FOOD STANDARDS AGENCY

PESTICIDE RESIDUE MINIMISATION

CROP GUIDE

CEREALS

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Contents

Liability Disclaimer

Every effort is made to ensure that the information provided in these guides is accurate. The information contained within the guides was correct to the best of the author's knowledge up to March 2006. No legal responsibility is accepted for any errors, omissions or misleading statements.

The guide offers broad approaches to be explored further. They are not intended to be used as detailed protocols and it would be advisable for users to consider the guidance in relation to an integrated crop management system.

Up-to-date information on pesticide regulations is available on the Pesticides Safety Directorate's website (www.pesticides.gov.uk). However, approvals and MRLs are subject to change over time and the users of the guide are reminded that it is their responsibility to ensure that any chemical intended for use by them is approved for use at the time of intended application. The user is reminded to carefully read the label attached to any chemical product and follow the instructions regarding application.

Products are mentioned as examples of those that contain particular active ingredients and no endorsement is intended.

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Preface

Why choose cereals for pesticide residue minimisation?

The FSA has a policy of pesticide residue minimisation because it recognises that people want residues reduced further than the current safe levels. Therefore the crop guides have not been produced because of any food safety concerns but with the aim of meeting people's choice in the food they buy. Further information on the rationale for the crop guides and on the safety of pesticides can be found in the General Introduction.

In producing the crop guides the FSA focussed on UK production because it is more practicable, in the first instance, to apply guidance at home than abroad. However, we recognise that cereal products may include a blend of produce sourced from both the UK and abroad. Cereals form a significant part of the UK diet and monitoring shows that each year some of the crop contains pesticide residues, albeit at safe levels.

Much work has been done by those involved in the UK food industry to keep pesticide residues to a minimum. Many of the measures recommended in this guide have already being adopted by growers. The FSA hopes to build on this body of knowledge, to help to maintain the momentum to keep residues to a minimum.

FSA Pesticide Residue Minimisation

Crop Action Plan - Cereals

1. Introduction

1.1 Crop description

Cereals are annual grasses grown for their grain. They include wheat (*Triticum aestivum*), durum wheat (*Triticum durum*), barley (*Hordeum vulgare*), oats (*Avena sativa*), rye (*Secale cereale*), triticale (cross between durum wheat and rye), maize (*Zea mays*), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*) and common millet (*Panicum milaceum*). In the UK, cereals are grown on 3.20 million hectares (ha) of the 4.76 million ha of arable land. Wheat, barley and oats make up over 99% of the UK cereal area, with only small amounts of triticale, rye and grain maize grown. The Crop Guide focuses on cereals for human consumption and in particular wheat, barley and oats because of their importance in arable crop production and staple food and drink products.

The majority of wheat and oat crops is sown between September and November and is harvested 10 to 11 months later in the following August and September. Less than half of the barley crop is sown in the autumn and then harvested in the following July or August. The remainder of the barley is sown in early spring. Autumn-sown barley is referred to as winter barley and spring sowings are referred to as spring barley in the Crop Guide.

Farmers can choose from a number of varieties for each of the cereal crops. Choice is usually based on the predicted yield, quality for a particular market, for example bread-making wheat or malting barley, various growth characteristics and resistance to disease and pest problems. Most of the commonly-grown cereal crop varieties are described in the Recommended Lists, which are produced by the Home-Grown Cereals Authority (HGCA). These lists rate each variety for its susceptibility to several fungal diseases, resistance to orange blossom midge and lodging. The current Recommended List is published on www.hgca.com.

1.2 Uses and markets

In 2002/03, 34% of wheat, 31% of barley and 36% of oats grown in the UK were used for human consumption (Table 1). UK-produced wheats are often mixed with imported wheat to achieve the necessary specifications for bread-making. Food and drink products from cereals include:

- Wheat - flour for bread, biscuits, cakes and pasta; breakfast cereals; starch; and some wheat is used for beer and whisky production;
- Barley grain is malted for beer and whisky production;
- Oats are used primarily for breakfast cereals and as flour and grain for baking.

Table 1. Utilisation of home-grown cereals in 2002/03
(percentage of total)

	Wheat	Barley	Oats
Human consumption	34	31	36
Animal feed	42	51	33
Seed	2	3	2
Other	1	<1	<1
Export	21	15	19

Source: HGCA

1.3 Area grown in the UK, volume produced and value

In 2003, wheat represented 60% of the UK area sown with cereals (Table 2) and 66% of cereal tonnage produced in the UK (Table 3). Spring barley represented 20% of the area and 16% of production. Winter barley represented 15% of the area and 13% of production. Oats represented 4% of the area and 3% of production, with other cereals making up less than 1%. Since 1992, the areas of wheat and oats have been reasonably stable. The area of winter barley has decreased by 41% and the area of spring barley has increased by 29%.

In 2003, the value of cereals produced in the UK was £1,531 million for wheat, £650 million for winter and spring barley and £79 million for oats, and 21%, 15% and 21% of the wheat, barley and oats respectively were exported.

Table 2. Area of cereals grown in the UK (thousand ha)

	1992	1998	1999	2000	2001	2002	2003
Wheat	2,056	2,045	1,847	2,086	1,635	1,996	1,837
Winter barley	777	769	548	589	462	546	456
Spring barley	481	484	631	539	783	555	622
Oats	98	98	92	109	112	126	122
Other cereals	19	22	23	25	21	23	23
Total	3,431	3,418	3,141	3,348	3,013	3,246	3,060

Source: http://statistics.defra.gov.uk

Table 3. Volume of cereals produced in the UK (thousand tonnes)

	1992	1998	1999	2000	2001	2002	2003
Wheat	14,022	15,449	14,867	16,704	11,580	15,973	14,288
Winter barley	7,456[=]	4,281	3,306	3,719	2,672	3,431	2,851
Spring barley		2,342	3,274	2,773	3,988	2,697	3,518
Oats	491	586	541	640	621	753	749
Other cereals	91	109	137	153	98	111	104
Total	22,060	22,767	22,125	23,989	18,959	22,965	21,510

Source: http://statistics.defra.gov.uk
[=] Winter and spring barley combined

1.4 Volume imported and value

In 2003, imported wheat was equivalent to 8% of the UK produced wheat tonnage after the subtraction of exports (Table 4). Imports represented about 1% of UK production for barley and oats. The value of the imported cereals in 2003 was £95 million for wheat, £5 million for barley and £0.8 million for oats.

Table 4. Volume of cereals imported into the UK (thousand tonnes)

	1992	1998	1999	2000	2001	2002	2003
Wheat	1,276	1,250	1,195	1,176	1,305	1,368	894
[=]Barley	241	184	128	70	100	82	47
Oats	4	11	12	7	10	18	8
Total	1,521	1,445	1,335	1,253	1,415	1,468	949

[=] spring and winter barley.
Source: http://statistics.defra.gov.uk

2. Pesticide use on cereals

2.1 Problems requiring the use of pesticides

The key disease, pest, growth and storage problems in cereals which may require the use of pesticides are listed in Table 5. Only those cereal problems which result in residues or require treatment relatively close to harvest and therefore have a greater risk of leaving residues have been included. The problems are rated for their importance according to their effect on crop yield and also for the occurrence of residues that might arise from the use of pesticides to control the problem.

Table 5. Key problems in cereals requiring the use of pesticides which are known to result in residues or are applied close to harvest. Their relative importance to the crop and pesticide residues *** = high; ** = medium; * = low; - = no importance because associated pesticides not found.

Problem	Species name	Importance		Description
		Crop	Residues	
Foliar diseases				
Septoria	*Septoria tritici, Phaeosphaeria nodorum*	***	-	Fungi which reduce green leaf area and grain yield. Can reduce wheat yield by more than 50%
Yellow rust	*Puccinia striiformis*	***	-	
Leaf blotch	*Rhynchosporium secalis*	**	-	Fungi which reduce green leaf area and grain yield of cereals
Mildew	*Erysiphe graminis*	**	-	
Net blotch	*Pyrenophora teres*	*	-	
Brown rust	*Puccinia recondita*	*	-	
Crown rust	*Puccinia coronata*	*	-	Fungus which reduces shoot growth and grain yield in oats
Ear diseases				
Fusarium ear blight	*Fusarium spp.*	**	-	Fungi which can produce toxic mycotoxins that contaminate grain. Also cause small yield reductions
Ergot	*Claviceps pupurea*	*	-	Produces poisonous purplish fungal bodies in ear
Septoria nodorum	*Septoria nodorum*	*	-	Fungi which reduce grain yield and quality
Mildew	*Erysiphe graminis*	*	-	
Sooty moulds	*Alternaria and Cladosporium spp.*	*	-	
Black point	*Alternaria spp.*	*	-	Fungi which infect the embryo and reduce milling quality
Loose smut	*Ustilago nuda*	*	-	Infected ears have no grain, but low infection rates
Lodging				
Lodging	-	**	***	Widespread flattening of cereal crops by wind and rain occurs on average every 3-4 years when 15-20% of cereals lodge. Localised lodging occurs in most years. Lodged areas yield about 25% less, grain quality is reduced and drying costs increased.
Summer pests				
Orange blossom midge	*Sitodiplosis mosellana*	**	-	Larvae feed on grain to reduce yield and bread making quality
Grain aphid	*Sitobion avenae*	*	-	Feed on grain to reduce yield by 3-

Rose-grain aphid	*Metopolophium dirhodum*	*	-	13%.

Pre-harvest treatment				
Green crop/ weeds		*	***	Prolonged crop greenness, and weeds both slow the rate of crop drying and combining, and can reduce grain quality.
Storage pests				
Mould	*Penicillium verrocosum*	**	-	Spoils grain and produces Ochratoxin A.
Grain weevil	*Sitophilus granarius*	**	***	Damage stored grain by feeding directly upon it.
Saw-toothed grain beetle	*Orzaephilus surinamensis*	**	***	
Rust-red grain beetle	*Crypolestes ferrugineus*	**	***	
Hairy fungus beetle	*Typhaea stercorea*	*	***	Secondary pests which feed primarily on fungi on the grain surface or on trash, but also directly on the grain
Foreign grain beetle	*Ahasverus advena*	*	***	
Fungus beetles	*Cryptophagus spp.*	*	***	
Mites	e.g. *Acarus siro, Lepidoglyphus destructor*	*	***	Normally only a problem on damp grain but can cause direct damage and taint grain
Moths	e.g. *Hofmannophila pseudospretella*	*	***	Damage grain

2.2 Pesticide use on cereals

The use of pesticides on arable crops is routinely surveyed every two years by Defra, SEERAD and DARDNI. Pesticide Usage Survey Reports are available from the Pesticide Usage Survey Group (PUSG) at the Central Science Laboratory (CSL) (www.csl.gov.uk/science/organ/pvm/puskm/pusg.cfm). At the time of writing the most recently published survey was for the 2002 cropping year [6]. The active ingredients contained within pesticide products are described in https://secure.pesticides.gov.uk/pestreg/ and https://secure.pesticides.gov.uk/offlabels/search.asp. The following section first describes the total amount of pesticide active substance applied to each cereal species per year, then describes the usage of herbicides, fungicides, plant growth regulators, insecticides, seed treatments and molluscicides separately.

2.2.1 Pesticide use on the growing crop – *pesticide breakdown in Tables 6-9*

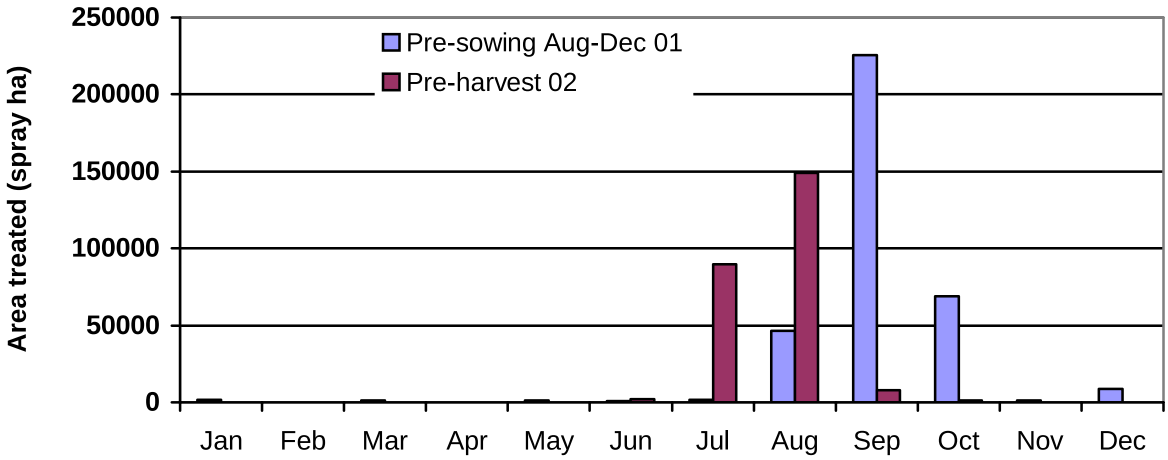
The pesticide usage rates from wheat, winter barley, spring barley and oats are summarised in Tables 6 to 9, full details of individual pesticides are available on the CSL website. Between 1992 and 2002, the weight of pesticide applied to wheat, oats and spring barley decreased by 0.18, 0.37 and 0.13 kg/ha respectively. The amount of pesticide applied to winter barley increased by 0.22 kg/ha over the same period.

Over the same period, the number of applications, products and active substances applied to wheat, barley and oats increased. Some of these increases have been caused by an increase in resistance to pesticides, in particular fungicides and herbicides. The difference in trends between the weight of pesticide applied per hectare and the number of applications products and active substances has occurred due to new products containing smaller amounts of active substance and farmers applying at rates below the full dose (manufacturer's maximum recommended rate).

In 2002, across the four main cereal species, herbicides represented the greatest weight of pesticide applied (1.56 kg/ha), followed by growth regulators (0.76 kg/ha), fungicides (0.43 kg/ha), seed treatments (0.07 kg/ha), molluscicides (0.04 kg/ha) and insecticides (0.02 kg/ha). It should be noted that neither seed treatments nor molluscicides result in residues in the final product. Between 1992 and 2002, the weight of fungicide and insecticide used per hectare decreased by 34% and 33% respectively. Use of herbicides remained relatively constant over this time period. The use of seed treatments and growth regulators increased by 34% and 18% respectively, and the use of molluscicides more than trebled. These overall trends mask some important changes for specific pesticides and crop species.

In 2002, herbicide use was greatest for wheat (2.31 kg/ha), followed by winter barley (2.24 kg/ha), spring barley (0.86 kg/ha) and oats (0.82 kg/ha). Between 1992 and 2002, the weight of herbicide used increased by 15% for winter barley, decreased by 35% for oats and remained relatively constant for wheat and spring barley. Since 1992, the area of all cereal species treated with, glyphosate, increased significantly, from 212,626 ha in 1992 to 934,426 ha in 2002. For the 2002 wheat crop, 356,688 ha were treated with glyphosate pre-sowing in autumn/winter 2001 and 249,465 ha of wheat were treated pre-harvest to desiccate the crop or to control green weeds in the ripe crop (Fig. 1). It is likely that the increase in glyphosate use on wheat resulted from greater pre-harvest use to desiccate the crop and kill weeds.

Fig. 1: Area of wheat crop treated with glyphosate pre-sowing and pre-harvest for wheat harvested in 2002 (sprayed hectares) (Source: CSL)



Growth regulator use was greatest for wheat (1.24 kg/ha), followed by winter barley (0.88 kg/ha), oats (0.84 kg/ha) and spring barley (0.07 kg/ha) in 2002. Between 1992 and 2002, growth regulator use on wheat and winter barley increased by 36% and 16% respectively, and remained constant for oats and spring barley. The increased use of growth regulators may have resulted from a greater emphasis on maintaining grain quality (which lodging reduces) and due to increasing yields causing a greater lodging risk. The increased growth regulator use on wheat and winter barley was caused by the increased use of chlormequat/choline chloride, chlormequat/imazaquin and trinexapac-ethyl. The amount of straight chlormequat applied to these crops remained relatively constant. Thus, the amount of chlormequat containing growth regulators used on wheat and winter barley increased between 1992 and 2002. The area of oats treated with chlormequat containing growth regulators increased slightly and a relatively small proportion of spring barley received chlormequat.

Overall insecticide use was 0.047 kg/ha for wheat and between 0.012 and 0.014 kg/ha for the other cereals in 2002. Between 1992 and 2002, insecticide use decreased by 43% and 30% for wheat and winter barley respectively, and increased by 44% for oats. No consistent trend can be detected for spring barley. The weight of carbamates, organochlorine and organophosphate insecticides used decreased from 0.070 kg/ha to 0.029 kg/ha in wheat, 0.007 to 0.002 kg/ha in winter barley and 0.016 to 0.011 kg/ha in spring barley. No change occurred for oats. Pyrethroid insecticides increased from 0.011 to 0.018 kg/ha in wheat and 0.005 to 0.008 kg/ha in oats. No change occurred for winter or spring barley.

Table 6. Pesticide usage in wheat 1992 – 2002.
Average application rate (kg active substance (a.s.)/ha of crop grown)

	1992	1998	2000	2002
Insecticides				
Carbamates	0.004	0.004	0.002	0.002
Organochlorines	0.003	0.004	0.000	0.002
Organophosphates	0.064	0.070	0.035	0.025
Pyrethroids	0.011	0.015	0.016	0.018
Other insecticides	0	<0.001	0	<0.000
Total insecticides	0.082	0.093	0.052	0.047
Fungicides	1.252	0.833	0.581	0.528
Growth regulators	0.910	1.112	1.166	1.240
Herbicides	2.168	2.336	2.233	2.310
Molluscicides	0.024	0.042	0.121	0.105
All seed treatments	0.031	0.093	0.086	0.094
All pesticides	4.549	4.602	4.291	4.370

Data from the Pesticide Usage Survey Reports of Arable Crops in Great Britain and Northern Ireland

Table 7. Pesticide usage in winter barley 1992 – 2002.
Average application rate (kg a.s./ha of crop grown)

	1992	1998	2000	2002
Insecticides				
Carbamates	<0.001	<0.001	0	<0.000
Organochlorines	0.002	0.004	0	0
Organophosphates	0.004	0.006	0.003	0.001
Pyrethroids	0.014	0.015	0.014	0.013
Other insecticides	<0.001	<0.001	0	<0.000
Total insecticides	0.020	0.025	0.017	0.014
Fungicides	0.687	0.595	0.570	0.526
Growth regulators	0.757	0.772	0.816	0.875
Herbicides	1.955	2.029	2.164	2.238
Molluscicides	0.009	0.009	0.029	0.023
All seed treatments	0.081	0.053	0.047	0.059
All pesticides	3.530	3.507	3.659	3.750

Data from the Pesticide Usage Survey Reports of Arable Crops in Great Britain and Northern Ireland

Table 8. Pesticide usage in spring barley 1992 – 2002.
Average application rate (kg a.s./ha of crop grown)

	1992	1998	2000	2002
Insecticides				
Carbamates	0.001	0.001	0.001	0.001
Organochlorines	0	0.006	0.001	0
Organophosphates	0.015	0.020	0.023	0.010
Pyrethroids	0.001	0.001	0.002	0.001
Other insecticides	0	0	0	0
Total insecticides	0.017	0.028	0.027	0.012
Fungicides	0.420	0.364	0.356	0.416
Growth regulators	0.074	0.037	0.044	0.071
Herbicides	0.953	0.821	0.902	0.863
Molluscicides	0.000	0.003	0.002	<0.000
All seed treatments	0.065	0.051	0.043	0.045
All pesticides	1.544	1.331	1.396	1.418

Data from the Pesticide Usage Survey Reports of Arable Crops in Great Britain and Northern Ireland

Table 9. Pesticide usage in oats 1992 – 2002.
Average application rate (kg a.s./ha of crop grown)

	1992	1998	2000	2002
Insecticides				
Carbamates	0	0	0.001	0.001
Organochlorines	0	0	0	0
Organophosphates	0.004	0.001	0.004	0.004
Pyrethroids	0.005	0.007	0.007	0.008
Other insecticides	0	0	0	0
Total insecticides	0.009	0.008	0.012	0.013
Fungicides	0.276	0.404	0.165	0.257
Growth regulators	0.820	1.071	0.880	0.839
Herbicides	1.274	0.780	0.771	0.822
Molluscicides	0.002	0.019	0.011	0.029
All seed treatments	0.024	0.092	0.114	0.074
All pesticides	2.413	2.383	1.968	2.046

Data from the Pesticide Usage Survey Reports of Arable Crops in Great Britain and Northern Ireland

2.2.2 Storage pesticides

In 2002/2003, a survey of grain stores found that farm stores contained 19.6 million tonnes (Mt) of grain and commercial stores contained 8.0 Mt [2,3]. Of the farm stores, 53% used pesticides to control storage pests such as the grain weevil, saw-toothed grain beetle and rust-red beetle. Most of the pesticides (85%) were applied only to the fabric of the store, 11% was applied to the fabric and direct to the grain, and 3% was applied directly to the grain only.

Of the commercial stores, 87% used pesticides to control storage pests, of which 61% was applied only to the fabric of the store, 34% was applied to the fabric and direct to the grain and 5% was applied directly to the grain only. Altogether, 13,876 kg of pesticide active substance was applied in farm stores and 3,492 kg was applied in commercial stores (Table 10 and 11). Data for the farm and commercial stores show that 61% of the pesticide weight was pirimiphos-methyl, 15% was aluminium phosphide, 11% was methyl bromide and 10% was chlorpyrifos-methyl.

Total pesticide usage in farm stores did not change significantly between 1990/1991 and 2002/2003 (Table 10). Total pesticide usage in commercial stores decreased from 28,746 kg in 1985/86 to 3,492 kg in 2002/2003 (Table 11). Across both types of store, the major changes in pesticide use between 1990 and 2003 was the reduction to nil or very low levels, of organochlorine (Gamma-HCH), and several organophosphate pesticides (etrimfos, fenitrothion, iodofenphos, malathion, methacrifos, chloryrifos-methyl). Approval for the use of carbon tetrachloride and ethylene dichloride were withdrawn during this period. The use of aluminium phosphide has increased significantly over the same time period, and also so has the use of some pyrethroids in farm stores. This is probably a result of farmers substituting these products for the organochlorine and organophosphate products which are no longer available. Pirimiphos-methyl use decreased from 17,040 kg to 10,528 kg across both store types, but nevertheless it remained the main grain storage pesticide used in 2002/2003.

Table 10. Usage of pesticides used in farm grain stores – total amounts used (kg)

Active substance	1990/1991	1994/1995	1998/1999	2002/2003
Organobromine				
Methyl bromide[1]	-	998	-	1,608
Organochlorine				
Gamma-HCH	343	55	25	-
Organophosphate				
Chlorpyrifos-methyl	1,120	602	446	1,658
Etrimfos	1,293	1,099	1,652	-
Fenitrothion	339	7	2	-
Iodofenphos	3	-	-	-
Malathion	45	-	-	-
Methacrifos	124	75	-	-
Pirimiphos-methyl	11,270	12,129	13,242	8,310
Organophosphate/pyrethroid				
Chloryrifos-methyl/permethrin/pyrethrins	1	-	-	-
Fenitrothion/permethrin/resmethrin	353	690	48	7
Gas generating compound				
Aluminium phosphide	26	144	473	1,824
Pyrethroids				
Alpha-cypermethrin	50	-	-	-
D-phenothrin/tetramethrin	-	<1	<1	38
Permethrin	1	-	<1	-
Pyrethrins	-	-	-	43
Other				
Diatamaceous earth	-	-	-	389
Total – all pesticides (kg)	14,968	15,799	15,889	13,876
Amount of grain surveyed (tonnes)	21,681,923	17,482,370	17,891,689	19,567,798

[1] The European Commission Ozone Depleting Substances Regulation (EC Regulation 2037/2000) has banned the use of methyl bromide within the UK, with the exception of use for quarantine and pre-shipment, emergency use, and uses where a ‘Critical Use Exemption’ (CUE) has been granted. Reductions in the use of methyl bromide have been imposed due to the phase out control schedule agreed by the parties to the Montreal Protocol.

Table 11. Usage of pesticides in surveyed commercial grain stores – total amounts used (kg)

Active substance	1985/1986	1998/1999	2002/2003
Organobromine			
Methyl bromide	2,879	352	334
Organochlorine			
Gamma-HCH	16	-	-
Organophosphate			
Chlorpyrifos-methyl	2,280	48	79
Etrimfos	1,355	1,174	5
Fenitrothion	634	-	-
Malathion	2,145	-	-
Methacrifos	903	-	-
Pirimiphos-methyl	5,770	2,755	2,218
Organophosphate/pyrethroid			
Chloryrifos-methyl/permethrin/pyrethrins	1	<1	-
Fenitrothion/permethrin/resmethrin	3	2	-
Gas generating compound			
Aluminium phosphide	41	314	824
Pyrethroids			
Bioallerthrin/bioresmethrin	<1	-	-
Deltamethrin	<1	-	-
D-phenothrin/tetramethrin	-	<1	2
Permethrin	1	10	2
Piperonyl butoxide/pyerthrins	-	-	2
Pyrethrins	<1	<1	-
Other			
Carbon tetrachloride/ethylene dichloride	12,706	-	-
Formaldehyde/gamma HCH	12	-	-
Diatamaceous earth	-	-	11
Total – all pesticides (kg)	28,746	4,657	3,492
Amount of grain surveyed (tonnes)	9,273,315	8,258,665	7,995,530

3. Pesticide residues on cereals

3.1 Pesticide residue survey data

Data on pesticide residues in cereals have been taken from the annual reports of the Working Party on Pesticide Residues (WPPR) from 1994 to 1999, and then from the quarterly Pesticide Residue Committee (PRC) survey reports from 2000 to 2004 (www.pesticides.gov.uk/prc_home.asp). The majority of cereal samples analysed for residues are bread products, including white, brown, wholemeal, multi-grain, ethnic, speciality and organic breads. Bread is monitored on a routine basis, as it is a major food staple. It is important to note however that the grain used to produce bread may come from a variety of sources/countries. For example, Canadian wheat flour is commonly used in small proportions to improve the quality of bread made from UK wheat. Other cereal products, which have been monitored at less frequent intervals, include wheat, barley, oats, rye and triticale grain, flour, bran and wheatgerm; biscuits, cereal bars, breakfast cereals and beer. Where cereal grains specifically were sampled, the samples were collected from UK farms. Details of the pesticide residues sought and found in the surveys between 1994 and 2004 are detailed in Appendix A and B.

The number of pesticides sought over this period has varied from 20 to 52 active ingredients per year. The PRC choose which pesticides to look for based on information from the Pesticide Usage Surveys, the likely occurrence of a residue appearing based on degradation data and time of application, and the availability of a cost-effective analytical test. Only a small percentage of the pesticides approved for use on wheat are sought as residues generally because the others are not considered to be of concern. Factors such as the availability or cost of the analytical procedure also have a bearing on which pesticides are sought.

3.2 Pesticide residue trends

A total of three MRL exceedances were recorded in cereal grains between 1994 and 2004 on oats and rye (Table 12). MRLs do not exist for cereal products such as bread, biscuits and flour, however, the residues in these samples were all substantially less than the MRL for grain. Table 13 shows the residues detected in cereal grain from UK farms between 1997 and 2004. This illustrates that the most commonly detected residues are the plant growth regulators chlormequat and mepiquat, the herbicide glyphosate and the storage insecticide pirimiphos-methyl. Use of Gamma HCH stopped after 1999.

Table 12. MRL exceedances in UK cereals 1994-2004 (mg/kg)

Pesticide	Year	Crop	MRL	Residue found
Chlormequat	2004	Oats	2	6.0, 8.7
Gamma HCH	1999	Rye	0.1	0.5

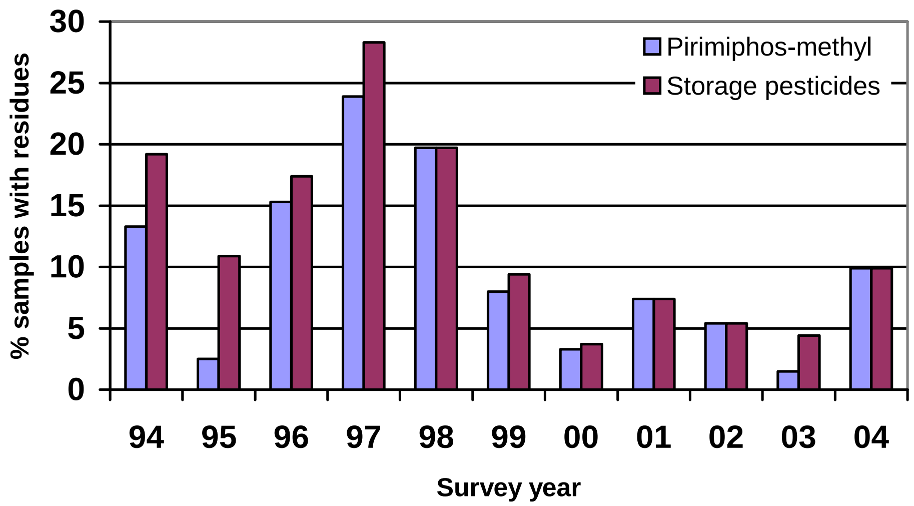
Table 13. Residues detected in cereal grain from UK farms from WPPR/PRC surveys

	1997	1998	1999	2003	2004
Samples tested	39	50	90	68	68
Chlormequat	0	31	36	50	57
Mepiquat	0	1	19	0	14
Glyphosate	0	3	1	5	8
Pirimiphos-methyl	1	4	7	2	5
Chlorpyriphos-methyl	0	1	0	0	1
Gamma HCH	0	2	6	0	0
Deltamethrin	0	0	3	0	0

In the nine year period from 1988 to 1996, 1600 bread samples were analysed for organophosphorus insecticides, and some were also analysed for organochlorine, pyrethroid and carbaryl residues (WPPR, 1996). A total of 1325 (83%) determinable residues were found in these samples. The pesticides most commonly present were pirimiphos-methyl and malathion, insecticides applied to stored grain to prevent pest damage post-harvest. The number of bread samples containing pesticide residues was higher for wholemeal bread (27%) compared with white bread (12%), as the residues are often contained within wheat bran, which is removed from white bread flour.

Between 1994 and 2004, a total of 2331 ordinary and speciality (excluding fruit-bread) bread samples were analysed for a wide range of pesticide residues. Overall, there were pesticide residues detected in 713 (31%) of these samples. It is difficult to establish trends from the overall figures because of the changes in the pesticide residues sought, and also because the bread products may contain flour from more than one country. The grain storage insecticides, pirimiphos-methyl, malathion, etrimfos and chlorpyrifos, were the main residues found up to 1998 and then the number of samples with residues started to decline to less than 5% of samples by 2003, although numbers rose again in 2004 (10%) (Fig. 2).

Fig. 2: Ordinary and speciality bread samples containing residues of pirimiphos-methyl and all storage pesticides 1994-2004 (%) (Source: WPPR/PRC survey data)



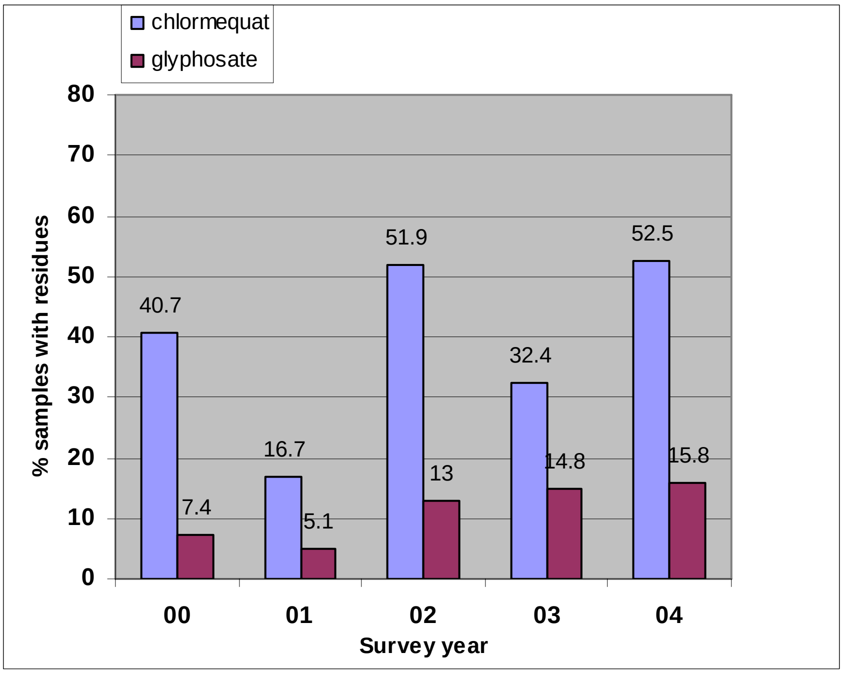
Food industry samples of grain between 1994 and 1997 also indicated that the storage pesticides were the most commonly found residues (Table 14).

Table 14. Occurrence of pesticide residues in food industry samples of wheat grain 1994-1997 (Source: WPPR reports)

	1994	1995	1996	1997
Total no. of samples	687	444	428	444
No of samples with residues	164	99	88	121
% with residues	23.9%	22.3%	20.6%	27.3%
No. of samples with individual residues				
Chlorpyrifos-methyl	40	39	4	17
Diazinon	-	-	1	-
Dichlorvos	2	-	-	1
Etrimfos	17	10	2	7
Gamma HCH	-	-	1	-
Malathion	19	-	19	26
Permethrin	-	-	1	-
Pirimiphos-methyl	118	50	74	98

From 2000 onwards, routine testing of chlormequat (plant growth regulator) and glyphosate (herbicide/desiccant) was included in the annual surveys, and significant numbers of samples containing residues of these pesticides were found in bread, flour, bran, wheat grain (Fig. 3). Chlormequat was also found in processed grain products such as breakfast cereals (25% of samples), biscuits (17%), cereal bars (100%) and also beer (35%), although sample numbers were relatively low (see Appendix B).

Fig. 3: Ordinary and speciality bread samples containing residues of chlormequat and glyphosate 2000-2004 (%) (Source: PRC survey data)



Use of chlormequat and glyphosate increased over the ten years from 1992 to 2002 (Table 6), and this is reflected in the increased number of samples containing residues of these pesticides. Possible reasons for the increased use are discussed in section 5.

No other significant pesticide residues were found in cereal products in the WPPR/PRC survey reports.

3.2.1 Producer/processor data

Data on pesticide residues from industry sources show similar results to the WPPR/PRC surveys, with the insecticide storage treatments being the most commonly occurring residues. Chlormequat and glyphosate are now occurring more frequently.

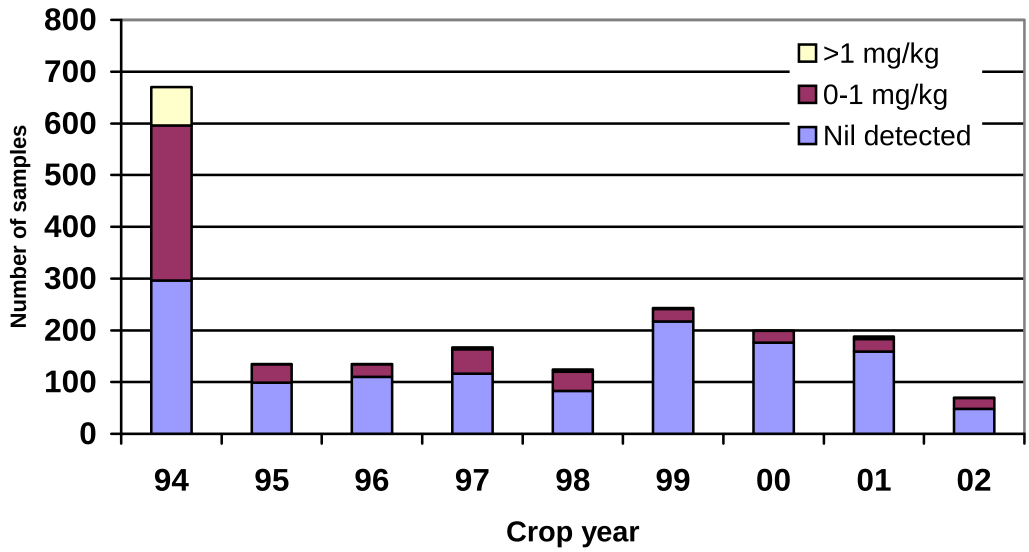
Breakfast cereals

In-house surveillance (UKAS accredited) of organophosphorus (OP) and organochlorine (OC) pesticides was done from 1996 to 2003 by a breakfast cereal manufacturer. Less than 1% of finished products contained pesticide residues (5 out of 550 samples). Analysis for pesticide active substances (product ingredients) showed 31 out of 255 wheat samples (12%), 11 out of 59 oat samples (19%) and 17 out of 40 bran samples (42.5%) contained OP storage pesticides. Samples are now being tested for chlormequat and glyphosate by external laboratories, and chlormequat is now being found routinely. None of the residues found have exceeded MRLs.

Malting barley

Routine pesticide residue tests are carried out on barley crops by the malting industry at intake, during storage and prior to steep at the start of the malting process. Samples are drawn from tonnages averaging over one million tonnes per year. The percentage of samples with no residues detected reached a peak of 89.3% in 1999 (Fig. 4). The percentage for 2002, on a lower crop tonnage was 68.6%. The main residues detected were storage insecticides such as pirimiphos-methyl. More recently residues of chlormequat and glyphosate and its metabolite, aminomethylphosphonic acid (AMPA) have been detected, which reflects the results of the PRC surveys.

Fig. 4: Number of malting barley samples containing pesticide residues at intake, for crop years 1994 to 2002 (Source: industry association)



4. Approaches to reduce pesticide residues

4.1 General approaches and policies to reduce residues

The low profit margins obtained by cereal producers in recent years have resulted in considerable efforts being made to reduce the cost of crop inputs. This has been achieved through a mixture of integrated crop management (ICM). ICM involves minimising pest, disease and weed pressure through careful selection of rotation, varietal choice, sowing date, nutrition and other management. Also, cereal producers have applied the principles of 'due diligence' to ensure the application of pesticides only where pest/disease pressures and/or potential crop losses make it cost effective. As a result, current pesticide application rates tend to be lower than the recommended amount, with growers aiming to use the minimum that is appropriate for cost-effective use. This pressure looks set to continue as grain prices and crop profitability remain at low levels. ICM strategies are described in the HGCA Guide 'Arable Cropping and the Environment' (section 7.1) and include;

a) **Crop rotation**. The sequences of crops grown in a field (the rotation) and the choice of crop variety both have a strong influence on the requirement for pesticides. Approximately 50% of wheat crops are grown after a crop of a different species, such as an oilseed crop e.g. winter sown oilseed rape or a legume crop e.g. field beans. Rotating crops in this way considerably disrupts the life cycle of damaging pests and diseases and reduces some weed problems, which may require pesticide applications to control them. Wheat crops, which are grown in a continuous sequence on the same field, are likely to experience greater pressure from pests, diseases and weeds carried over from the previous wheat crops. It is unusual for either barley or oats to be grown in consecutive years in the same field. However, these cereals frequently follow another cereal crop, which may host similar pests.
b) **Variety choice**. Most cereal varieties have some level of resistance to certain pests and diseases but this varies considerably and may not be sufficiently robust to completely obviate the need for chemical intervention. No single variety is resistant to the whole spectrum of pests and diseases, but if a particular problem is anticipated then its impact can be greatly reduced through careful variety choice.
c) **Seed quality**. The use of seed with disease levels below the recommended threshold for certified and basic seed can reduce the need for fungicides later in the growing season. Such high grade certified seed can be expensive.
d) **Sowing date**. Sowing cereals later often reduces the risk to diseases such as the root fungus known as take-all and the stem disease known as eyespot. Later sowing also reduces lodging risk and allows soil cultivations to be used to kill early germinating weeds. However, delaying sowing invariably carries a yield penalty.

4.2 Assurance schemes

All home grown wheat used for human consumption, and all malting barley, is grown by producers who belong to assurance schemes registered with Assured Food Standards (AFS). The 'Assured Combinable Crops Scheme' (ACCS) (www.assuredcrops.co.uk/ACCS) is the most common and nearly 12,000 growers and more than 2 million ha of cereal production across England and Wales are registered under the scheme. Over 80% of the UK crop of cereals, oilseeds and pulses are grown under this scheme. ACCS requires members to employ a crop protection programme strategy to avoid unnecessary chemical applications (see standard 1.2). AFS have worked with the key UK registration holders for the important chemical products to produce the Assured Combinable Crops Farmer Advisory Bulletin No.1 'Minimising pesticide residues on cereals'. In addition, the standards relating to crop storage require producers to employ a specific storage strategy, (measuring moisture and temperature regularly) which then reduces the need to use post harvest chemicals.

The Scottish Quality Cereals (SQC) assurance scheme was formed in 1994 and its members now account for 90% of Scottish combinable produce. SQC operates through Scottish Food Quality Certification Limited (SFQC) and more details about SQC, including SQC standards, can be found on the SFQC website http://www.sfqc.co.uk/farm/sqc.asp. Membership of SQC ensures members meet the requirements of the Food Safety Act, 1990. SQC supplies all approved members with 'Pesticide Declarations'. The Pesticide Declarations are unique for each member, thus ensuring complete traceability. SQC protocol guidelines refer to the need to adopt best practice, standards for crop protection practices, the need for spray records and the use of appropriate doses and not anything higher than what is stated on the label. Northern Ireland growers can use the Code of Practice for the Northern Ireland Farm Quality Assurance Scheme Explanatory Booklet. This scheme is organised by the Ulster Farmers Union (02890 370222) and gives guidance about the safe use of pesticides. This scheme is not accredited. Over 1000 growers are members of this scheme at the time of writing this report.

Other assurance schemes include organically produced cereals: Soil Association - www.soilassociation.org/farmassurance, Organic Farmers & Growers - www.efsis.com/htm/en/subp4page5.php and conservation grade cereals - www.conservationgrade.co.uk. UK organic growers produced approximately 128,000 t of organic grain in 2002. Crop management for conservation grade cereals includes guidance on pesticide use and the management of non-cropped areas on the farm to benefit wildlife.

4.3 Decision support systems

Several decision support systems are now available for use by growers, their consultants or agronomists to assist with crop management decisions. They give guidance on the most cost-effective use of pesticides, and although none of them consider the issue of pesticide residues directly, all will consider harvest interval recommendations when advising on pesticide use.

The 'Wheat Disease Manager' produced by HGCA (www.hgca.com) is an interactive computer programme, that helps farmers decide upon the most economic use of fungicides, across a broad range of crop and environmental conditions, and disease pressures. 'The Grain Storage Guide', published by the HGCA in 2003 (www.hgca.com), describes a decision support system for minimising storage pests which is based on frequent pest monitoring. Within this environmental control methods are always recommended before the use of storage pesticides. GrainPlan is software for managing grain storage (www.grainplan.info). 'Weed Manager' available from www.wmss.net is an interactive computer programme that provides guidance on reducing weeds through the use of rotation planning, soil cultivations and herbicides.

CropMonitor (www.cropmonitor.co.uk) is a Defra initiative that provides an alternative approach to monitoring crop health status and crop protection practice in winter wheat and winter barley.

4.4 Industry initiatives

***HGCA** (www.hgca.com)*

The HGCA, as the levy body with responsibility for cereals, has direct contact with cereal growers, processors and manufacturers, and indirect contact via agronomists (e.g. 'Agronomists Alliance' newsletters). HGCA manages the transfer of information between cereal growers and their markets. HGCA has funded research and technology transfer activities to directly minimise residues of chlormequat and monitors residue levels of chlormequat (see also Section 5.1) and other pesticides. HGCA also funds research to minimise pesticide use through Integrated Crop Management (ICM) practices, avoid pesticide use altogether by developing alternative non-pesticide approaches such as natural plant resistance to pests or non-chemical control materials. Whilst not directly aimed at reducing pesticide residues, these initiatives are expected to reduce residues. The relevant research and technology transfer projects funded by HGCA are listed in Appendix C.

The cereal industry has also co-funded several projects under the Defra-LINK scheme (www.defrafarmingandfoodscience.gov.uk) which aims to reduce pesticide use. In general these projects do not aim to specifically reduce residues although may do so indirectly. A list of relevant projects is given in Appendix C.

National Association of British and Irish Millers (NABIM) *(www.nabim.co.uk)*

The main procedures carried out by NABIM designed to ensure that pesticide residues are minimised include:

1) the purchase of cereal grain only from crop assured sources - i.e. where farmers have adopted best practice in growing their wheat, kept records of how the crop is grown and had these practices independently audited by a third party;
2) check every delivery of wheat for any food safety hazards and reject any that is not fit for purpose; and
3) apply HACCP (hazard analysis, critical control points) systems through the milling process including monitoring residues of pesticides and other possible agricultural contaminants.

NABIM maintain a regular dialogue with agro-chemical manufacturers regarding pesticide residue levels and test new chemicals to determine their impact on bread quality.

Maltsters' Association of Great Britain (MAGB)*(www.ukmalt.com)*

The use of pesticides on grain for malting is restricted with only a narrow range of pesticides accepted by brewers and distillers for use on the growing crops and stored grain. This is to ensure the malting process is not affected by residues. Only those pesticides listed on the British Beer & Pub Association (BBPA) Approved Chemicals list are permitted (see www.ukmalt.com for full list). These are standards that all malting grain producers must comply with. To ensure that the standards are met, every load of grain supplied to a UK maltings has to carry its own 'pesticide passport' to declare if pesticide has been used at any stage on the grain post-harvest. Spot loads are also tested at intake, to ensure that the passport information is correct and that MRLs are not exceeded. MAGB has also carried out a few spot tests for a very wide range of pesticides, most of which are not approved for use on malting barley in the UK. Excellent results showing nil or very low levels of permitted pesticides have been found, and there has been no detection of the use of MAGB excluded pesticides.

British Oat and Barley Millers Association (BOBMA) (no home website, but contacts can be found at: www.envirowise.gov.uk/page.aspx?o=MBEN4Z4MSM)

The UK oat industry is working to reduce the use of chlormequat, to meet the requirements of oat processors and export markets. As a result, some purchasers in BOBMA only accept oats that have not been treated with chlormequat and this is specified in crop contracts.

Crop protection industry *(* www.cropprotection.org.uk/)

The Crop Protection Association (CPA) has issued general advice on pesticide residues, on behalf of the crop protection industry. This advice seeks to ensure compliance with statutory limits and is available in a leaflet from their website (www.cropprotection.org.uk/), 'Keeping residues well within the limits'.

In Spring 2006, BASF circulated a technical bulletin 'BASF guidelines to minimise chlormequat residues in wheat' to their immediate customer base.

5. Approaches for specific problems related to residues

In this section of the Crop Guide, only those issues relating to key pesticide residues found in cereal products are considered. However, it should be noted that there are general husbandry principles which are used to reduce pesticide use (see Section 4.1) which will also minimise the occurrence of some residues. With the exception of pesticides to control storage pests and chlormequat on oats grown on contract, cereal farmers generally do not select pesticides for use on their cereal crops by their residue profiles, unlike growers of fresh produce crops. Farmers will select products based on efficacy, yield and financial return. Cereal farmers and agronomists do however take account of the environmental profile of the active ingredient using Environmental Information Sheets (EIS's) developed by agrochemical manufacturers as part of the Voluntary Initiative.

The key pesticide residues for cereals, based on their frequency of occurrence in PRC surveys, are chlormequat, mepiquat, glyphosate and grain storage pesticides.

5.1 Chlormequat and mepiquat

In cereal production, plant growth regulators (PGRs) such as chlormequat are used to shorten plant stems and thereby reduce their susceptibility to lodging i.e. being flattened by wind and rain. The prevention of lodging is regarded as important because lodged crops can yield up to 50% less (25% less on average), have lower bread-making quality, require more drying and are more difficult to harvest than standing crops. Severe lodging occurs, on average, every three to four years and is estimated to cost UK wheat growers £60 million due to loss of yield and £60 million due to loss of bread-making premium and greater drying costs [5]. Lodged crops have also been shown to increase the likelihood of mycotoxin contamination of cereal grains[1] (SANCO/1719/2005). Mycotoxins are produced by fungi, such as *Fusarium* spp and *Aspergillus* spp growing on grain. These fungi develop more quickly on damp grain. Lodged crops take longer to dry out and are more likely to be harvested and stored in a wet condition. Mycotoxins exhibit toxic effects in humans and in all animals investigated so far. Pigs are generally recognised as being the most sensitive animal species. Adverse effects of exposure to mycotoxins in pigs include reduced feed intake, vomiting, reduced fertility and renal toxicity (SANCO/01993/2005). European Commission Recommendation (SANCO/1719/2005) recommends the use of PGRs to reduce the likelihood of *Fusarium* mycotoxins that may result from lodging.

Farmers currently rely on variety choice and PGRs as the main means of preventing lodging. Varieties vary in their resistance to lodging and scores describing their resistance are published in the HGCA Recommended Lists for Cereals and Oilseeds. These scores typically vary from 4 to 9 (out of 9) across varieties of winter wheat, winter barley and oats. A score of 4 is very lodging susceptible, whereas scores of 8 or 9 suggest that the stem is stiff or very stiff, and therefore less likely to lodge. In addition, rooting strength can play a part in determining lodging resistance.

PGRs are applied in the spring to 89% of the winter wheat crop area, 77% of winter barley and 78% of winter oats [6]. Several PGR products are commonly used and the active ingredients include chlormequat, mepiquat, imazaquin, trinexapac-ethyl and 2-chloroethylphosphonic acid. About 75% of the PGRs applied contain chlormequat. Winter wheat, barley and oat crops receive on average 1.7, 1.4 and 1.4 PGR applications per crop respectively in the growing season [6]. Growers can use up to three applications of a PGR, hence the current application frequencies are already below those permitted as part of the pesticide approval. Currently, cereal growers do not consider the issue of residues in grain when making a decision to apply a PGR, with the exception of oat growers contracted to grow crops without the use of chlormequat, but this is only on a small area of production.

Best practice for minimising lodging risk in cereals also involves the use of other crop husbandry measures in addition to variety choice and PGR treatment. These include delaying sowing, reducing seed rate, reducing and delaying nitrogen fertiliser applications and rolling fields in the spring to consolidate the soil. Specific information about how these factors affect lodging in wheat is given in the HGCA guide, '*Avoiding lodging - a practical guide*' published in 2005. This shows that moderate alterations can be made to these elements of husbandry without reducing grain yield or quality. The continued increase in the number of cereal crops that receive PGRs suggests that even when farmers use these additional methods of lodging control, they still use PGRs to minimise lodging risk. This may be due to the low cost of many PGRs and the economic importance of protecting bread-making and other quality premiums.

Approaches to minimise chlormequat and mepiquat residues

Chlormequat can be effectively used to reduce lodging risk by applying to the crop between the end of tillering and the formation of the 2nd stem node (GS32). This period commonly spans March and April. Recent research concluded that the concentration of chlormequat residues in wheat could be significantly reduced (by up to 60%) by applying chlormequat at the beginning of this period compared with the end[13]. It must be emphasised that this early timing will only be possible if the soil is dry enough to support a sprayer and the treatment will only be effective at reducing lodging risk if the crop is actively growing. Reducing chlormequat dose rates reduces residues but also substantially reduces efficacy. No research has investigated the effect of dose and rate of mepiquat on residues.

Although lodging occurs in the summer, control methods such as PGRs must be applied in the spring. Therefore a method of predicting lodging is required so that PGRs can be targeted at those crops with high lodging risk. However, a comprehensive and fully tested prediction scheme does not yet exist and, as a result, PGRs tend to be applied to the majority of cereal crops prophylactically as a safeguard. The HGCA lodging guide provides farmers with information about how different crop management techniques affect lodging risk in wheat. Its primary function is to help farmers design crop management strategies that minimise lodging risk without adversely affecting yield. It is a relatively crude method for assessing a crop's lodging risk which may be used to identify which crops may not require a PGR. There are no comprehensive guides for using husbandry to minimise lodging risk in other cereals.

Alternative PGR treatments with lower levels of chlormequat include: 2-chloroethyl/phosphonic acid/mepiquat, chlormequat/2-chloroethyl/ phosphonic acid, and chlormequat/imazaquin. These products can contain as little as a third of the normal rate of chlormequat within a full dose (maximum rate recommended by manufacturer) and are effective at reducing lodging risk. However, use of these products is likely to be limited by cost considerations, as they tend to be 2-3 times more expensive than chlormequat alone.

Alternatives to chlormequat and mepiquat

If farmers were to stop using PGR products containing chlormequat and mepiquat, the PGRs available for use would be trinexapac ethyl and 2-chloroethyl phosphonic acid. These are effective at reducing lodging in wheat and barley, but are 2-3 times more expensive than chlormequat. Additionally, trinexapac ethyl residues can be detected in cereal grain at very low levels, although they are currently not included in the suite of pesticides tested for in PRC surveys.

Non-chemical approaches

Farmers could minimise lodging risk by choosing varieties with a high resistance to lodging (a score of 8 or 9), sowing crops after mid-September at lower seed rates and applying moderate amounts of nitrogen fertiliser. However, using only lodging-resistant varieties would severely restrict the farmer's choice of varieties to one third of those currently available. For example, only one milling wheat variety has a lodging resistance score of 8 or 9, but this has a grain yield some 5 to 11% less than other milling wheat varieties. The farmer would also have less scope for choosing disease-resistant varieties. Many farms sow wheat in early September because they have large areas that must be drilled, so later drilling to reduce lodging risk would not be an option for all. Use of moderate amounts of nitrogen will also reduce the chance of achieving protein levels required for bread-making. Previous HGCA research on oats[13] showed that lodging risk could be lowered by reducing nitrogen and using semi-dwarf varieties. However, nitrogen fertiliser had to be reduced to below optimum levels to reduce lodging substantially and the current semi-dwarf variety (Buffalo) is not favoured by millers due to its low kernel content. Whilst there is scope to avoid lodging and maintain yield/quality without using PGRs in certain situations, it will not be possible across the whole of the UK. Individual farmers will need to assess the scope for residue minimisation based on their particular circumstances and their market requirements.

5.2 Glyphosate

Glyphosate is a broad spectrum herbicide that is effective against most plant species[9,10]. Early label recommendations for its use were for pre-sowing applications only. In this situation, the herbicide did not come into contact with the crop and so there were no crop/grain residues. It is extremely unlikely that a crop could take up soil residues of glyphosate from pre-sowing treatments which could result in grain residues because of the broad spectrum activity of the herbicide. There is large variation in the rate at which glyphosate degrades in the soil with 50% degradation reported as taking between 3 to 174 days. In general, it degrades more rapidly in wet soils.

During the mid 1980s, it was discovered that glyphosate could be applied to grass weeds prior to harvesting the cereal crop. Application at this time had no adverse effects on the crop, but was effective at killing grass weeds such as black-grass[11]. Pre-harvest glyphosate is also an effective treatment for the control of potato volunteers in wheat crops. Treatment of crops pre-harvest also improved the efficiency of harvesting. Glyphosate is now used as a pre-harvest desiccant for cereals and 12% of GB wheat crops were treated in 2002. Its primary use is to promote even and rapid ripening. Information on the manufacturer's website (www.monsanto-ag.co.uk) states that glyphosate can improve the Hagberg Falling Number (a key indicator of bread-making quality) by reducing the proportion of green grains, reduce the moisture content of the harvested grain and reduce losses at combining. Other benefits stated by the manufacturer include lower mycotoxin levels in store due to the drier grain, weed control, earlier harvest, and a longer harvest window.

Applications are recommended when the grain is at less than 30% moisture content and a minimum harvest interval of seven days is required. User guidelines state that growers must consult grain merchants before treating crops grown for contract and barley grown for malting or distilling.

The recent increase in glyphosate use pre-harvest (Section 2.2.1) has been linked with the introduction of strobilurin fungicides, as these tend to prolong canopy greenness. Strobilurins are part of the QoI group of fungicides which are broad-spectrum fungicides with activity against a wide range of diseases in many crops. Strobilurins are used routinely on cereal crops to prevent foliar diseases. They are largely protectant in nature and are applied before the onset of significant disease levels. As well as increasing yield through broad-spectrum disease control, strobilurins increase green canopy persistence, resulting in increased yields when compared with more traditional fungicides[4]. They have been shown to increase the amount of green leaf area and prolong its duration, with a yield benefit of between 0.5 to 1.0 t/ha. However, the effect of this prolonged retention of green leaf area can make harvesting of cereals more difficult, particularly in northerly areas of the UK where crops are slower to senesce naturally. It is therefore likely that the increase in pre-harvest glyphosate use is at least partially caused by the introduction of strobilurin fungicides.

Residues of the strobilurin fungicides, azoxystrobin, trifloxystrobin and kresoxim-methyl, were sought in the 2003 PRC survey, but no residues were found.

Approaches to minimise glyphosate residues
Aside from information given on the manufacturer's website, there are no independent guidelines describing best practice for pre-harvest glyphosate use. Previous research shows that reducing the dose of glyphosate and possibly delaying its application would reduce residues[29]. Delayed applications would also reduce efficacy of the product as a crop desiccant, so there may be a trade-off between minimising residues and efficacy. This would require further investigation.

Alternative approaches to glyphosate
Currently, there are no other approved desiccants for use on cereal food crops used for human consumption.

Non-chemical approaches
The majority of the cereal acreage is not treated with glyphosate pre-harvest (>80%), however, the increasing occurrence of residues in bread and other products would suggest that premium crops are being treated to protect quality. Non-chemical methods of overcoming this would be to grow varieties which maintain quality for longer or that senesce and ripen more quickly. However, the latter option is seldom used because varietal range in the ripening date is only modest, and rapidly maturing varieties do not always give the best quality and yield. Sowing crops earlier would bring forward the harvest date but would also exacerbate, pest, disease and lodging problems. Replacing strobilurin fungicides with other types of fungicides would reduce the requirement to desiccate the canopy. However, the recent occurrence of resistance in some plant pathogens to strobilurin fungicides may reduce their use, although this will be influenced by many additional factors such as the yield response without complete disease control and the price of alternative fungicides.

Avoiding pre-harvest use of glyphosate in cereals is also important for conservation purposes. Overwinter stubbles after wheat cropping are important for providing food for farmland birds from shed seed and weeds growing in the stubble. Glyphosate-treated crop stubbles are usually weed-free and provide little food resource for birds. Farmers can use untreated overwinter stubbles to gain 120 points/ha for the new Entry Level Environmental Stewardship Scheme (option EF6), so this may also reduce pre-harvest glyphosate use in future.

5.3 Storage chemical residues e.g. pirimiphos-methyl

Pesticides are used to control insects, mites and fungi which occur on and in stored grain. These pests can multiply quickly in storage (up to 60-fold per month) and can greatly reduce the quality of the stored grain. Fungi can also increase the occurrence of mycotoxins such as ochratoxin A and to a lesser extent fusarium toxins. Information about the reduction of mycotoxins can be found in *'Practical guidelines to minimise mycotoxin development in UK cereals'* HGCA report 289 and in the European Commission recommendation (SANCO/1719/2005) *'The reduction and prevention of Fusarium toxins in cereals and cereal by-products'* (see Section 5.1). Pesticides can be applied to the empty store by spraying directly onto the surfaces (fabric) of the store or directly onto the grain (e.g. pirimiphos-methyl or chlorpyrifos-methyl). Aerial sprays may be used to control flying insects (e.g. d-phenothrin + tetramethrin), and fumigants are used in stores which can be sealed (e.g. aluminium phosphide or magnesium phosphide which produce phosphine gas). The use of the fumigant methyl bromide will be phased out by the end of 2005.

In 2002/2003, 63% of grain stored in the UK was treated with pesticides, and this amounted to 17.4 tonnes of pesticide[2,3]. Most of these pesticides were applied only to the fabric of the store itself, from 61% in commercial stores to 85% in farm stores. The remainder was applied direct to the grain and the store fabric. Pirimiphos-methyl was the most commonly used pesticide on stored grain in 2002/2003. Rodenticides were used in 86% and 78% of commercial and farm stores respectively.

Approaches to minimise residues
The percentage of grain samples containing storage chemical residues decreased from 25% in 1997 to 10% in 2004. A proportion of this decrease in residues has probably resulted from a switch to aluminium phosphide, possibly as a result of pressure from processors and management advice. The best practice for storing grain is described in 'The Grain Storage Guide' published by the HGCA in 2003. It draws upon a tranche of recent research, (much of which has been funded by the HGCA) and includes 51 research reviews and reports and nine books. The guide explains the biology of various pests and explains how environmental control, by lowering the temperature and moisture content of the grain or by modifying the atmosphere, is almost always the most effective strategy and should be employed before recourse to pesticides. The guide describes a decision support system for pesticide use, which is based on frequent pest monitoring.

Alternative approaches
Improving store hygiene and environmental controls, cleaning grain, drying grain to 15% moisture content and cooling grain will all reduce the need to apply chemical storage treatments. Pesticides are usually only applied if these measures are not followed. Monitoring pest levels in store will give an early indication of problems, so that swift and minimal action can be taken.

Use of a fumigant such as aluminium phosphide, for which no residues have been found, provides a chemical alternative that is already being taken up. However, it must be noted that aluminium phosphide is a Part One Poison under the 1982 poisons rules. When applied it gives off a very toxic gas, hydrogen phosphide (phosphine). Therefore, unlike pirimiphos-methyl, because of its high inhalational toxicity it must be applied by operators with specific training and certification and can only be used in stores that can be sealed. Furthermore, whilst pirimiphos-methyl provides some residual control, aluminium phosphide only controls insect pests present at the time of application.

Non-chemical approach
Diatomaceous earth is a potential alternative to the chemicals that are traditionally used for controlling some pests such as mites. This works by desiccating the pests, but it is slow to act and must be combined with cooling and drying. There are health concerns associated with using dust in confined spaces. Diatomaceous earth may adversely affect the milling process and as a result is not favoured by millers. Although, it is widely accepted that environmental control is most effective, there is no information about how many grain stores have the facility to fully exploit this. If the use of chemical methods for controlling storage pests was restricted, it seems likely that many grain stores would need to be upgraded at significant cost. High heat treatments are being investigated in commercial grain stores and flour mills to reduce infestation problems. Developmental work is being carried out on the use of fungal biological control of pests in stored grain and heating to disinfest grain (See Appendix C).

5.4 Implications of reducing pesticides on mycotoxin development

When using the husbandry methods to minimise pesticide use described in section 5 the possible impact on mycotoxin development must also be borne in mind. This is particularly important in view of the new EU limits for fusarium mycotoxins which are now in place. Growers are recommended to use these guidelines in conjunction with guidelines for minimising mycotoxins[2], e.g. *'Practical guidelines to minimise mycotoxin development in UK cereals'* HGCA report 289 and the European Commission recommendation (SANCO/1719/2005) *'The reduction and prevention of fusarium toxins in cereals and cereal by-products'*.

[2] The FSA is currently developing a code of practice to reduce fusarium mycotoxins in cereals, see the following link - http://www.food.gov.uk/foodindustry/farmingfood/fusariumadvice

6. Research

6.1 Recent research

Plant growth regulators - chlormequat and mepiquat

Previous research into lodging has quantified how PGRs, variety choice and other husbandry practices affect lodging risk in wheat[5,12]. This should enable farmers to plan strategies for growing lodging-resistant wheat. More recent research has quantified how the rate and timing of chlormequat affects the residues in winter wheat, winter barley and winter oats[13]. This research did not find any chlormequat residues that were greater than the MRL. In common with previous studies[14,15,16,17], residues were lowered by reducing the dose rate and increasing the interval between application and harvest. This study concluded that chlormequat residues in wheat could be reduced by up to 60% by applying chlormequat at the beginning of the effective chlormequat application period compared with the end, without reducing its efficacy for lodging control. This is described in the HGCA guide, '*Avoiding lodging - a practical guide*' published in 2005. It was noted that earlier PGR applications would be dependent on crop sprayers being able to travel on the land. Reducing the dose rate significantly reduced product efficacy.

In oats, the trials indicated that chlormequat residues could not be reduced by changing the time of application or reducing the dose rate without greatly reducing the efficacy of lodging control. In winter barley, chlormequat did not reduce lodging or crop height, but has often been associated with increases in yield of around 0.25 t/ha, which more than covered the cost of the treatment.

There is also some evidence that chlormequat residues are increased when the supply of water to the plant is limiting. High rainfall or irrigation during cereal growth has been associated with lower chlormequat residues[16,18,19]. This may be caused by the dilution effect that results from more dry matter accumulating when the supply of water is adequate. Alternatively, Gans *et al.* (2000) postulated that increased water supplies may affect the transportation of chlormequat around the plant. No other factors have been shown to consistently affect the level of chlormequat residues.

Mepiquat residues have been detected in cereal grains grown in Denmark[7]. The authors know of no other published research on mepiquat residues.

Pre-harvest treatments and glyphosate

Levels of weed control[20] have an important impact on yield. Yield increases of 14% have been recorded for barley in response to pre-harvest application of glyphosate for weed control. Subsequent crops have also been shown to yield more heavily as a result of fewer weeds where the previous crop was treated with glyphosate pre-harvest[21]. Other studies have shown that pre-harvest glyphosate use can effectively reduce weeds without altering the yield of the current crop[22,23].

In Canada, drying time was shown to be shorter when glyphosate was applied at grain moisture contents of above 25%, but not at lower moisture contents[24]. This study showed that applying glyphosate at less than 40% grain moisture had no effect on yield, baking quality, seed size, protein content or seed germination. In Argentina, glyphosate applications at 40 to 45% grain moisture hastened harvest by 3 to 7 days. Yield was not affected in two years and reduced by 9% in one year[25].

A recent UK study[26] showed that pre-harvest glyphosate improved bread-making quality in terms of the Hagberg falling number by reducing the number of immature green grains. In the

USA, glyphosate applied close to crop maturity was shown to increase gluten content by 2 to 8 units, increase dough mixing stability by 1.7 minutes, increase dough mixing time by 0.5 minutes with no effect on loaf volume[27].

Interestingly, two Canadian papers by the same authors found that glyphosate residues in barley and wheat grain were reduced when glyphosate was applied at later stages of crop development when there was less moisture in the grain[28,29]. Increasing dose rate increased the residues as expected. These studies concluded that the size of the residues was determined by the physiological maturity of the crop, rainfall wash-off and application rate.

Grain storage treatments

A large amount of research has been carried out on grain storage in recent years which has greatly increased understanding of storage pest control (see Appendix C). This research on grain storage treatments has been reviewed and the key findings and messages are included in 'The Grain Storage Guide' published by the HGCA.

6.2 Ongoing research

The cereals industry undertakes its own residue surveillance through an HGCA-funded project and makes these data available to the PRC: *RD-2004-3100 Monitoring the wholesomeness of UK grain.* A list of HGCA research can be found on the HGCA website.

At the time of writing this Crop Guide BASF (www.basf.de/en/uk) and Bayer CropScience (www.bayercropscience.co.uk) had commissioned research to evaluate the efficacy of their PGR products in different conditions for the purpose of providing farmers with guidelines about their best practice.

Research is being funded through the Sustainable Arable LINK programme (which brings together Government and industry funding) on the 'Identification of genetic markers for lodging resistance in wheat' (LK0958). This aims to provide plant breeders with tools for rapidly selecting lodging resistant varieties and should lead to increased lodging resistance in new varieties of wheat. Improving lodging resistance in oat varieties is also one of the aims of LK0954 'The incorporation of important traits underlying sustainable development of the oat crop through combining 'conventional' phenotypic selection with molecular marker technologies (OATLINK)'.

Funding is also being provided by the Sustainable Arable LINK programme for the 'Further development of heat-based methods for disinfesting flour mills'. This project is led by ADAS with CSL, NABIM, IGROX Ltd as research partners. It aims to demonstrate a heat-based disinfestation method to replace methyl-bromide use in flour mills.

Other LINK projects that are likely to reduce the use of storage pesticides include:

'Improving the detection and monitoring of storage beetle pests by the development of a multi-species lure'; 'Biopesticides for the control of insect storage pests; and 'Use of mycopesticides as a means of reducing organo-phosphate pesticide and methyl bromide usage in the control of stored food pests'.

For other relevant LINK projects that aim to reduce pesticide use see Appendix C.

6.3 Gaps in knowledge and research needs

Much of the research has been targeted at wheat (e.g. lodging research). Further research must focus on other cereals.

A method for quantitatively predicting lodging risk at the time when PGRs are applied does not exist. PGR use could be better targeted, if a model was developed. Previous research has shown that the structure of wheat crops in the spring could be used as a guide for its lodging susceptibility[5], but further research is required to develop a quantitative prediction scheme that works in a range of conditions. Little research has been done to quantify the effect of husbandry on the lodging risk of barley and oats and no research has been done on how the lodging risk of these species may be predicted early in the growing season.

Research is needed to develop methods for identifying crops that will benefit most from pre-harvest glyphosate so that its use can be targeted, and to look at the possible interactions between the use of strobilurin fungicides and glyphosate. And to assess whether guidelines need re-investigating in light of usage of strobilurins and modern high yielding varieties.

Storage pests are most effectively controlled by environmental management, such as cooling and ventilating the grain. Most, if not all, farm stores will have some of these facilities but these may vary widely from heated air drying through to near-ambient air drying on floor with various approaches to subsequent ventilation. It is not known how many farms have sufficient cooling and ventilation facilities to control storage pests without the use of pesticides.

High temperature disinfestation strategies have been developed for mill structures. These can be effective in some situations but depend on relatively low heat loss to achieve target temperatures. These strategies are highly unlikely to be applicable to farm or even commercial stores where metal silos are used due to heat loss. There has been work on strategies using heated air grain dryers to disinfest grain bulks. This has some potential but there are concerns about spreading infestations by moving grain to the dryer and the approach will not disinfest the store structure. Also, the approach will only be applicable to situations where heated air drying facilities are available. The potential health risk associated with diatomaceous earth must be investigated along with the possible adverse effects on the milling process.

7. Knowledge/Technology transfer initiatives

7.1 Ongoing activities

A series of best practice guides have been published by the HGCA, some of which have also received financial support from Defra and industry sponsors. The guides incorporate research results into relevant and practical advice and are sent to all levy payers. Presentations and workshops are usually held when each guide is launched to raise awareness in the industry. Between 2003 and 2005, the ACCS and HGCA have run a series of seminars to transfer information in the Grain Storage Guide (Assured Food Standards). The guides are usually incorporated into the assurance schemes, as essential documents for growers to read and refer to. All of these have relevance to pesticide residues but do not make specific recommendations to reduce residues.

The published guides include:

- Wheat Disease Management Guide, 2000, with updates in 2003, 2004
- Introductory guide to malting barley, 2001.
- Arable Cropping and Environment Guide, 2002.
- Grain Storage Guide, Edition 2, 2003.
- Wheat Seed Health and Seed-borne Diseases Guide, 2004.

In 2005, HGCA also funded the production of a Guide 'Avoiding lodging in winter wheat – practical guidelines' which explains how variety choice, sowing date, seed rate, previous crop, fertiliser nitrogen, rolling and PGRs affect lodging risk. This will help producers plan crop management strategies for growing wheat crops with a low risk to lodging. HGCA have also developed the GrainPlan software for managing grain storage (www.grainplan.info). In addition, 'The Wheat Disease Management Guide', produced by HGCA, has been updated and expanded and is available in electronic format with revised dose response curves at: www.hgca.com.

The HGC ran a "sow2succeed" campaign aimed to help growers explore the wide range of agronomic and financial implications associated with date of drilling, all within the context of whole farm planning and risk management. A key part of the workshops and field visits held in 2004 and 2005, was to explore drilling date in relation to variety choice, seed rates, establishment and plant numbers, and the subsequent agronomy needed. If all these factors are managed correctly and in a timely manner the need for PGRs to stop a crop from lodging is minimised. All materials from the campaign are on the HGCA website: http://www.hgca.com/sow2succeed/.

The Assured Food Standards (AFS) Crop Sector has produced a review on the issue of residues in cereals and cereal-based products in April 2005. Arising from this, a two-part action plan is being implemented. Part 1 has been a "warm up" article to growers in the November 2005 Newsletter, sent to all farmer members. The second part was be sent out in the Spring 2006 Newsletter 'Minimising pesticide residues on cereals', and includes best practice guidance from the key UK registration holders of chlormequat, glyphosate and pyrimiphos-methyl on how best to minimise any residues. The reading of relevant HGCA guidance documents will also be encouraged.

7.2 Required activities and how to achieve them

Major activity is required to raise awareness with growers of the issue of pesticide residues in cereal food products. There is less general awareness in the cereal sector than in the fresh produce sectors where growers have more direct links with their markets, retailers and consumers. The activity required can be addressed at all levels of the cereal supply chain, and could include the following actions:

- Workshops, farmer conference presentations, breakfast meetings, discussion groups to raise awareness about residues.
- Website links to key stakeholders, sources of information and documents.
- Product stewardship initiatives by the pesticide manufacturers, to raise awareness with distributors, crop consultants and agronomists when advising on pesticide use.
- Inclusion in combinable crop assurance schemes as a detailed section with issues and proposed actions. Some of this is ongoing (section 7.1).
- Inclusion in BASIS training for agrochemical company staff, consultants and agronomists as past of continuing professional development.

These activities will require collaborative funding from key stakeholders to ensure that all sectors of the supply chain are reached.

8. Conclusions

It is recognised that in general, farmers' awareness of pesticide residues in cereals is not high. Part of the reason for this must be because grain buyers seldom request grain without any pesticide residues. Action to increase awareness of residues, in conjunction with management practices that reduce them, will be a significant first step towards minimising pesticide residues in cereal products. There is significant scope to reduce residues without reducing productivity through this mechanism. Any reduction in pesticides must be done with care in order to minimise the risk of contaminating food products with mycotoxins from the growth of moulds. Further R & D is required to further reduce residues towards negligible amounts through the production of new resistant crop varieties, improved predictions schemes and the development of new control methods.

8.1 Key actions to minimise pesticide residues on cereals (*** high importance, ** medium importance)

Chlormequat and Mepiquat * **	**Scope for residue minimisation – medium to long-term** Wheat - There is moderate scope for reducing chlormequat residues using current knowledge. Barley and oats - There is limited scope for reducing chlormequat residues using current knowledge. More research is required to make significant progress. **The problem** Chlormequat is applied to more than ¾ of the cereal area and is the most frequently occurring residue, mepiquat is used less frequently. Chlormequat is used frequently because it has a low cost, a high rate of efficacy and the problem it reduces (lodging) is both expensive and causes health concerns due to greater likelihood of mycotoxins. **Best practice to minimise residues** Wheat – use the HGCA Guide published in 2005 'Avoiding lodging – practical guidelines' to develop cropping strategies that minimise lodging risk and help target PGRs at the crops at risk to lodging. Use HGCA guidelines for bringing forward chlormequat applications to increase the harvest interval. Wheat, barley and oats – grow varieties with high resistance to lodging. This will restrict varietal choice. **Alternatives to chlormequat and mepiquat** Use products containing 2-chloroethyl-phosphonic acid. These are more expensive than chlormequat. **Research needs** Wheat – need a validated method for predicting which crops are at risk to lodging so that PGRs can be better targeted. Barley and oats – need to develop husbandry strategies for minimising lodging risk. All species – develop varieties with greater lodging resistance (this is ongoing for wheat) **Knowledge transfer needs** A series of workshops, farmer conferences, breakfast meetings and discussion groups could be held to help transfer information from the HGCA guide about how best to manage crops to reduce lodging risk without using plant growth regulators. Wheat – convey HGCA work about reducing residues by bringing forward application dates and about cropping strategies to minimise lodging risk Incorporation of information on residues in decision support systems would flag up potential problems with residues when pesticide recommendations are given. Product stewardship initiatives by the pesticide manufacturers, to raise awareness with distributors, consultants and agronomists when advising on pesticide use. Inclusion in combinable crop assurance schemes as a detailed section with issues and proposed actions. Some of this is ongoing (section 7.1). Inclusion in BASIS training for agrochemical staff, consultants and agronomists and continuing professional development.

Glyphosate ***	**Scope for residue minimisation – medium term** **The problem** Glyphosate residues are the second most frequently found residues in cereals. Glyphosate is used just before harvest to desiccate the crop and kill weeds. Its use as a desiccant has increased recently possibly with the use of strobilurin fungicides which prolong canopy greenness, 12% of the wheat acreage was treated with glyphosate in 2002. Use of glyphosate can give savings in terms of reduced drying, better grain quality, faster harvest, and may reduce the occurrence of mycotoxins. **Best practice to minimise residues** Follow guidelines for its use as described on the product label. Instructions are also available at www.monsanto-ag.co.uk. Applications are recommended when the grain is at less than 30% moisture content. A minimum harvest interval of seven days is required. Aside from information given on the manufacturer's website, there are no independent guidelines describing best practice for pre-harvest glyphosate and how to reduce residues. Reducing the late-season use of strobilurin fungicides may reduce the need for pre-harvest treatment. The overwinter stubble option in the Entry Level of the Environmental Stewardship requires farmers not to use glyphosate prior to harvest. **Alternatives to glyphosate** There are no alternative desiccants approved for use on cereal crops for human consumption. **Research needs** Assess whether the optimum dose and timing for minimising residues needs re-investigating . Methods for identifying which crops will benefit from pre-harvest glyphosate are required. Alternative products require evaluating. **Knowledge transfer needs** Incorporation of information on residues in decision support systems would flag up potential problems with residues when pesticide recommendations are given. Product stewardship initiatives by the pesticide manufacturers, to raise awareness with distributors, consultants and agronomists when advising on pesticide use. Inclusion in combinable crop assurance schemes as a detailed section with issues and proposed actions (some of this is ongoing, see section 7.1). Inclusion in BASIS training for agrochemical advisors and continuing professional development.

Grain storage chemicals (mainly pirimiphos-methyl) **	**Scope for residue minimisation – medium term** There is significant scope for minimising and possibly eradicating storage residues by using the HGCA guide and taking on-board findings from on-going HGCA research. **The problem** Pesticides are used to control insects and mites on stored grain. These pests can multiply quickly in storage (up to 60-fold per month) and can greatly reduce the quality of the stored grain. **Best practice to minimise residues** The best practice for storing grain is described in 'The Grain Storage Guide' published by the HGCA in 2003. This explains how to use environmental control methods and cleaning, drying and cooling grain as the best measures, followed by chemical methods. **Alternatives to pirimiphos-methyl** Use of a fumigant such as aluminium phosphide, for which no residues have been found, provides a chemical alternative which is already being taken up. However, this product has several drawbacks for applicators due to its hazardous nature and can only be used in stores which can be sealed. Diatomaceous earth is a potential alternative to the chemicals that are traditionally used for controlling some pests such as mites. But this may adversely affect the milling process High heat treatment may be an effective treatment for problem infestations in flour mills. **Research needs** Further evaluation of non-chemical means of grain store pest management, including diatomaceous earth, for farm and small commercial stores could help reduce the occurrence of pesticide residues from storage treatments (some of this is ongoing section 6.2). Although, it is widely accepted that environmental control is most effective, there is no information about how many grain stores have the facility to fully employ this type of control. **Knowledge transfer needs** A series of workshops, farmer conferences, breakfast meetings and discussion groups could be held to help transfer information from the HGCA guide. This has been ongoing, but must continue. Incorporation of information on residues in decision support systems would flag up potential problems with residues when pesticide recommendations are given. Product stewardship initiatives by the pesticide manufacturers, to raise awareness with distributors, consultants and agronomists when advising on pesticide use. Inclusion in combinable crop assurance schemes as a detailed section with issues and proposed actions. (Some of this is ongoing, see section 7.1) Inclusion in BASIS training for agrochemical advisors and continuing professional development.

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Glossary of terms – (This glossary applies to all 5 crop guides)

Acceptable Daily Intake (ADI):- the estimated amount of a substance that can be consumed every day for a lifetime by humans without presenting a significant risk to their health, based on current scientific evidence.

Active ingredient:- Synonym for active substance.

Active substance:- Any substance or micro-organism, including a virus, that has a general or specific action: against harmful organisms; or on plants, parts of plants or plant products. Active substances are usually formulated with other materials in a pesticide product.

BASIS:- An independent registration, standards, certification and training organisation (serving pesticide, fertiliser, horticulture, forestry and other relevant interests), working with and through industry organisations to implement relevant sections of 'The Food and Environment Protection Act 1985' and other legislative and industry Code of Practice requirements.

Bio-control or Biological Control Agent (BCA):- Biological control of pests by use of other organisms.

Conservation Grade:- Conservation Grade farming is a system which encourages biodiversity and ensures a sound environmental provenance for food production (www.conservationgrade.co.uk).

Desiccants:- Products used to dry out unwanted plant material.

Diatomaceous earth:- Fine hygroscopic clay material used for controlling grain storage pests.

Disease:- A condition causing damage to a plant usually by a fungal or viral infection.

DMI:- demethylation inhibitors, group of fungicides, affect a particular biochemical step in the production of ergosterol.

Early potatoes:- Crops harvested before 31 July.

Fungicides: - Chemical substances that kill or inhibit the growth of fungal pathogens affecting plants.

Good Agricultural Practice (GAP):- The way products should be used according to the statutory conditions of approval, which are stated on the label.

HACCP: - **H**azard **A**nalysis & **C**ritical **C**ontrol **P**oints. A system, which identifies, evaluates and controls hazards which are significant for food safety.

Hagberg Falling Number (HFN): – a measure of bread making quality. Values of >250 seconds are required by millers.

Harvest Interval (HI): The time which must elapse between the final treatment with an individual pesticide and the harvest of the crop, as detailed on the pesticide label.

Haulm:- Potato foliage.

Herbicide:- A pesticide used to control unwanted vegetation (weed killer). A chemical that kills plants, sometimes designed to kill specific weeds.

Insecticide:- A pesticide used to control unwanted insects.

Integrated Crop Management (ICM):- ICM is a method of farming that balances the requirements of running a profitable business with responsibility and sensitivity to the environment. It includes practices that avoid waste, enhance energy efficiency and minimise pollution. ICM combines the best of modern technology with some basic principles of good farming practice and is a whole farm, long-term strategy including:
the use of crop rotations;

- appropriate cultivation techniques;
- careful choice of seed varieties;
- minimum reliance on artificial inputs such as fertilisers, pesticides and fossil fuels;
- maintenance of the landscape;
- enhancement of wildlife habitats.

Limit of Determination (LOD):- The limit of determination is the lowest concentration of a pesticide residue or contaminant that can be routinely identified and quantitatively measured in a specified food, agricultural commodity or animal feed with an acceptable degree of certainty by the method of analysis. It is also known as the Limit of Quantification (LOQ).

Lodging:- Term used to describe crops that are flattened by wind and rain.

Maximum Residue Level (MRL):- A legal limit for the maximum amount of residue that will be left on a food when a pesticide is applied according to instructions based on good agricultural practice. The MRL is a maximum legal level based on what would be expected if the pesticide was used correctly, it is not a safety limit. MRLs are intended primarily as a check that good agricultural practice is being followed and to assist international trade in produce treated with pesticides. MRLs are not safety limits and exposure to residues in excess of an MRL does not automatically imply a hazard to health.

In cases where there are no UK or EC MRLs, the acceptability of residues may be judged against Codex Maximum Residue Levels (**CAC MRL**). These limits give an indication of the likely residue that should occur in edible crops.

MBC:- Group of fungicides, methylbenzimidazole carbamates, the active component of carbendazim and thiophanate-methyl.

Molluscicide:- A pesticide used to control unwanted slugs and snails.

Nematicide:- A pesticide used to control harmful nematodes.

Pest:- Any organism harmful to plants or to wood or other plant products, any undesired plant and any harmful creature.

Pesticide:- Any substance, preparation or organism prepared or used for controlling any pest. A pesticide product consists of one or more active substances co-formulated with other materials. Formulated pesticides exist in many forms, such as solid granules, powders or liquids. Sometimes called a plant protection product.

Pesticide Usage Survey Group (PUSG):- The group that regularly surveys the UK use of agricultural pesticides. It is based at the Central Science Laboratory.

Pheromone:- A chemical substance secreted by an animal which influences the behaviour of others of its species.

Plant Growth Regulator (PGR):- A substance that has a marked and specific effect on plant growth, without killing the plant.

Plant Protection Product:- An active substance or preparation containing one or more active substances, formulated as it is supplied to the user, intended to:

- protect plants or plant products against all harmful organisms or prevent the action of such organisms;
- influence the life processes of plants other than as a nutrient (e.g. as a growth regulator);
- preserve plant products, in so far as such substances or products are not subject to the provisions of Community law on preservatives;
- destroy unwanted plants;
- destroy parts of plants or check or prevent the undesired growth of plants.

Sometimes used as a synonym for 'pesticide', but not in the strict legal sense.

QoI: – Class of fungicides that work by inhibiting mitochondrial respiration by binding at the Qo site of cytochrome b

Sclerotia:- Also known as fungal resting bodies. Pathogenic fungal sclerotia are able to survive long periods in the absence of the host plant.

SOLA (Specific Off-Label Approval):- For many reasons, label recommendations of approved pesticides do not cover the control of every problem which may arise. This is particularly true for crops that are grown on a comparatively small scale in the UK as well as for sporadic pests and diseases. It is for this reason that the extrapolations presented in the Long Term Arrangements for Extension of Use have been developed. If these do not address particular needs growers or their representatives may apply to the Pesticides Safety Directorate (PSD) for a specific off-label approval (SOLA). Such approvals are only granted after consumer, operator, bystander and environmental safety have been assessed and found acceptable.

Sprout suppressant:- A chemical or treatment that inhibits dormancy break and growth of potatoes during the storage period.

Steep:- Barley is soaked or 'steeped' in water to stimulate the embryo in the grain to grow to begin the malting process.

Trap cropping:- The planting of a potato crop to encourage the hatching of the potato cyst nematode (PCN) and invasion of the roots. The trap crop is subsequently sacrificed before the PCN matures and in this way populations are reduced.

Volunteer potatoes:- Self-set potatoes from a commercial crop growing as weeds in other crops.

Ware potatoes:- Crops grown for human consumption either before or after processing (excludes seed potatoes grown for planting).

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Useful contacts

ADAS UK Ltd
Woodthorne, Wergs Road, Wolverhampton WV6 8TQ. Tel 01902 754190
www.adas.co.uk

Assured Combinable Crops Scheme (ACCS)
48-50 Ashley Rd, Hampton, Middlesex, TW12 2HU.
www.assuredcrops.co.uk/ACCS

Assured Food Standards
University of Hertfordshire, College Lane, Hatfield, Hertfordshire, AL10 9AB.
Tel 01707 284548
www.littleredtractor.org.uk

Assured Produce Ltd
48-50 Ashley Road, Hampton, Middlesex TW12 2HU. Tel 0208 979 8966
www.assuredproduce.co.uk

BASIS Registration Ltd.
34 St John Street, Ashbourne, Derbyshire. DE6 1GH. Tel 01335 343945
www.basis-reg.com

British Oat and Barley Millers Association (BOBMA)
Food & Drink Federation, 6 Catherine Street, London WC2B 5JJ. Tel 0131 2299415
www.fdf.org.uk/fullmembers_bobma.aspx

Central Science Laboratory
Sand Hutton, York YO41 1LZ. Tel 01904 462000
www.csl.gov.uk

Conservation grade produce
info@conservationgrade.co.uk
www.conservationgrade.co.uk.

Crop Protection Association
Units 18 & 20 Evans Business Centre, Cully Court, Bakewell Road, Orton Southgate, Peterborough PE2 6XS. Tel 01733 367213
www.cropprotection.org.uk

Department of Environment, Food & Rural Affairs
Nobel House, Smith Square, London SW1P 3JR. Tel 0207 238 6000
www.defra.gov.uk

Food Standards Agency
Aviation House, 125 Kingsway, London WC2B 6NH. Tel 0207 276 8000
www.food.gov.uk

Home-Grown cereals authority
Caledonia House, 223 Pentonville Road, London N1 9HY. Tel 020 7520 3945
www.hgca.com

LEAF (Linking Farming And Environment)
The National Agricultural Centre, Stoneleigh Park, Warwickshire CV8 2LZ.
www.leafmarque.co.uk

Maltsters' Association of Great Britain (MAGB)
31 Castlegate, Newark, Notts, NG241AZ. Tel 01636 700781
www.ukmalt.com

National Association of British and Irish Millers (NABIM)
21 Arlington Street ,London SW1A 1RN. Tel 020 74932521.
www.nabim.co.uk

Organic Farmers & Growers
Elim Centre, Lancaster Rd, Shrewsbury, Shropshire SY1 3LE. Tel 0845 3305122
www.efsis.com/htm/en/subp4page5.php

Pesticide Residues Committee
Mallard House, Kings Pool, 3 Peasholme Green, York YO1 7PX. Tel 10904 445775
www.pesticides.gov.uk/prc_home.asp

Pesticides Safety Directorate
Mallard House, Kings Pool, Peasholme Green, York YO1 2PX. Tel 01904 640500
www.pesticides.gov.uk

Soil Association
Bristol House, 40-56 Victoria Street, Bristol BS1 6BY. Tel 0117 3145000
www.soilassociation.org/farmassurance

APPENDIX A. Pesticide residues sought on UK cereals and cereal food products in WPPR/PRC surveys 1994-2004 (See footnote below table for key to abbreviations)

Pesticide active substance	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Acephate								Y			Y
Aldrin	Y	Y	Y								
Azoxystrobin										Y	Y
Bifenthrin					Y	Y		Y	Y	Y	Y
Carbaryl	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Carbendazim	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Chlordane	Y	Y	Y	Y	Y	Y					
Chlormequat					**F**	**F**	**F**	**F**	**F**	**F**	**F**
Chlorpyrifos	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Chlorpyrifos-methyl	Y	**F**	Y	**F**	**F**	Y	Y	Y	Y	Y	Y
Cyhalothrin						Y					
Cypermethrin	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y
2, 4 D					Y	Y					
2, 4 DB					Y	Y					
DDT	Y	Y	Y	Y	Y	Y					
Deltamethrin	Y	Y	Y	Y	Y	**F**	Y		Y	Y	Y
Diazinon	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Dichlorprop					Y	Y					
Dichlorvos	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y
Dieldrin	Y	Y	Y	Y	Y	Y		Y	Y		
Diquat					Y	Y					
Dithiocarbamates						Y					
Endosulfan	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y
Endrin	Y	Y	Y	Y	Y	Y					
Etrimfos	Y	Y	Y	**F**	Y	Y	Y	**F**	Y	Y	Y
ETU						Y					
Famoxodone											Y
Fenitrothion	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fenvalerate	Y	Y	Y	Y	Y	Y	Y		Y	Y	Y
Glyphosate		Y			**F**	**F**	**F**	**F**	**F**	**F**	**F**
HCH	Y	Y									
Alpha HCH			Y	**F**	Y	**F**					Y
Beta HCH			Y	Y	Y	**F**					Y
Gamma HCH			**F**	**F**	**F**	**F**	Y	Y	Y		
Heptachlor	Y	Y	Y	Y	Y	Y					
Hexachlorobenzene	Y	Y	Y	Y	Y	Y					
Hydrogen phosphide								**F**			
Imazalil						Y					
Inorganic bromide					**F**						
Iprodione	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Isoproturon					Y	Y					
Kresoxyim-methyl										Y	Y
Lindane										Y	Y
Malathion	**F**	**F**	Y	**F**	Y	**F**	**F**	Y	Y	**F**	**F**
MCPA					Y	Y					
MCPB					Y	Y					
Mecarbam						Y					
Mecoprop					Y	Y					
Mepiquat					**F**	**F**					**F**
Metalaxyl						Y					
Methacrifos	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Methamidophos						Y					
Methidathion						Y					
Methyl bromide					Y						
Nitrofen											Y
Permethrin	Y	Y	Y	**F**	Y	Y	Y	Y	Y	Y	Y
Phosphamidon	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Pesticide active substance	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Pirimiphos-methyl	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**
Iso PTU	Y					Y					
Thiabendazole						Y					
Triazophos						Y					
Trifloxystrobin										Y	Y
Trifluralin						Y					
Vinclozolin						Y					
Total residues sought	27	27	28	27	42	52	20	20	23	25	31

(NB Not all residues are sought on all samples taken in any one year.)

Key to symbols and abbreviations:

- = pesticide not sought
Y = pesticide sought but not found
F = pesticide above the Limit of Detection (LOD) found

APPENDIX B. Pesticide residues found in UK cereals and cereal food products from WPPR/PRC surveys 1994-2004, number of samples with residues (range of residues found mg/kg) – (See page 47 for the key to the abbreviations in these tables.)

Cereal grains

	Wheat				**Barley**		**Oats**		**Rye**		**Triticale**
Pesticide residue	**1997**	**1998**	**1999**	**2003**	**1997**	**1999**	**1998**	**2004**	**1999**	**2004**	**1999**
Total samples	18	38	20	68	21	44	12	34	17	34	9
No. samples with no residues detected	17	16	19	14	21	20	0	5	0	3	2
% samples with no residues detected	94.4	42.1	95	20.6	100	45.5	0	14.7	0	8.8	22.2
Chlormequat (PGR) (MRL=5/2#)	-	19 (0.05-0.7)	Nil	50 (0.06-0.9)	-	18 (0.06-1.1)	12 (0.2-5)	28** (0.1-8.7)	13 (0.07-1.6)	29 (0.05-1)	5 (0.2-0.7)
Chlorpyrifos-methyl (I) (MRL=3)	Nil	1 (0.1)	Nil	Nil	Nil	Nil	Nil	1 (0.07)	Nil	Nil	Nil
Deltamethrin (I) (MRL=1)	Nil	Nil	3 (0.05-0.06)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Glyphosate (H/D) (MRL=5)	-	1 (0.2)	Nil	8 (0.1-0.8)	-	1 (0.5)	2 (0.3-2.8)	3 (0.2-1)	Nil	2 (0.2-0.5)	Nil
Gamma HCH (I) (MRL=0.1)	Nil	Nil	Nil	Nil	Nil	Nil	2 (0.03-0.04)	-	5* (0.01-0.5)	-	1 (0.01)
Inorganic bromide (F) (MRL=50)	-	37 (1-4)	-	-	-	-	11 (1-2)	-	-	-	-
Mepiquat (PGR)	-	1 (0.05)	-	-	-	9 (0.05-1)	-	Nil	8 (0.08-1.4)	14 (0.05-1)	2 (0.08-0.1)
Pirimiphos-methyl (I) (MRL=5)	1 (0.3)	4 (0.08-0.7)	1 (0.06)	5 (0.05-1.4)	Nil	4 (0.07-0.2)	Nil	2 (0.09-1.1)	Nil	Nil	2 (0.06-0.2)
MRL exceedances	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2	1	Nil	Nil

= MRL=5 refers to oats; MRL=2 refers to wheat, barley, triticale and rye.

Ordinary bread

Pesticide residue	1994	1995	1996	1998	1999	2000	2001	2002	2003	2004
Total samples	255	239	241	239	142	214	144	137	136	144
No. samples with no residues detected	214	213	202	192	133	118	89	48	55	48
% samples with no residues detected	83.9	89.1	83.8	80.3	93.7	55.1	61.8	35	40.4	33.3
Chlormequat (PGR)	-	-	-	-	-	88 (0.05-0.2)	32 (0.05-0.2)	80 (0.05-0.2)	63 (0.05-0.2)	88 (0.05-0.3)
Chlorpyrifos-methyl (I)	Nil	14 (0.1)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Etrimfos (I)	3 (0.06-0.07)	1 (0.1)	4 (0.06-0.3)	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Glyphosate (H/D)	-	-	-	-	-	16 (0.1-0.3)	9 (0.1-0.2)	26 (0.1-0.4)	30 (0.1-0.5)	27 (0.1-0.6)
Gamma HCH (I)	-	-	1 (0.01)	Nil	Nil	Nil	Nil	Nil	-	-
Malathion (I)	12 (0.05-0.1)	5 (0.08-0.3)	Nil	Nil	1 (0.05)	1 (0.06)	Nil	Nil	4 (0.05-0.1)	4 (0.05-0.1)
Pirimiphos-methyl (I)	34 (0.05-0.4)	6 (0.1-0.2)	37 (0.05-0.2)	47 (0.05-0.2)	9 (0.05-0.1)	7 (0.07-0.2)	15 (0.05-0.1)	6 (0.06-0.2)	2 (0.08-0.2)	7 (0.05-0.2)
MRL exceedances	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Other breads and processed grains

	Speciality			Savoury		Part-baked	Flour		Wheat bran/germ	
Pesticide residue	**1997**	**1999**	**2004**	**2001**	**2002**	**2002**	**1995**	**2002**	**1994**	**2001**
Total samples	184	59	58	72	31	36	52	36	69	47
No. samples with no residues detected	132	51	28	66	15	14	49	9	30	7
% samples with no residues detected	71.7	86.4	48.3	91.7	48.4	38.9	94.2	25	43.5	14.9
Chlormequat (PGR)	-	-	22 (0.05-0.1)	4 (0.05-0.09)	15 (0.05-0.1)	21 (0.06-0.1)	-	27 (0.05-0.3)	-	40 (0.2-6.3)
Chlorpyrifos-methyl (I)	1 (0.02)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	3 (0.06-1.9)	Nil
Etrimfos (I)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	2 (0.06-0.2)
Glyphosate (H/D)	-	-	7 (0.1-0.2)	2 (0.1-0.2)	2 (0.1-0.2)	Nil	3 (0.05-0.1)	2 (0.2-0.4)	-	34 (0.1-1.8)
Alpha HCH (I)	1 (0.02)	1 (0.01)	-	-	-	-	-	-	-	-
Beta HCH (I)	Nil	1 (0.01)	-	-	-	-	-	-	-	-
Gamma HCH (I)	1 (0.01)	Nil	-	Nil	Nil	Nil	-	Nil	-	Nil
Malathion (I)	4 (0.03-0.04)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	1 (0.07)	Nil
Permethrin (I)	1 (0.03)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Pirimiphos-methyl (I)	44 (0.02-0.3)	7 (0.06-0.5)	9 (0.06-0.2)	1 (0.07)	3 (0.05-0.1)	2 (0.05-0.09)	Nil	6 (0.06-0.3)	37 (0.05-2)	21 (0.06-1.5)
MRL exceedances	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Biscuits, cereal bars, breakfast cereals and beer

Pesticide residue	Biscuits		Cereal bars	Breakfast cereals		Beer	
	1997	2003	2001	1997	2001	1999	2004
Total samples	43	88	13	108	47	68	45
No. samples with no residues detected	40	71	0	107	34	44	30
% samples with no residues detected	93	80.7	0	99.1	72.3	64.7	66.7
Chlormequat (PGR)	-	15 (0.05-0.4)	13 (0.07-0.4)	-	12 (0.05-1.1)	24 (0.02-0.05)	15 (0.02-0.05)
Etrimfos (I)	Nil	Nil	Nil	1 (0.1)	Nil	Nil	Nil
Glyphosate (H/D)	-	1 (0.4)	Nil	-	3 (0.2-0.4)	-	Nil
Hydrogen phosphide (F)	-	-	2 (0.002-0.003)	-	-	-	-
Pirimiphos-methyl (I)	3 (0.06)	3 (0.06)	1 (0.06)	Nil	2 (0.06-0.08)	Nil	Nil
MRL exceedances	Nil	Nil	Nil	Nil	Nil	Nil	Nil

Key to symbols and abbreviations:

MRLs shown are the most recent values presented in the latest PRC survey report for cereals. Where an MRL exceedance is recorded it relates to the MRL which was current at the time the survey was conducted.
- = pesticide not sought
nil = residue not found
* = one MRL exceedance found
** = two MRL exceedances found
***= three MRL exceedances found

Pesticide types:
D = desiccant; F = fungicide; Fu = fumigant; H = herbicide; I = insecticide; PGR = plant growth regulator.

APPENDIX C. Relevant research and knowledge transfer projects

HGCA have funded several relevant projects described below. More information about each specific project is available by searching for the project number (given in brackets) on the HGCA website (www.hgca.com) or by contacting roger.williams@hgca.com. New projects that have begun after this report was written can be found on the HGCA website. Relevant Defra-LINK Projects are also described below for which further information can be found on http://defrafarmingandfoodscience.csl.gov.uk/. New projects that have begun after this report was written can be found on the Defra website.

General

‘Analysis of chlormequat and glyphosate residue levels in wheat grain’
HGCA Project 299

Forty-eight wheat samples were analysed for chlormequat and glyphosate residues.
Residues of chlormequat were found in 44 of the 48 samples in the range 0.02 mg/kg to 0.5 mg/kg. None of the residues found exceeded the MRL set for chlormequat in wheat of 2.0 mg/kg.
Residues of glyphosate were found in 17 of the 48 samples in the range 0.1 mg/kg to 2.3 mg/kg. None of the residues found exceeded the MRL set for glyphosate in wheat of 5.0 mg/kg.

‘National grain sampling and analysis system for improved food marketing and safety’
HGCA Project 349

The objective of this project was to develop an innovative, independent national structure for cereals sampling and analysis that would significantly improve the marketing of UK grain and bring about cost reductions.

‘Development of 'RL *Plus*': winter wheat variety performance in relation to site characteristics’
HGCA Project 365

Development of a web tool for characterising cereal varieties for their resistance to disease and lodging. This will enable growers to match the use of plant growth regulators and fungicides with varietal traits and will reduce their use on resistant varieties.

‘LINK Integrated Farming Systems (a field-scale comparison of arable rotations) Volume I: Experimental work’ This lead to the Arable Cropping and Environment Guide, published 2002
HGCA Project 173

Aim to investigate integrated cropping systems. Pesticide use was substantially reduced across most crops (30% less cost and 18% less active ingredient) on IFS, with no measurable increases in pest, disease or weed problems. Also, the IFS rotations used 20% less nitrogen overall than the conventional. Although yields were generally lower on the IFS, variable and production costs were also reduced, giving an overall lower cost of production per tonne from the IFS. Although, there was some variation between sites, IFS was as economically viable as the conventional system overall.

Chlormequat residues

‘Effects of timing and dose on residues of chlormequat in wheat, barley and oats’
HGCA Project 334

In winter wheat, the most effective method of reducing chlormequat residues, without significantly reducing lodging control, was achieved by applying chlormequat earlier in the plant's life-cycle. The effect of changing the application timing from GS31 to tillering was to reduce the chlormequat residues in the grain by 60% and only cause a small and non-significant reduction in efficacy. In oats, the trials in this single season study indicated that chlormequat residues could not be reduced by changing the time of application or reducing the dose rate without greatly reducing the efficacy of lodging control. In winter barley, chlormequat did not reduce lodging or crop height, but did cause a non-significant increase in yield of 0.25 t ha-1 at one of the two sites. Previous studies have also shown that, in certain circumstances, chlormequat can increase the yield of winter barley. Applying chlormequat at late tillering reduced residues by 33% compared with applications at GS30. Reducing the dose rate to ¼ only reduced the residues by 36%.

'To establish separate standing power ratings for stem and root lodging in the UK Recommended Lists for wheat'
HGCA Project 305

Previous HGCA funded research has shown that crops should be managed differently to reduce stem and root lodging: establishing fewer plants and rolling before GS30 are the best methods for reducing root lodging; delaying and reducing fertilizer N are best for reducing stem lodging. So far, winter wheat varieties have not been assessed for their risks to stem and root lodging separately and the current standing powers are a combination of both types. Therefore, the two primary objectives of this project were to investigate:

1) whether winter wheat varieties differ in their rankings for stem and root lodging risk.
2) methods for rapidly assessing stem and root lodging risk.

This work was used to help develop the HGCA 2005 Guide 'Avoiding lodging in wheat guidelines'.
This project showed how varietal resistance to lodging could be exploited, thus reducing reliance on plant growth regulators.

'Identification of genetic markers for lodging resistance in wheat'
Defra LINK Project (LK0958)

To develop wheat varieties with high resistance to lodging and low requirement for plant growth regulators.

'The incorporation of important traits underlying sustainable development of the oat crop through combining conventional phenotypic selection with molecular marker technologies'
Defra LINK Project (LK0954)

Part of the project remit is to improve varietal lodging resistance of oats which should reduce reliance on plant growth regulators.

Glyphosate residues

Many of the projects described here aim to reduce weeds and to reduce the need for and improve the targeting of fungicides. Both of these objectives may help to reduce the requirement for late season glyphosate by reducing weed infestations and reducing late fungicides which often prolong crop greening and increases the need for crop desiccation.

'Weed Management Support System (WMSS)'
Defra LINK Project LK0916.

The WMSS will allow users (both farmers and advisers) to plan and develop strategies for weed management for the coming year and to make decisions in response to observations from the current season, providing strategic information on a range of options, without being prescriptive.

‘Cost-effective weed control in cereals using vision guided inter-row hoeing and band spraying systems’
HGCA Project 373

Weed control is one of the most economically and agronomically significant problems for both conventional and organic cereal production. This project developed generic precision row guidance technology to benefit cereal producers through better targeting of both chemical and mechanical weed control inputs.

‘Maximising disease escape, resistance and tolerance in wheat through genetic analysis and agronomy ‘
HGCA Project 358

Three mechanisms can act in sequence to reduce yield loss caused by foliar diseases: **escape** inhibits spore transfer to the upper crop canopy, **resistance** reduces the capacity of spores which arrive on the upper leaves to infect and cause symptoms, and **tolerance** reduces the impact of symptoms on yield. This research tested the extent to which escape, resistance and tolerance might be improved in order to contribute to a reduction in disease and yield loss, and hence reduced dependence on fungicides.

Fungicide dose-response trials in wheat: the basis for choosing 'Appropriate Dose'
HGCA Project 373

In spite of changes in sensitivity in populations of mildew and *S. tritici*, most pathogens attacking wheat crops are well controlled by modern fungicides. The main pathogen of wheat, *S. tritici*, is well controlled by the azole fungicides, chlorothalonil and boscalid. The morpholines, in mixture with azoles, also add to the control of septoria. Although control of mildew by the strobilurin fungicides has almost been lost completely in the last few years, it is still well controlled by cyprodinil, metrafenone, the morpholines, quinoxyfen, and spiroxamine. The azoles also still add to mildew control. Yellow and brown rust are well controlled by many of the azole and strobilurin fungicides. This work is used to develop the HGCA Wheat Disease Management Guide updated 2005.

‘Appropriate fungicide doses on winter barley: producing dose-response data for a decision guide’
HGCA Project 373

The aim of the research was to provide an independent source of information about the activity of current and newly introduced fungicides against the major barley diseases.

‘Breeding for improved resistance to Septoria tritici’
Defra Link Project LK0913.

To reduce fungicide use by improving varietal resistance to septoria tritici.

‘Reduced fusarium ear blight and mycotoxins through improved resistance (REFAM)’
Defra LINK Project LK0932

The REFAM project aims to identify and characterise both the best available and new sources of resistance to FEB and toxin accumulation in wheat. This approach will facilitate long-term progress in the scientific study of resistance to the disease and toxin accumulation and enable the development of efficient marker assisted selection (MAS) procedures within breeding programmes of the companies that are partners in this application.

‘Improved Resistance to Septoria in Superior Varieties (IMPRESSIV)’

Defra LINK Project LK0945

The aim of this project is to enable wheat breeders to improve the effectiveness of breeding for resistance to septoria tritici blotch. This may be achieved by using genes which control disease effectively but do not have undesirable side-effects on plant performance. This will lead to the production of a steady supply of wheat varieties which have good resistance to septoria and are well adapted to UK conditions.

Storage pesticide residues

Many of the projects described below have contributed to the integrated grain storage research leading to the Grain Storage Guide edition 2 published in 2003

‘Biopesticides for the control of storage insect pests’
Ongoing HGCA Project 3079

The primary aim of this project is to provide the basis for a whole new class of biological pesticides for use in the storage of a wide range of commodities including cereals and oilseeds.

‘Development of a biosensor array to rapidly detect and measure organophosphate pesticides in grain’
HGCA Project 373

The aim of this three-year project was to investigate scientific and technological issues involved in the implementation of rapid sensor technology, for the detection of organophosphate residues in raw food products. The project succeeded in demonstrating that an array of biosensors can be used to rapidly detect and measure organophosphates in samples of grain.

‘Further development of heat-based methods for disinfesting flour mills’
HGCA Project 378 now extended in ongoing project 3013.

Following detailed studies at two mills, (volumes 3078 and 6600 m^3) a target temperature of 50^o C and a total heating period greater than 40 hours is recommended for heat treatments. Commonly about half of this period will be required for the structure to approach target temperatures. Heating larger mills will take longer, and the scaling up of heating requirements may introduce other problems that could preclude the use of heat as a whole-site disinfestation strategy.

‘Completing the development of a detection kit for a range of grain storage mite species’
HGCA Project 377, now extended in ongoing project 2693

This work demonstrated the feasibility of Lateral Flow Devices (LFDs) being used in grain stores to target mite control effort in problem areas. LFDs are easy to use, rapid and cheap (approximately £3-5) and enable more samples to be analysed than previous methods. The LFD could be used throughout the food supply chain to establish the degree of contamination and point of entry by mites. Validation work is required to confirm the commercial capability of the LFDs and to develop kits from the other species/genera specific antibodies; however, *A.*

siro and mite species of the genus *Tyrophagus* are the most prevalent in UK grain stores. Further work is required to construct a model to simulate mite distributions in grain bulks.

‘Disinfestation of grain using hot-air dryers: Killing hidden infestations of grain weevils without damaging germination’
HGCA Project 345

This project aimed to provide recommendations on using hot-air dryers to disinfest grain as an alternative to OP admixture or fumigation. To do so, the most heat tolerant stages and species of insects were identified by oven heating of infested grain. A model of their mortality at elevated temperatures was integrated with existing models of germination loss, incorporated into a simulation of hot-air dryer operation and used to study the conditions needed for disinfestation. Based on information from these models, a practical-scale trial was undertaken.

‘Efficacy of diatomaceous earths, applied as structural treatments, against stored product insects and mites’
HGCA Project 344

Diatomaceous earth (DE), a silicon-based dust that can desiccate insect and mite pests, acts by removal of water-proofing waxes found in the cuticle. Three DE products marketed for stored product protection were launched in the UK from 2001 onwards. Following on from previous research, that enabled recommendations for use on grain, this project aimed to investigate their use to control residual pests in empty grain store structures. The project concluded that DE is ideal for treating empty stores if used as part of an integrated strategy.

‘The potential use of insect-specific fungi to control grain storage pests in empty grain stores’
HGCA Project 341

Stored grain and grain products are at risk of infestation by insects and mites. However, some OP pesticides currently used to control these pests are being withdrawn from use and methyl bromide will be phased out for most uses by the end of 2004. Alternative approaches for the control of storage pests are needed urgently. This project aimed to collect UK isolates of naturally occurring insect specific fungi and evaluate their use for grain store structure treatments.

The results of the laboratory efficacy tests showed that UK isolates of B. bassiana have the potential to control a range of arthropod pests in UK grain stores. However, before this potential can be realised in practice, it will be essential to conduct further research to improve spore formulation and delivery systems.

‘Immunoassays for the detection of organophosphorus pesticides on stored grain: Assessment of three commercially available kits and recommendations for laboratory and field use’
HGCA Project 122

Rapid semi-quantitative assays for grain protectant pesticides based on immunological methods have been studied at the Central Science Laboratory (MAFF) in order to provide a comparison with established chromatographic methods. The ease-of-use of the kits in both laboratory and field situations was appraised and it was found that in order to achieve optimum results, some degree of user training was required. The instructions supplied with the kits were not easy to follow and could lead to erroneous results, hence a protocol for practical use on stored grain was developed which will allow grain store keepers, millers and maltsters to obtain reliable estimates of pesticide residues.

‘Use of mycopesticides as a means of reducing OP pesticide and methyl bromide usage in the control of stored food pests’
Defra LINK Project (LK0914)

The main objectives of the proposed project is to evaluate the use of naturally-occurring insect specific fungi as a means of reducing OP pesticide and methyl bromide usage for the control of invertebrate pests of storage premises, while at the same time maintaining high standards of pest control. The results of this work will be used directly by the arable farming industry including farmers, commercial grain stores and processors including flour millers.

‘Improving the detection and monitoring of storage beetle pests by development of a multi-species lure’

Defra LINK Project (LK0929)

As a result of a DEFRA-funded project which has just been completed, a mixture of materials has been identified which shows promising and long lasting activity as a multi-species lure for the saw-toothed grain beetle, the grain weevil and the rust-red grain beetle in laboratory conditions. The purpose of the proposed LINK project is to exploit this innovative invention by undertaking pre-competitive research to ensure that the multi-species lure can be brought to market. Monitoring protocols for the presence of beetle pests will be optimised.

‘Biopesticides for the control of insect storage pests’
Defra LINK Project (LK0967)

Investigating the use of biopesticides in place of chemical pesticides for controlling insect pests in stores.