood, P. L. (1990). The role of the United Kingdom Cereal Pathogen Virulence Survey in crop protection. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 221-222.
- Bertholdsson, NO and Jonsson, R. (1994). Weed competition in barley and oats. Proceedings of the 3rd Congress of the European Society of Agronomy, Padova, Italy. pp.656-657.
- Bethlenfalvay, G.J and Barea , J-M (1994). Mycorrhizae in sustainable agriculture. 1. Effects on seed yield and soil aggregation. *Am J Alt Ag* 9, 157-61.
- Birzele, B., Backes, F., Berleth, M. and Kramer, J. (1998). Mycoflora, DON and OTA contents of winter wheat in the years 1995 until 1997. *Revue Med Vet.* 149, 527.
- Bond, W. and Baker, P.J. (1990). Patterns of weed emergence following soil cultivation and its implications for weed control in vegetable crops. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 63-68.
- Bruggen, A. H. C. Van (1995). Plant disease severity in high-input compared to reduced-input and organic farming systems. *Plant Disease* 79, 976-984.

- Bulson, H. A. J.; Snaydon, R. W.; Stopes, C. E. (1997). Effects of plant density on intercropped wheat and field beans in an organic farming system. *Journal of Agricultural Science* 128, 59-71.
- Bulson, H.; Welsh, J., Stopes, C. and Woodward, L. (1996) Weed Control in Organic Cereal Crops. Final Report of EU contract AIR-CT93-0852, Elm Farm Research Centre.
- Campiglia, E., Caporali, F., Bàrberi, P. and Mancinelli, R. (1999). Influence of 2-, 3-, 4- and 5-year stands of alfalfa on winter wheat yield. In *Designing and Testing Crop Rotations for Organic Farming* (eds J.E. Olesen, R. Eltun, M.J. Gooding, E.S. Jensen, & U. Kopke), DARCOF Report No 1, 165-171.
- Carmona, D. M. and Landis, D. A.; (1999). Influence of refuge habitats and cover crops on seasonal activity-density of ground beetles (Coleoptera: Carabidae) in field crops. *Environmental Entomology* 28, 1145-1153.
- CEC (1991). Council Regulation No 2092/91 on organic production. *Official Journal of the European Communities* L198, 1-15.
- CEC (1999). Council Regulation No 1804/1999 supplementing Regulation No 2092/91 on organic production. *Official Journal of the European Communities* 42, L222, 1-28.
- Clements, R.O., George, S., Martyn, T., Donaldson, G. and Balsdon, S. (1996). Clover, Cereal Bi-cropping - A low-input cost-effective method of growing whole crop winter wheat. In *Legumes in Sustainable Farming Systems* (ed. D. Younie), Occasional Symposium of the British Grassland Society No. 30, 300-302.
- Cook S. (1997). Organic Wheat Survey. Report of MAFF contract OF107, ADAS.
- Cook, A. (2000). Production of organic seed for the organic farming sector. Report of MAFF project OF0154, Elm Farm Research Centre, Newbury, UK.
- Corcuera, L. J.; Argandona, V. H.; Zuniga, G. E.; Rizvi, S. J. H; Rizvi, V. (1992). Allelochemicals in wheat and barley: role in plant-insect interactions. In *Allelopathy: basic and applied aspects* (ed. S. J. H. Rizvi), Chapman & Hall. pp.119-127.
- Cormack, W.F. (1997). Testing the sustainability of a stockless arable rotation on a fertile soil in Eastern England. In *Resource Use in Organic Farming* (eds J. Isart and J.J. Llerena), Proceedings of the 3rd ENOF Workshop, Ancona 4-6 June 1997. pp.127-135.
- Cormack, W.F. (1999). Testing a Stockless Arable Rotation on a Fertile Soil. In *Designing and Testing Crop Rotations for Organic Farming* (eds. J. E. Olesen, R. Eltun, M. J. Gooding, E. S. Jensen & U. Kopke), DARCOF Report No. 1, 115-123.
- Cosser, N.D., Gooding, M.J. and Froud-Williams, R.J. (1995). The effect of wheat dwarfing genes on competition against blackgrass. *Brighton Crop Protection Conference, 1995: Weeds*, 361-362.
- Cosser, N.D., Gooding, M.J. and Froud-Williams, R.J. (1996). The impact of wheat cultivar, sowing date and grazing on the weed seedbank of an organic farming system. *Aspects of Applied Biology* 47, *Rotations and Cropping Systems*, 429-432.
- Cosser, N.D., Gooding, M.J., Thompson, A.J. and Froud-Williams, R.J. (1997). Competitive ability and tolerance of organically grown wheat cultivars to natural weed infestations. *Annals of Applied Biology* 130, 523-535.

- Dann, P.R., Derrick, J.W, Dumaresq DC and Ryan M.H. (1996). The response of organic and conventionally grown wheat to superphosphate and reactive rock phosphate. *Aust J Exp Agric* 36, 71-78.
- David, C., Jeuffroy, M.H., Laurent, F., Mangin, M., Recous, S. and Meynard, J.M. (1999). La fertilisation azotée du blé en agriculture biologique. Mise au point d'un outil de gestion stratégique de la fertilisation de printemps. *Congrès COMIFER-GEMAS*. 12pp.
- Davies, D.H.K., Christal, A., Talbot, A.M., Lawson, H.M. and Wright G.M. (1997). Changes in weed populations in the conversion of two arable farms to organic farming. *Brighton Crop Protection Conference, 1997: Weeds*, 973-978.
- Dornbusch, Ch., Schauder, A., Piorr, H.-P. and Kopke, U. (1992). Seed production in organic agriculture - improved criteria of seed quality in winter wheat. Proceedings of the 9th International IFOAM Scientific Conference, 16-21 November 1992, Sao Paulo, Brazil, vol I (eds U. Kopke & D. G. Schulz). pp.19-24.
- Dover, P. A. and East, J. (1990). The effects of variety blends and seedrates on disease and weed incidence in wheat grown in organic systems. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin). British Crop Protection Council Monograph No. 45, 239-243.
- Douds, D.D., Janke, R.R. and Peters, S.E. (1993). VAM fungus spore populations and colonisation of roots of maize and soybean under conventional and low-input sustainable agriculture. *Agriculture, Ecosystems and Environment* 43, 325-336.
- Eisele, J.-A., (1998). Strategies for the control of *Vicia hirsuta* (L.) S F Gray in organic farming. Proceedings 50th International Symposium on Crop Protection, 5.5, Gent. pp.705-711.
- Eisele, J.-A. and Köpke, U. (1997). Choice of cultivars in organic farming: new criteria for winter wheat ideotypes. *Pflanzenbauwissenschaften* 1 (2), 84-89.
- Ellis, P. R. (1990). The role of host plant resistance to pests in organic and low input agriculture. *ibid.*, 93-102.
- Eltun, R. (1996). The Apelsvoll cropping system experiment. III. Yield and grain quality of cereals. *Norwegian Journal of Agricultural Sciences* 10, 7-22.
- Eriksen, J., Askegaard, M. and Kristensen, K. (1999). Nitrate leaching in an organic dairy/crop rotation as affected by organic manure type, livestock density and crop. *Soil Use and Management* 15, 176-182.
- Fagerberg, B., Salomon, E. and Jonsson, S.(1996). Comparisons between conventional and ecological farming systems at Ojebyn. *Swedish J. agric. Res.* 26, 169-180.
- Fenwick, R. (2000). Selecting your cereal. *Organic Farming*, Spring 2000, Issue 65, 21-23.
- Finckh, M. R. and Mundt, C. C. (1992a). Stripe rust, yield, and plant competition in wheat cultivar mixtures. *Phytopathology* 82, 905-913.
- Finckh, M. R. and Mundt, C. C. (1992b). Plant competition and disease in genetically diverse wheat populations. *Oecologia* 91, 82-92.
- Finckh, M. R. and Mundt, C. C. (1993). Effects of stripe rust on the evolution of genetically diverse wheat populations. *Theoretical and Applied Genetics* 85, 809-821.

- Finckh, M. R. and Mundt, C. C. (1996). Temporal dynamics of plant competition in genetically diverse wheat populations in the presence and absence of stripe rust. *Journal of Applied Ecology* 33, 1041-1052.
- Finckh, M. R., Gacek, E. S., Czembor, H. J. and Wolfe, M. S. (1999). Host frequency and density effects on powdery mildew and yield in mixtures of barley cultivars. *Plant Pathology* 48, 807-816.
- Fokkema, N. J. (1996). Biological control of fungal plant diseases. *Entomophaga* 41, 333-342.
- Foster, C. and Lampkin, N. (1999). Organic and in-conversion land area, holdings, livestock and crop production in Europe. Final Report to the EU of FAIR3-CT96-1794.
- Foulkes, M.J., Sylvester-Bradley, R. and Scott, R.K. (1998). Evidence for differences between winter wheat cultivars in acquisition of soil mineral nitrogen and uptake and utilization of applied fertilizer nitrogen. *Journal of Agricultural Science* 130, 29-44.
- Fragstein, von P. (1996). Conversion to organic farming- experiences of a case study and evaluation years later. In *Steps in the conversion and development of organic farms*. Proceedings of the Second ENOF Workshop, Barcelona, 3-4 October 1996.
- Gooding, M.J., Cosser, N.D., Thompson, A.J., Davies, W.P. and Froud-Williams, R.J. (1997). The effect of cultivar and *Rht* genes of the competitive ability, yield and breadmaking quality and of organically grown winter wheat. In *Resource Use in Organic Farming* (eds J. Isart and J.J. Llerena). Proceedings of the 3rd ENOF Workshop, Ancona, 4-6 June 1997.
- Gooding, M.J., Cannon, N.D., Thompson, A.J. and Davies, W.P. (1999). Quality and value of organic grain from contrasting breadmaking wheat varieties and near isogenic lines differing in dwarfing genes. *Biological Agriculture & Horticulture* 16, 335-350.
- Gooding, M.J., Cosser, N.D., Thompson, A.J., and Davies, W.P. (1998). Sheep grazing and defoliation of contrasting varieties of organically grown winter wheat with and without undersowing. *Grass and Forage Science* 53, 76-87.
- Goulding, K.W.T. and Loveland, P.J. (1986). The classification and mapping of potassium reserves in soils of England and Wales. *Journal of Soil Science* 37, 555-565.
- Guest, S. J., Samuel, A. M. and Davies, W. P. (1990). Establishment, diseases and yield of organically-grown wheats. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 223-226.
- Hagel, I. and Schnug, E. (1997). Schwefelgehalte in biologisch-dynamischem Weizen. *Getreide, Hehl und Brot* 51, 201-202.
- Halberg, N. and Kristensen, I.S. (1997). Expected crop yield loss when converting to organic dairy farming in Denmark. *Biological Agriculture & Horticulture* 14, 25-41.
- Hald, A.B. (1999). Weed vegetation (wild flora) of long established organic versus conventional cereal fields in Denmark. *Annals of Applied Biology* 134, 307-314.
- Helander C. A. (1997). The Logården project: development of an ecological and integrated arable farming system. In *Perspectives for agronomy - adopting ecological principles and managing resource use*. (eds M.K. Van Ittersum and S.C. Van de Geijn). Developments in Crop Science Volume 25. Elsevier. pp.309-317.

- Henriksen, T.M., Eltun, R. and Riley, H. (1999). Nutrient supply in organic arable production systems: nitrogen mineralisation from clover subcultures. Proceedings of 21st congress of NJF – Jorbruk og Samfunn 28 June to 1 July 1999. pp.108-114.
- Henriksen, T.M., Korsæth, A. and Eltun, R. (2000). Impact of incorporation time on the residual N effect of a clover subcrop. Proceedings of the 13th International IFOAM Scientific Conference, 28-31 August 2000, Basel (eds T. Alfoldi, W. Lockeretz and U. Niggli). p.68.
- HGCA (2000a) Organic Farming - the next step. *HGCA MI Prospects*, 2 (19), 4-5.
- HGCA (2000b) Organic cereal supply to 2002. *HGCA MI Prospects*, 3 (4), 6.
- Higginbotham, S. (1996). The monitoring of disease levels in organic and conventionally managed wheat. *Aspects of Applied Biology* 47, *Rotations and Cropping Systems*, 167-172.
- Holm, S. (1994). Diseases and pests in organic agriculture. Afdeling for Plantepatologi og Jordbrugszoologi, Lottenborgvej 2, 2800 Lyngby, Denmark. Rapport No. 17. 44pp.
- IFOAM (1998). *Basic Standards of Organic Agriculture*. International Federation of Organic Agriculture Movements, Tholey-Theley, Germany.
- Inderjit and Dakshini, K.M.M. (1998). Allelopathic interference of chickweed, *Stellaria media* with seedling growth of wheat (*Triticum aestivum*). *Canadian Journal of Botany* 76, 1317-1321.
- Jaskulski, D. (1997). Allelopathic effects of spring triticale on spring barley, oats and spring wheat. *Zeszyty Naukowe Akademii Rolniczej w Szczecinie, Rolnictwo* 65, 127-133.
- Karutz, C. (1999). Infobulletin für die Bioproduktion. Winterweizen: Sortenversuche 1996-1998. *Bio Aktuell* 7/99, 4-6.
- Keatinge, R., Cormack, W., Padel, S. and Wolfe, M. (2000). A review of current European research on organic farming. Report of project OF0171, MAFF, London.
- Kho, R.M. (2000). On crop production and the balance of available resources. *Agriculture, Ecosystems and Environment* 80, 71-85.
- Korsæth A. and Eltun R. (2000). Nitrogen mass balances in conventional, integrated and ecological cropping systems and the relationship between balance calculations and nitrogen runoff in an 8-year field experiment in Norway. *Agriculture, Ecosystems and Environment* 79, 199-214.
- Knudsen, I. M. B.; Deboz, K.; Hockenhull, J.; Jensen, D. F.; Elmholt, S. (1999). Suppressiveness of organically and conventionally managed soils towards brown foot rot of barley. *Applied Soil Ecology* 12, 61-72.
- Kurle, J.E. and Pflieger, F.L. (1996). Management influences on arbuscular mycorrhizal fungal species composition in a corn-soybean rotation. *Agronomy Journal* 88, 155-161.
- Lambin, J., Falisse, A., Montford, B. and Poelart J. and Thomas, J.M. (1994). Weeding in organic agriculture – results of trials from 1988 to 1992. *Maitrise des adventices par voie non chimique* 2, 259-264
- Landessorten- und Anbautechnische Versuche (1999). Ergebnisse der Versuche im. *Ökologischen Landbau*.

- Le Gouis, J., Béghin, D., Heumez, E. and Pluchard, P. (2000). Genetic differences for nitrogen uptake and nitrogen utilisation efficiencies in winter wheat. *European Journal of Agronomy* 12, 163-173.
- Leake, A.R. (1996). The effect of cropping sequences and rotational management: an economic comparison of conventional, integrated and organic systems. *Aspects of Applied Biology* 47, *Rotations and Cropping Systems*, 185-94.
- Ledgard, S.F. and Steele, K.W. (1992). Biological nitrogen fixation in mixed legume/grass pastures. *Plant and Soil* 141, 137-153.
- Leszczynski, B.; Dixon, A. F. G.; Bakowski, T.; Matok, H. (1995). Cereal allelochemicals in grain aphid control. *Allelopathy Journal* 2, 31-36.
- Liebman, M. and Davis, A.S.(2000). Integration of soil, crop and weed management in low-external- input farming systems. *Weed Research* 40, 27-47.
- Limpert, E.; Finckh, M. R.; Wolfe, M. S. (1996). Population studies of airborne pathogens on cereals as a means of improving strategies for disease control - integrated control of cereal mildews and rusts: towards coordination of research across Europe. COST Report EUR 16884, xi + 276pp. (eds. E. Limpert & M. R. Finckh), European Commission, DG XII, Science, Research and Development, Luxembourg.
- Lockhart, J.A.R. and Wiseman, A.J.L. (1983). *Introduction to Crop Husbandry*. 5th edition. Pergamon Press, Oxford.
- McKinlay, R. G. (1998). Crop Protection in Organic Farming. In *The Future of the Organic Farming Systems* (eds. J. Isart & J. J. Llerena.), Proceedings of the 4th ENOF Workshop, Edinburgh 25-26 June 1998, pp.73-78
- McKinlay, R. G.; McCreath, M. (1995). Some biological alternatives to synthetic insecticides for sustainable agriculture. *Pesticide Outlook* 6, 31-35.
- Millington, S, Stopes, C.E., Woodward, L. & Vogtmann, H. (1990). Rotational designs and limits of organic systems – the stockless organic farm. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 163-174.
- Mintel (1999) Organic Food and Drink. Report , Mintel International Group Ltd.
- Moreby, S.J. (1996). The effects of organic and conventional farming methods on plant bug densities (*Hemiptera: Heteroptera*) within winter wheat fields. *Annals of Applied Biology* 128, 415-421.
- Nguyen, M.L., Haynes, R.J., and Goh, K.M. (1995). Nutrient budgets and status in three pairs of conventional and alternative mixed cropping farms in Canterbury, New Zealand. *Agriculture, Ecosystems and Environment* 52, 149-162.
- Nicholson, F.A., Chambers, B.J., Smith, K.A. and Harrison, R. (1999). Spring applied organic manures as a source of nitrogen for cereal crops: experiments using field scale equipment. *Journal of Agricultural Science* 133, 353-363.
- Nix, J. (1999). *Farm Management Pocketbook*. 30th edition. Wye College Press, Ashford.
- Nolte, C. and Werner, W. (1994). Investigations on the nutrient cycle and its components of a biodynamically-managed farm. *Biological Agriculture and Horticulture* 10, 235-254.

- Ogren, E., Bath, B. and Ramert, B. (1998). First and second year nitrogen effects of autumn and spring incorporated green manure crops on field vegetable production. *Swed. J. Agric. Res.* 28, 137-146.
- Olofsson, M. (1999). Allelopathy - a future component of weed management. Proceedings of the 16th Danish Plant Protection Conference: Weeds. DJF-Rapport,-Markbrug. 1999, No. 9, 101-112.
- Pedersen, B.T. (1990). Test of the multiple row brush hoe. Proceedings of the 3rd International Conference on Non-Chemical Weed Control. Linz, 1990. pp.109-125.
- Perez FJ and Ormeno-Nunez, J (1993). Weed growth interference from temperate cereals: the effect of a hydroxamic-acids-exuding rye (*Secale cereale* L.) cultivar. *Weed Research* 33, 115-119.
- Pfiffner, L. and Niggli, U. (1996). Effects of bio-dynamic, organic and conventional farming on ground beetles (Col. Carabidae) and other epigeic arthropods in winter wheat. *Biological Agriculture and Horticulture* 12, 353-364.
- Pfiffner, L.; Luka, H. (2000). Overwintering of arthropods in soils of arable fields and adjacent semi-natural habitats. *Agriculture, Ecosystems and Environment* 78, 215-222.
- Phelan, P. L. (1997). Soil management history and the role of plant mineral balance as a determinant of maize susceptibility to the European corn borer. *Biological Agriculture and Horticulture* 15, 1-4.
- Philipps, L., Stopes, C.E. and Woodward, L. (1995). The impact of cultivation practice on nitrate leaching from organic systems. In *Soil Management in Sustainable Agriculture* (eds H.F. Cook and H.C. Lee), Wye College Press. pp.488-96.
- Poutala, RT, Kuoppamaki, O, Korva J & Varis, E. (1994). The performance of ecological, integrated and conventional nutrient management systems in cereal cropping in Finland. *Field Crops Research* 37, 3-10.
- Przepiorkowski, T. and Gorski, S.F. (1994). Influence of rye (*Secale cereale*) plant residues on germination and growth of three triazine-resistant and susceptible weeds. *Weed Technology* 8, 744-747.
- Rasmussen, I. A.; Askegaard, M.; Olesen, J. E. (1999). Plant protection in an organic crop rotation experiment for grain production. In *Designing and Testing Crop Rotations for Organic Farming* (eds. J. E. Olesen, R. Eltun, M. J. Gooding, E. S. Jensen & U. Kopke), DARCOF Report No. 1.
- Ravn, H. P.; Holm, S. (1997). On the importance of the surroundings for insect pests in fields. Proceedings of the 14th Danish Plant Protection Conference No. 8, 179-188.
- Raupp, J. (1996). Yield patterns with organic or mineral fertilization. In *New Research in Organic Agriculture* (eds.N.H. Kristensen and H. Høgh-Jensen). Proceedings of the 11th International IFOAM Scientific Conference, Copenhagen, 11-15 August 1996, Vol.2, 62-69.
- Rayns, F.W. and Lennartsson, E.K.M. (1995). The nitrogen dynamics of winter green manures. In *Soil Management in Sustainable Agriculture* (eds H.F. Cook and H.C. Lee), Wye College Press. p.308.
- Richards, M.C. and Heppel, V. (1990). Cereal varieties for the organic and low input grower. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 147-156.
- Richards, M.C. and Whytock, G.P. (1993). Varietal competitiveness with weeds. *Aspects of Applied Biology* 34, *Physiology of Varieties*, 34-54.

Ryan, M.H., Chilvers, G.A. and Dumaresq, D.C. (1994). Colonisation of wheat by VA-mycorrhizal fungi was found to be higher on a farm managed in an organic manner than on a conventional neighbour. *Plant & Soil* 160, 33-40.

SAC (2000). Monthly Economic Report. 26 (5). SAC, Edinburgh.

Samuel, A. M. and Guest, S.J. (1990). Weed studies in organic and conventional cereals. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 183-186.

Schäfer, W., Pihala, M., Lötjönon, T., Mikkola, H. Granstedt, A. and Lilja, T. (2000). Organic nitrogen fertilisation of spring cereals. Proceedings of the 13th International IFOAM Scientific Conference, Basel 28-31 August 2000. p.77.

Schmitt, L. and Dewes, T. (1997). N₂ fixierung und N-flüsse in und unter kleesgrasbeständen bei wiehloser und viehhaltender bewirtschaftung. *Schriftenreihe - Institut für Organischen Landbau* 4, 258-64.

Schuhbeck, A., Moreth, L., Winterer, A. and Ammer, U. (1995). Comparative studies of animal pests and their natural enemies in winter wheat in various forms of extensive cultivation systems. *Gesunde Pflanzen* 47, 207-216.

Scullion, J., Eason, W.R. and Scott, E.P. (1998). The effectivity of arbuscular mycorrhizal fungi from high input conventional and organic grassland and grass-arable rotations. *Plant and Soil* 204, 243-254.

Soil Association (1998). *The Organic Food and Farming Report 1998*. Soil Association, Bristol.

Soil Association (1999) *The Organic Food and Farming Report 1999*. Soil Association, Bristol.

Speiss, H. (1999). Probleme bei der Erzeugung von Saatgut im ökologischen Landbau am Beispiel von Getriebe. Plant protection in organic farming. Proceedings of a workshop held in Kleinmachnow 18 June 1998. *Reports of the Federal Biological Research Centre for Agriculture and Forestry* 50, 64-70.

Spieß, H. and Dutschke, J. (1991). Control of common bunt of wheat in Biodynamic Agriculture under experimental and practical conditions. *Gesunde Pflanzen* 43.

Sprent, J.I. and T'Mannetje, L. (1996). The role of legumes in sustainable farming systems: Past, present and future. In *Legumes in Sustainable Farming Systems* (ed. D. Younie), Occasional Symposium of the British Grassland Society No.30. pp.2-13.

Stanhill, G. (1990). The comparative productivity of organic agriculture. *Agriculture, Ecosystems and Environment* 30, 1-26.

Starling, W. and Richards, M.C. (1993). Quality of commercial samples of organically-grown wheat. *Aspects of Applied Biology* 36, *Cereal Quality III*, 205-209.

Stein-Bachinger, K. and Werner, W. (1997). Effect of manure on crop yield and quality in an organic system. *Biological Agriculture and Horticulture* 14, 221-235.

Steiner, R. (1970). *The Agriculture Course*. English by G. Adams. Bio-dynamic Agriculture Association, London.

- Stockdale, E.A., Lampkin, N., Hovi, M., Keatinge, R., Lennartsson, E.K.M., Macdonald, D.W., Padel, S., Tattersall, F.H., Wolfe, M.S. and Watson, C.A. (2000). Agronomic and environmental implications of organic farming systems. *Advances in Agronomy* 70, 261-327.
- Stolze, M., Piorr, A., Häring, A and Dabbert S. (2000). *Organic Farming in Europe: Economics and Policy. Volume 6 Environmental and resource use impacts of organic farming in Europe*. University of Hohenheim.
- Stopes, C., Millington, S. and Woodward, L. (1995). Dry matter accumulation by three leguminous green manure species and the yield of a following wheat crop in an organic production system. *Agriculture, Ecosystems and Environment* 57, 189-96.
- Temple, S.R., Somasco, O.A., Kirk, M. and Friedman, D.(1997). Conventional, low-input and organic farming systems compared. *California Agriculture* 48, 14-19.
- Thompson, A. J.; Gooding, M. J. and Davies, W. P. (1993). Blackpoint on the grain of organically grown cultivars of wheat. *Annals of Applied Biology*, 122 (Supplement), *Tests of Agrochemicals and Cultivars* 14, 164-165.
- Thorup-Kristensen, K. (1993). The effect of nitrogen catch crops on the nitrogen nutrition of a succeeding crop I. Effects through mineralization and pre-emptive competition. *Acta Agric.Scand.* 43, 74-81.
- Thorup-Kristensen, K. (1994). The effect of nitrogen catch crop species on the nitrogen nutrition of succeeding crops. *Fertiliser Research* 37, 227-234.
- UKROFS (1998). *Topic areas for research*. United Kingdom Register of Organic Food Standards, London.
- UKROFS (1999). *UKROFS Standards for Organic Food Production*. United Kingdom Register of Organic Food Standards, London
- Unwin, R.J., Browning, H.M. and Smith, A. (1990). Nitrogen uptake as a measure of weed competition in organic cereals. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 201-204.
- Watson, C.A., Fowler, S.M. and Wilman, D. (1993). Soil inorganic-N and nitrate leaching on organic farms. *Journal of Agricultural Science* 120, 361-369.
- Watson, C.A. and Goss, M.J. (1997). The estimation of nitrogen fixation by grass/white clover mixtures in cut and grazed swards. *Soil Use and Management* 13, 165-167.
- Welsh, J.P., Bulson, H.A.J., Stopes, C.E., Froud-Williams, R.J. and Murdoch, A.J. (1999). The critical weed-free period in organically-grown winter wheat. *Annals of Applied Biology* 134, 315-320.
- White, R. E. (1987). *Introduction to the Principles and Practice of Soil Science*. 2nd Edition. Blackwell Scientific, Oxford UK.
- Wieser, I., Hess, J. and Lindenthal, T. (1996). Nutrient balances on organically managed farms in Upper Austria. *Bodenkultur* 47, 81-88.
- Wolfe, M. S. (1990). Intra-crop diversification: disease, yield and quality. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 105-114.

Wolfe, M.S.; Hartleb, H.; Sachs, E. and Zimmermann, H. (1991). Variety mixtures of malting barley are healthier. *PSP Pflanzenschutz Praxis* No. 2, 33-35.

Wolfe, M.S.; Jacobs, T. and Parlevliet, J.E. (1993). Can the strategic use of disease resistant hosts protect their inherent durability? In *Durability of disease resistance* (ed. T. Jacobs), Current Plant Science and Biotechnology in Agriculture, Volume 18, 83-96.

Woodward, L. and Lampkin, N. (1990). Organic agriculture in the United Kingdom. In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 19-30.

Wratten, S.D. and Thomas, M.B. (1990). Environmental manipulation for the encouragement of natural enemies of pests. . In *Crop Protection in Organic and Low Input Agriculture* (ed. R. Unwin), British Crop Protection Council Monograph No.45, 87-92.

Younie, D., Watson, C.A. and Squire, G.R. (1996). A comparison of crop rotations in organic farming: agronomic performance. *Aspects of Applied Biology* 47, *Rotations and Cropping Systems*, 379-382.

APPENDIX 1

Buyers and processors contacted by telephone to assess grain quality requirements for organic cereals

F W P Mathews Ltd, Station Road, Shipton under Wychwood, Chipping Norton, Oxon OX7 6BH

Grampian Oat Products, Cairnton Road, Boyndie, Banff AB45 2LR

National Association of British and Irish Millers, 21 Arlington Street, London SW1A 1RN

J B B (Greater Europe) Ltd, Invergordon Distillery, Cottage Brae, Invergordon, Ross-shire IV18 0HP

Muntons Plc, Cedars Maltings, Stowmarket, Suffolk IP14 2AG

Robert Kilgour Ltd, Dunnikier Maltings, Kircaldy, Fife KY1 2EF

W & H Marriage & Sons Ltd, Chelmer Mills, New Street, Chelmsford, Essex CM1 1PN

Doves Farm Foods Ltd, Salisbury Road, Hungerford, Berks RG17 0RF

European Oat Millers Ltd, Mile Road, Bedford MK42 9TB

Gleadell Banks (Agriculture) Ltd, Lindsey House, Hemswell Cliff, Gainsborough, Lincs DN21 5TH

APPENDIX 2

**Review of Organic Cereal Production
Farmers' Questionnaire**

About your farm and crops

1 Soil type (tick as many as apply)

Sand

Sandy loam

Loam

Silt loam

Clay loam

Silt

Clay

Peaty/fen

Other (please specify)

2 Altitude feet or m (delete units that do not apply)

3 Annual Rainfall ins or mm (delete units that do not apply)

4 Total farm size acres or ha (delete units that do not apply)

5 What animals do you have on the farm? (tick as many as apply)

Dairy cattle Beef cattle

Sheep Pigs

Poultry Goats

Other (please specify)

6 In the rotation, what is the proportion of:

Grass/clover ley%

Other fertility-building crops%
(peas, field beans, red clover for ploughing in, etc)

7 What areas of cereals will you harvest in 2000? (delete units that do not apply)

Winter wheat acres or ha Spring wheat acres or ha

Winter barley acres or ha Spring barley acres or ha

Winter oats acres or ha Spring oats acres or ha

Other (please specify)

8 Do you buy in any of the following plant nutrients? (tick as many as apply)

Lime

Phosphates (rock phosphate, etc)

Potash (rock potash, sulphate of potash)

Organic manure

Organic wastes

Proprietary organic fertilisers

Other (please specify)

9 Which crops have priority for home-produced farm yard manure application? (tick as many as apply)

Cereals Roots

Grass for grazing Vegetables

Grass for cutting

Other (please specify)

10 Where do you get advice about organic cereals? (tick as many as apply)

ADAS/SAC/DANI Press articles

Elm Farm adviser Private consultant

Own experience Neighbours/friends

Other (please specify)

For each cereal crop
(winter wheat, spring barley, spring oats, etc)

11 What was the previous crop in the rotation?

12 What is the intended market?

Kept for feed Sold for feed

Sold for malting Sold for milling

Other (please specify)

14 What is the variety?

15 Why did you choose the variety you are using? (tick as many as apply)

NIAB/SAC/DANI leaflet Press article

Elm Farm adviser Private consultant

Own experience Neighbours/friends

Other (please specify)

16 Where did you get the seed?

Home saved Bought-in organic Bought-in not organic

Other (please specify)

17 Compared to conventional cereal production, was the seed rate:

below average average above average

18 What yield do you expect? tons/acre or tonnes/ha
(delete units that do not apply)

19 What do you see as the major problems of growing the crop?

(tick as many as apply)

Availability of suitable varieties Low fertility Weeds

Achieving required quality Diseases Pests

Other (please specify)

20 How do you aim to control weeds in this cereal crop? (tick as many as apply)

- | | | | |
|-----------------------|--------------------------|-------------------------|--------------------------|
| By crop rotation | <input type="checkbox"/> | Aggressive/tall variety | <input type="checkbox"/> |
| Increased seed rate | <input type="checkbox"/> | Undersowing | <input type="checkbox"/> |
| Narrow row spacing | <input type="checkbox"/> | Cross drilling | <input type="checkbox"/> |
| Direction of drilling | <input type="checkbox"/> | Mechanical cultivation | <input type="checkbox"/> |

Other (please specify)

21 How do you provide nitrogen fertility for this crop? (tick as many as apply)

- | | |
|------------------------------|--------------------------|
| Through crop rotation | <input type="checkbox"/> |
| Home-produced organic manure | <input type="checkbox"/> |
| Bought-in nutrients/manure | <input type="checkbox"/> |
| Green manure cropping | <input type="checkbox"/> |

Other (please specify)

APPENDIX 3

NIAB regions for UK cereal recommendations

Source: Cereal Variety Handbook. NIAB 2000.

APPENDIX 4

Scientists who responded to requests for information for the literature review

Askegaard, Dr. M., Danish Institute of Agricultural Sciences, PO Box 50, DK 8830 Tjele, Denmark

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APPENDIX 5

Projects being carried out in 1999 containing the keyword 'cereals', taken from MAFF project OFO171 "A review of current European research on organic farming". Further details can be found at www.adas.co.uk/organic/.

Austria	Comparison of intensive and extensive cereal varieties under the conditions of biological agriculture.
	Ecological measures for the regulation of <i>Oulema melanopa</i> .
Belgium	Production of high quality baking wheat in organic farming
Denmark	Ecological workshop sites at Flakkebjerg
	Optimising seed vigour on cereals in ecological agriculture.
	Regulation of common bunt in organic farming.
Finland	Comparison of different intensity in farming systems.
	Development of new farming systems, which substitute traditional farming.
	Fertilizing of spring cereals with liquid manure.
	Organic farming development.
	Organic nitrogen fertilisation in cereals.
	Weed flora in spring cereal fields.
	Biodiversity and plant protection
	Farming systems.
France	Références Technico-economiques sur des fermes agrobiologique
Germany	Breeding of cereal varieties for bio-dynamic agriculture
	Demonstration of biological, sustainable and thermal treatment of seeds.
	Seed quality of organic cereals in terms of spores of <i>Tilletia caries</i> (Bunt).
	Seed treatment for the regulation of <i>Tilletia caries</i> (Bunt).
Italy	Demonstrative action and setting up of organic farming production in Apulia region
Netherlands	Effects of crop husbandry on prevention of cereal diseases and pests in different farming systems
Norway	Demonstration fields for organic cereals and potatoes.
	Large scale research into organic cultivation of cereals.
	Organic production of cereals and other protein rich crops for food and fodder.
Sweden	Aphids and stressed cereal crops.
	Biological resistance aspects of cereal varieties and their plant pathogenic fungi, especially biotrophic fungi.
	Cultivation systems/effect on cereal nutrient quality.
	Ley preceding spring straw crops in organic cultivation; maximisation of nitrogen effect through time of tilling the ley land.
	Organic variety testing of cereals, peas, oil plants and potatoes.
	Plant nutrition and environmental effects when spreading poultry manure in spring cereals.
	Quality cultivation of organic spring wheat after a clover-rich ley.
	Species and varieties for organic cultivation - spring sown grain.
	The use of KRAV approved fertilisers for cereal nitrogen provision in organic farming.
	Trials with farmyard manure for spring grain.
	Weed harrowing in spring grain.
UK	Agronomic guidelines for the production of organic wheat (Home Grown Cereals Authority (HGCA) funded)
	Clover:cereal bi-cropping for organic farms (MAFF project OF0173)
	Evaluation of cereal varieties suitable for organic farming systems (Funded by the British Society of Plant Breeders)
	Organic cereal mixtures trials 1999 - 2000 (EFRC funded)
	Testing the sustainability of a stockless arable rotation on a fertile soil (MAFF project OF0145)