EFRC: Cereals Programme – Paper 1
Trial Results

Organic Cereal Variety and Variety Mixture Trials 1999 - 2003

July 2004

Triticale and Oat Plots at Sheepdrove Organic Farm in 2001

Sheepdrove Organic Farm

ELM FARM RESEARCH CENTRE

Acknowledgments.

Elm Farm Research Centre would like to take this opportunity to thank everyone involved with this project over the years, particularly those farmers whom allowed us to place trial plots on their farms. A special thank you to Triodos Bank and The Sheepdrove Trust for providing the funding for this project and without whom it would not have been possible.

Executive Summary.

i. The aim of this work was to improve the productivity and stability of organic cereal production by identifying cereal varieties and variety mixtures that are best adapted to organic farming systems.

ii. The scientific question and objective was to evaluate the relative performance of cereal mixtures against single varieties in organic systems, in terms of consistency, robustness of yield and quality.

iii. The project has run over four years on six sites chosen to represent a range of soil types, climatic conditions and organic systems. All sites were located in the south and east of England.

iv. A range of cereal species, varieties, variety mixtures and interspecies mixtures were investigated. This range included winter and spring wheat, winter and spring oats, winter and spring barley and triticale.

v. Winter oats and triticale performed best under organic conditions followed by winter wheat, spring barley and spring oats. Spring wheat performed poorly. Winter oats and triticale also showed the greatest yield stability across the years and sites.

vi. Cereal mixtures performed reasonably well when compared with pure stands and were much more stable than individual varieties. This is due to compensation and complementation between varieties in mixtures. For all species except winter oats, the yield and quality of mixtures were less variable than the components in pure stands.

vii. It is clear that cereal varieties that have been bred for conventional production perform less well within organic systems. The trials confirmed that the performance of cereals in organic systems, both in terms of yield and conventional measures of grain quality, were much lower than would be expected in conventional systems. This may be because the UK varieties have been bred for monocultural production systems that rely on synthetic inputs to provide high fertility and control weeds, pests and diseases.

viii. Variety mixtures provided some compensation between varieties for problems with seed-borne disease using farm-saved seed. This was seen in mixtures that were re-sown on sites as opposed to regenerated from new seed each season. Variety mixtures also provided the expected benefit of preventing air-borne foliar diseases and there was some evidence for improved weed competition in variety mixtures compared with the pure stands.

ix. Variety mixtures also stabilised grain quality in certain mixtures; however, the need to choose varieties carefully when designing mixtures was highlighted.

x. Variability within the data sets illustrates the difficulty in defining organic systems and in the lack of adaptability in cereal varieties. This work has underpinned two EFRC initiatives, the development of participatory variety trials to deal with differences between organic systems and the development of breeding programmes to deal with a lack of adaptability in currently available cereal varieties.

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1. Background.

1.1. This report contributes to the EFRC cereals programme and reports on four years of research on cereal varieties and mixtures. Further reports will address other issues thrown up by the data and other areas of the cereals research programmes.

1.2. In the UK there is a lack of information on the relative performance of modern crop species and type, varieties and variety mixtures under organic conditions. To address this Elm Farm Research Centre, in partnership with a number of organic farmers around the south and east of England, launched a series of organic cereal variety and variety mixture trials.

1.3. Varieties of triticale, wheat, barley and oats, both winter and spring types were included in the trials.

1.4. The purpose of the project was to determine the relative performance of cereal varieties grown under organic conditions and to provide background information for innovative breeding programmes (see page 17).

1.5. Variety mixtures were included in the trials in order to try and quantify the benefits of growing mixtures in organic systems, to prevent weeds, pests and diseases and to investigate the stabilisation of grain yields and grain quality across a number of environments.

2. Aim.

2.1. To improve the productivity and stability of organic cereal production by identifying cereal varieties and variety mixtures that are best adapted to organic farming systems. This would be undertaken by evaluating the relative performance of cereal mixtures against single varieties in organic systems, in terms of consistency, robustness of yield and quality.

3. Objectives.

3.1. To address this aim two scientific objectives were set;

3.1.1. To determine the relative performance of modern cereal varieties grown under organic conditions.

3.1.2. To determine whether growing mixtures of selected varieties compared with growing pure stands alone results in better performance.

4. Introduction

4.1. Farming for profit is an activity with risk management as its basis. This risk management is important in terms of dealing with markets and in terms of agronomy; dealing with variability in nutrient supply and negative interactions between crops and weeds, diseases and pests. All these risks are especially crucial in organic systems, where alternative markets must be encouraged to maintain premiums and synthetic inputs cannot be relied upon to control negative abiotic and biotic interactions. So, it is important to develop cereals that are as stable as possible in terms of their yield and market productivity through the buffering potential of the genotypes or the system of production itself. Organic farmers therefore require researchers to better define systems that buffer, in so far as is possible, against market and biological variability.

4.2. Cereals, especially wheat, are the most important cash crops for farmers in the UK, being an essential component of animal and human food. Therefore, this project has assessed varieties of the commonly grown cereal varieties to understand their productivity and stability of productivity under UK organic conditions. Where possible, these varieties have been chosen to reflect the range of modern varieties that are available and to encompass newly available varieties that are purported to be more suitable for organic production. It has also been an important component of this project to aim to understand how the stability of different species, as well as varieties, is affected by different sites and seasons. For instance, how do triticale, oats, wheat and barley compare year-on-year across a number of sites?

4.3. To generations of farmers brought up on a diet of monoculture, the idea of mixing varieties seems novel. In fact, it is the monoculture that is novel. Different forms of mixed cropping have been the norm since agriculture became a settled occupation, some 10,000 years ago. At the level of the variety an early definitive statement on the value of variety mixtures comes from Charles Darwin's Origin of Species: ''…if a plot of ground be sown with several distinct genera of grasses, a greater number of plants and a greater weight of dry herbage can thus be raised. The same has been found to hold good when first one variety and then several mixed varieties of wheat have been sown on equal spaces of ground." But, from Darwin's time onwards, the Age of Monoculture developed rapidly, hastened by the revolutions in agricultural chemistry and engineering. The first consequence of this change, at least in Europe and North America, was a declining interest in the value of mixtures and inter-cropping – kept alive by only a handful of agricultural scientists. The second consequence was that plants, especially cereals and even more especially wheats have been bred for monocultural use with the support of synthetic agrochemicals. Therefore agricultural systems and varieties for those systems may be inappropriate for preventing all the risks associated with modern organic production.

4.4. One area that has been well defined is the prevention of the risk from fungal diseases using variety mixtures. Recently, the mechanisms have become clear. The most important factor is that, in a mixture, identical plants are separated by greater distances than they would be in a monoculture. So, spores of a pathogen produced on one plant are less likely to be blown on to an identical plant that they can infect – so disease spreads more slowly. The space between identical plants is occupied by plants that may be resistant to spores coming from their neighbours – so they provide a physical barrier to spores being blown from one susceptible plant to another, further reducing the probability of successful infections. A third mechanism is the vaccination process. Spores that are not able to infect a particular plant induce a resistance reaction. If a spore that would normally infect that plant then lands by chance in the area of the resistance reaction, it may die or develop only to a limited extent.

4.5. Disease develops slowly in the mixture, but inevitably, one of the varieties will become more infected than the others. This variety may use less space and resources (light, water, nutrients) than its neighbours – which can then use those surplus resources. So, the reduced yield of the more susceptible plants is compensated by the increased yield of the more resistant plants. Such compensation is less likely in a monoculture where all plants are equally susceptible. This is part of the reason why mixtures are more stable than monocultures in terms of yielding ability in different environments.

4.6. Researchers in China stimulated a unique cooperation among farmers, researchers and advisory staff in Yunnan Province, China, whereby all rice fields in five townships in 1998 (812 ha) and in 10 townships in 1999 (3,342 ha) were planted to rice mixtures (Zhu *et al.* 2000). The objective was to restrict development of the notorious fungal blast disease in the susceptible rice varieties grown in the mixtures. These varieties were the glutinous or 'sticky' varieties that are popular because of their culinary characteristics. They normally receive 3-8 foliar fungicide applications to keep them free from disease. However, blast was 94% less severe on these varieties planted in mixtures with resistant varieties than when grown in monocultures, and fungicidal sprays were eliminated. The reason for this effect was due to buffering against the risk of exposure to a virulent pathogen population. There was a more diverse pathogen population in the mixed stands contributing to greater induced resistance from incompatible interactions. This would also mean that, in the second year, the surviving population of the pathogen might have been less well able to infect the next season's mixtures. But these effects were heavily dependent on the large scale of the experiment.

4.7. The large disease restriction by the mixtures was correlated with a substantial yield increase relative to monocultures. The results showed a land equivalent ratio of 1.18 – in other words, it would have needed 1.18 ha of monoculture of the varieties used to gain the same yield as was obtained from 1 ha of mixtures. These results stimulated great interest among farmers and the project area was expected to reach 33,400 ha in 2000 and beyond. Furthermore, logic suggests, and evidence confirms, that mixtures can be designed not only to restrict disease, but also to improve product quality by combining complementary characters.

4.8. Therefore, in attempting to develop appropriate systems of production to buffer against the risks of growing organically, it is important to test as many different varieties as possible and to try to maximise the value of mixing varieties. This should both achieve the identification of most appropriate varieties and methods of growing those varieties and should inform the breeding of more appropriate varieties in the future. In mixing varieties, it is almost too much to expect modern varieties, bred for monocultural production, to perform outstandingly when in variety or species mixtures. However, varieties were chosen for mixing that were as close as possible in terms of agronomy and product quality, but diversified in terms of disease resistance and niche occupancy. The aim being to buffer against low and variable fertility, weeds and diseases thereby stabilising yield and providing sufficient complementation to improve and stabilise grain quality and therefore stabilise the performance of cereals in markets.

5. Method.

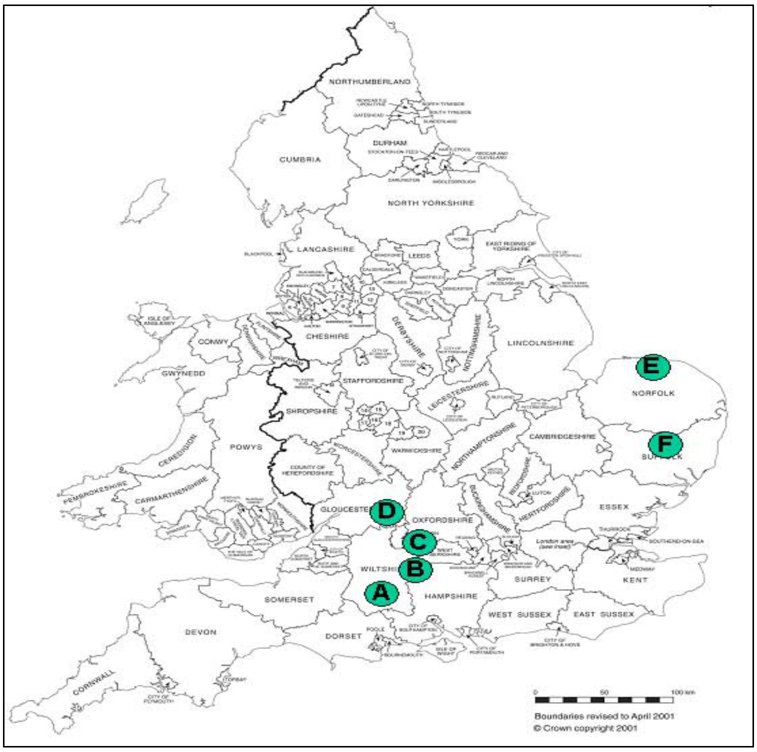

Figure 1. Trial site locations: (**A**) Lower Pertwood Farm, (**B**) Bowden Farm, (**C**) Sheepdrove Farm, (**D**) Abbey Home Farm, (**E**) Bagthorpe Farm and (**F**) Wakelyns Agroforestry

5.1. Over the four years of the project, six sites, all of which were established organic farms, have been used for the trials. The trial sites were chosen to represent a range of soil types and climatic conditions and were all located in the south and east of England.

5.1.1. Abbey Home Farm, Cirencester, Gloucestershire
5.1.2. Bagthorpe Farm, Kings Lynn, Norfolk
5.1.3. Bowden Farm, Burbage, Wiltshire
5.1.4. Lower Pertwood, Salisbury, Wiltshire
5.1.5. Sheepdrove Organic Farm, Lambourn, Berkshire
5.1.6. Wakelyns Agroforestry, Fressingfield, Suffolk

5.2. Figure 1 shows the site locations and Table 1 shows which species were placed where in each year, as not all species were grown at all sites and not all sites were used each year.

Table 1. Location of each species by year (1999-2003)

	W Wheat	W Oats	Triticale	S Wheat	S Oats	S Barley
Abbey Home Farm	1999-00	1999-00	1999-00			
				2001-02	2001-02	2001-02
	2002-03	2002-03	2002-03	2002-03	2002-03	2002-03
Bagthorpe	1999-00					
Bowden	1999-00					
	2000-01					
	2001-02					
Lower Pertwood				1999-00	1999-00	1999-00
				2002-2003	2002-2003	2002-2003
Sheepdrove	1999-00	1999-00	1999-00			
	2000-01	2000-01	2000-01			
	2001-02	2001-02	2001-02	2001-02	2001-02	2001-02
	2002-03	2002-03	2002-03	2002-03	2002-03	2002-03
Wakelyns	1999-00	1999-00	1999-00	1999-00	1999-00	1999-00
	2000-01			2000-01	2000-01	2000-01
	2001-02	2001-02	2001-02			
	2002-03	2002-03	2002-03			

5.3. The varieties used in the trials were determined firstly as the most promising varieties from available recommended lists, secondly as the most promising varieties from 'organic breeders' and thirdly as organic seed availability. Winter varieties of wheat, triticale, oats and barley and spring varieties of wheat, oats and barley were included in the experiments. Where possible, organically certified seed was used in the experiments otherwise conventionally produced untreated seed (re-cleaned only) was used.

5.4. The trials comprised of a randomised block design with either 3 or 4 replicates, depending on the number of varieties and mixtures in the trial. With the exception of Wakelyns Agroforestry, the plot size at all sites was 4.2 m x 10 m, which included a 1 m discard area around the central 2 m x 8 m area of the plot. The discard area was included to minimise any edge effects and seed carry over from the previous plot. At Wakelyns Agroforestry, the plots size was 1.5 m x 11 to 22 m, depending on the location of the trial. The trials were situated in fields at the appropriate position in the rotation, e.g. wheat was generally sown as a first cereal crop after the fertility building phase of rotation. All cultivations prior to crop establishment were completed by the farm using their standard practice. The trials were drilled and harvested using specialist plot-scale equipment. Drilling and harvesting dates were planned to coincide with the farms standard practice, although, occasionally, these times varied due to delays in obtaining seed.

5.5. As well as yield and grain quality other agronomic parameters were measured; Table 2 shows which and the methods used to assess them.

5.6. The severity of seed-borne diseases on some of the grain was also assessed by NIAB, this was evaluated as part of the Participatory Cereals project (OFO330 Participatory Cereals: Generating and evaluating a novel genetic resource in wheat in diverse environments) and any findings will be disseminated in reports relating to that project. For examples, on wheat the diseases being assessed include ergot (caused by *Claviceps purpurea),* bunt (caused by *Tilletia tritici*) and snow mould (caused by *Microdochium nivale*).

Table 2: Agronomic assessments and methodology

Assessment	Method	Frequency
Plant emergence	Use a 0.25 m^2 quadrat. Randomly throw onto the plot making sure that all of the quadrat is well within the plot. Count the number of individual plants within the quadrat and record on sheet. Multiply the number by 4 to get plants per m^2.	Approximately 1-2 months after sowing.
Estimate of weed content	Either using the same method as for Plant emergence or Look at the whole plot when estimating weed content. Score the plot on a scale of 1-3; 1 = less than 10% cover of weeds 2 = between 10-50% cover of weeds 3 = greater than 50% cover of weeds.	Every field visit.
Estimate of growth stage	Estimate the growth stage of the plant using the Growth stage identification key for cereals. (Tottman& Broad (1987). Provide the range of growth stages for each plot and an overall growth stage average per plot.	Every field visit.
Estimate of the incidence of pest and disease	Identify the diseases present in each plot using the NIAB Disease assessment manual (NIAB, 1985) for crop variety trials and the Cereal disease assessment technique guidelines. Record the disease and the percentage of the crop that is infected.	At flag leaf emergence. At the milky ripe stage.

6. Objective 1: To determine the relative performance of modern cereal varieties grown under organic conditions.

6.1. Results and Discussions

6.1.1. In this report we concentrate on grain quality and yield data as these are invariably the parameters of most interest to farmers and they describe the cumulative pest, disease and environmental interactions that occur during a growing season.

6.1.2. Species Performance – Oats.

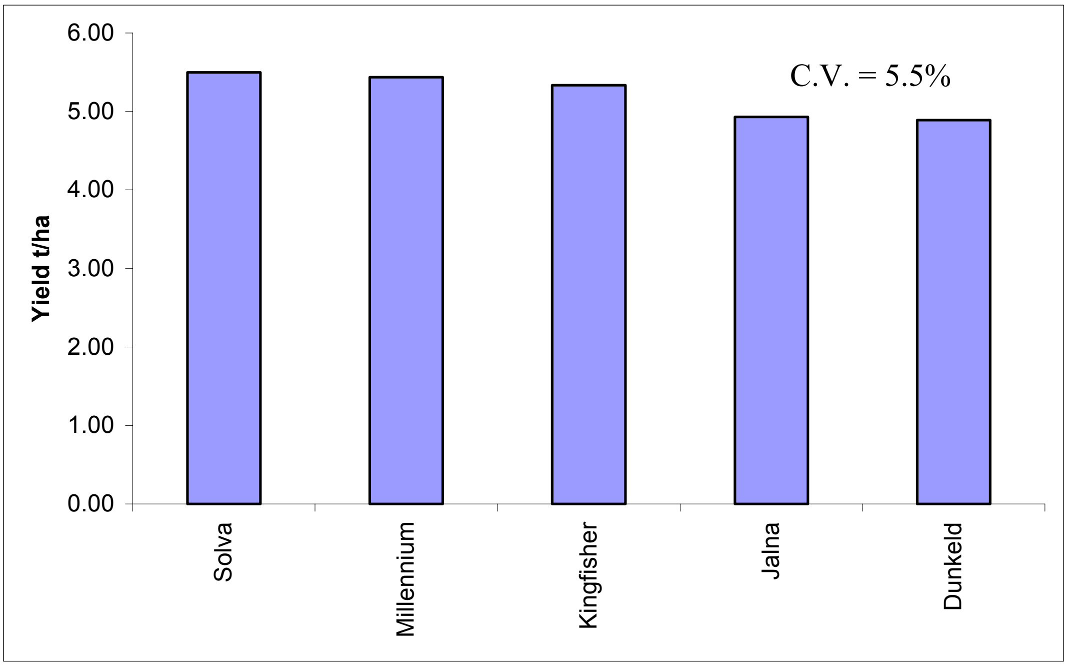

Figure 2. The mean yield (t/ha) of all winter oat varieties grown during the four-year trial (data combined across sites & years).

6.1.2.1. The coefficient of variation (CV) for winter oats is 5.5%; this shows that they offer a consistent performance across the five varieties with an average yield of around 5t/ha. Kingfisher, Millennium and Solva produced slightly higher yields than Dunkeld and Jalna, although these differences are not statistically significant and so this is an unreliable basis on which to choose these varieties above others. The very low CV, 5.5%, demonstrates that the winter oats have a low degree of variability. There were no statistically significant differences between oat varieties when data was combined across years and sites.

Coefficient of Variation.

The coefficient of variation (CV) is a statistic that is used to compare variability within a data set. Throughout this report it has been used to illustrate the amount of variability within a particular data set and thereby provides a figure representing the stability of that data.

The % CV is calculated by dividing the standard deviation of the data set by its mean and multiplying by 100. It is presented as a *percentage.* A high percentage illustrates a large amount of variability and so a low degree of stability. A low percentage shows a low variability and so more stability and a more consistent performance.

6.1.2.2. Spring oats yield less than winter oats (see Figure 3), with a mean of 3.13t/ha compared with a mean of 5.22t/ha (a 60% difference). Winston performs better than the other four varieties with a yield of 3.84t/ha, however this difference was not statistically significant and so Winston cannot be relied upon to outperform other spring oat varieties consistently. The spring oats also have a higher degree of variation than the winter oats as demonstrated by the higher CV, 13.3%. Amigo and Banquo in particular contribute to this increased instability through time (over years) and space (across sites). However they still show a lower variability than spring and winter wheats and spring barley (see section 6.1.3.2 - 6.1.4.3). With data combined across years and sites, no differences between varieties were statistically significant.

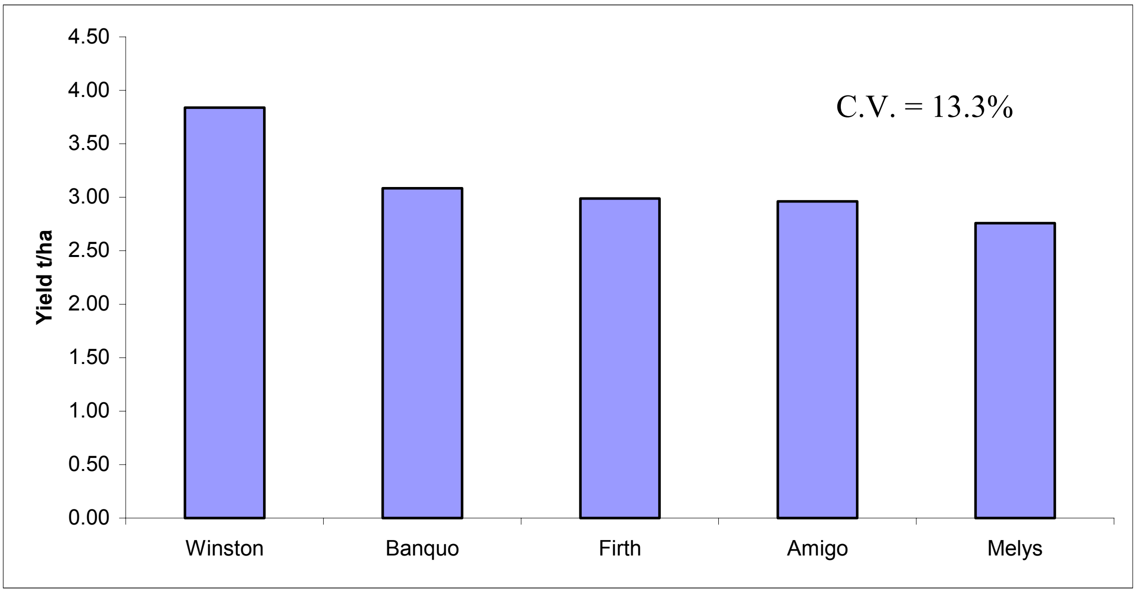

Figure 3. The mean yield (t/ha) of all spring oat varieties grown over the four-year trial (data combined across sites & years).

6.1.3. Species Performance – Triticale and Spring Barley.

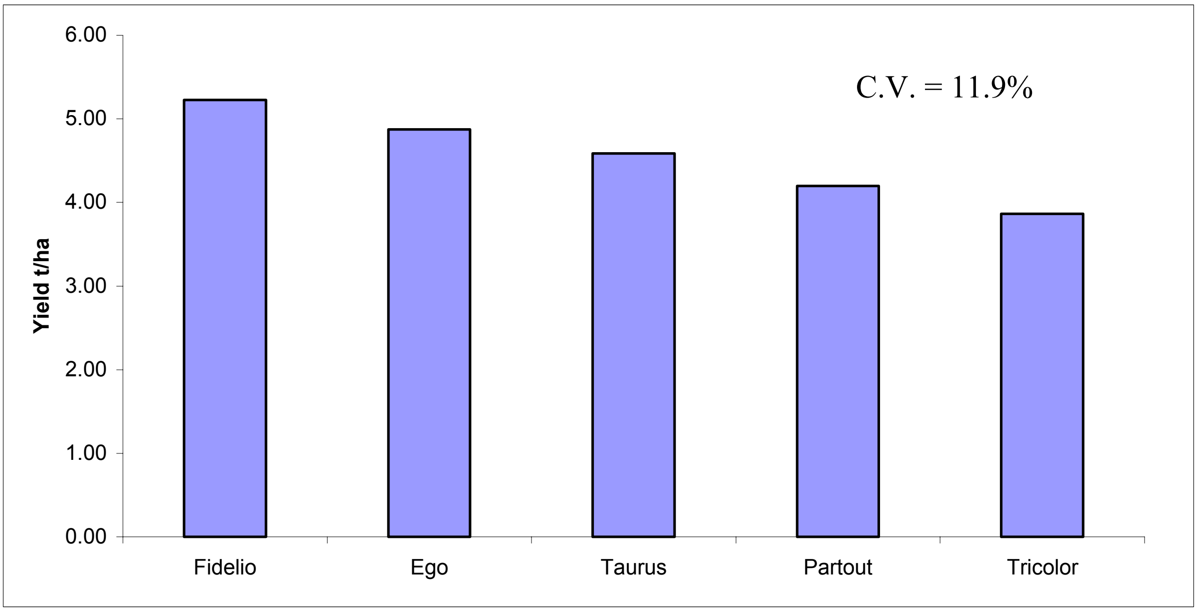

Figure 4. The mean yield (t/ha) of all triticale varieties grown over the four-year trial (data combined across sites & years).

6.1.3.1. The triticale varieties ranged in yield from under 4 t/ha to more than 5 t/ha. Fidelio and Ego show the greatest yields (at around 5 t/ha) and Tricolor the lowest (at just under 4 t/ha), however this may be an unreliable difference across sites and years as differences between varieties were not statistically significant. As with the spring oats the low CV, 11.9%, demonstrates a relatively low variability compared with the spring and winter wheat and spring barley (see sections 6.1.3.2 - 6.1.4.3), but Triticale yields are not as stable as the winter oats. With data combined across years and sites differences between varieties were not statistically significant.

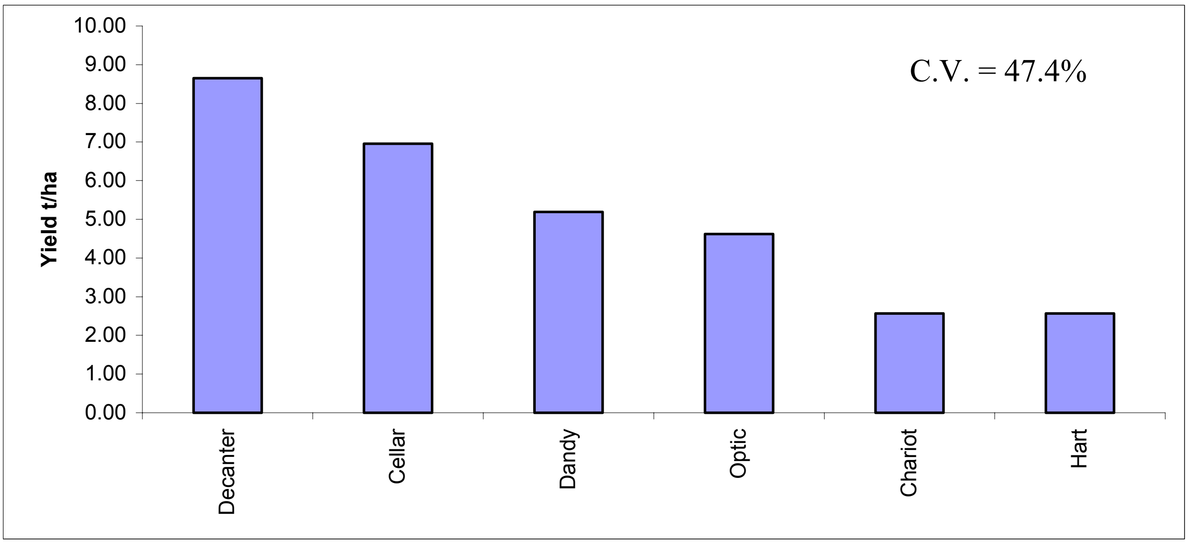

Figure 5. The mean yield (t/ha) of all spring barley varieties grown over the four-year trial (data combined across sites & years).

6.1.3.2. The spring barley varieties produced a wide range of yields, some reaching over 8 t/ha while others barely 2.5 t/ha. Cellar and Decanter were the best performing spring barley varieties, while Hart and Chariot performed equally poorly. The CV for spring barley was very high, 47.4%; it exceeded the CV for all the other species by over 20% suggesting that there was great variation within the data and that the performance of spring barley was inconsistent. This again reflects the large effects of sites and seasons on the performance of spring barley in organic systems. Differences between varieties for the combined data set were not statistically significant, however variation between sites and years had a greater influence.

6.1.4. Species Performance – Wheat.

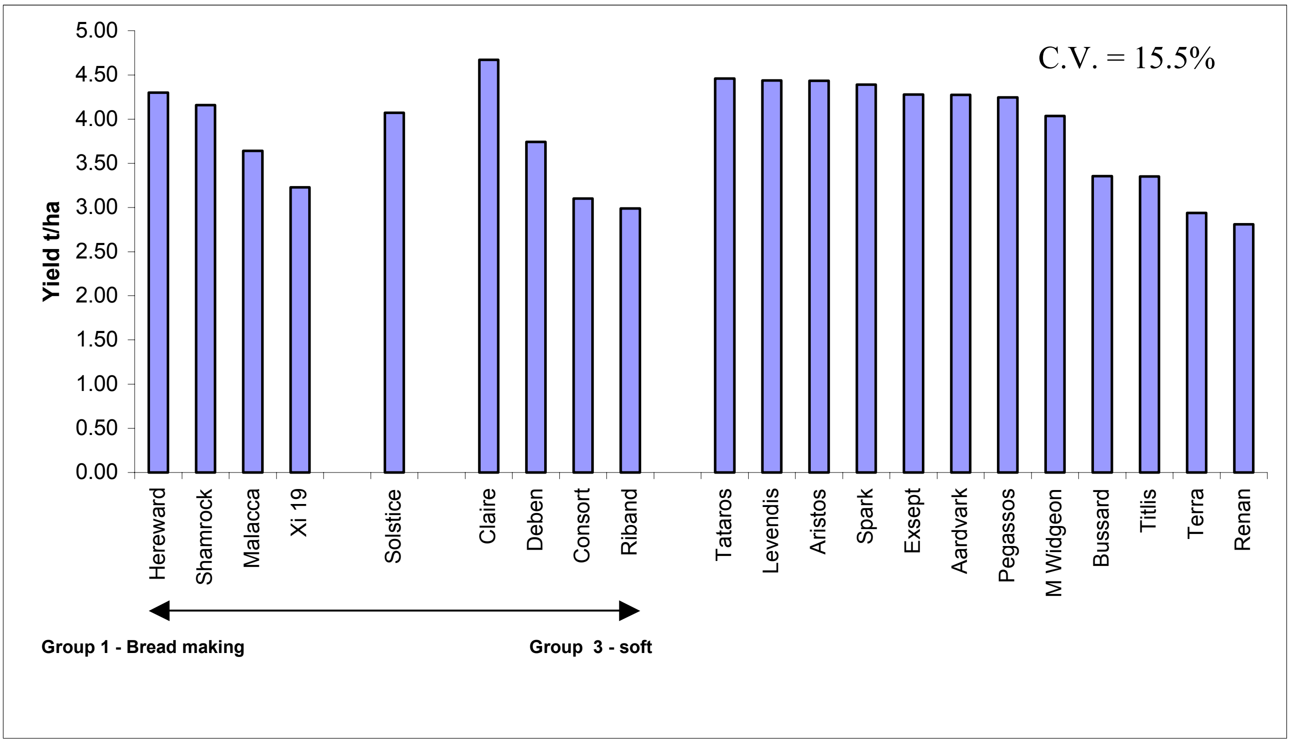

Figure 6. The mean yield (t/ha) of all winter wheat varieties grown over the four-year trial (data combined across sites & years).

6.1.4.1. The National Association of British and Irish Millers (Nabim) Group 3 biscuit wheat Claire was the variety that produced the greatest yield. Amongst the bread-making (Nabim Group 1) wheats Hereward performed the best. These differences were statistically significant within wheat 'class' and are therefore likely to be reliable through time and across sites. Three German varieties, Aristos, Levendis, and Tataros, showed good potential for organic production, these varieties performed well and have a low variability as they compete well with weeds possibly because they tend to be tall and may have an improved ability to scavenge for nutrients. Two other European varieties, Renan and Terra, performed poorly, with Consort also performing particularly poorly. These effects are robust as they were statistically significant and so we can expect Aristos, Levendis and Tataros to consistently outperform Renan and Terra. The CV of 15.5% for winter wheats suggests they have a lower degree of variability than spring wheats (see section 6.1.4.3) and spring barley (see section 6.1.3.2) but that this species is not as stable or high yielding as the oats or triticale varieties (see sections 6.1.2 – 6.1.3.1).

6.1.4.2. Differences between the bread making wheats, group 1, were statistically significant ($P<0.05$), as were the variations between the Nabim group 2 & 3 wheats ($P<0.001$). Differences between the remaining varieties, shown as a block on the right of Figure 6, were highly statistically significant ($P<0.01$).

6.1.4.3. The spring wheat varieties performed poorly, producing yields about half those of the winter varieties. Ashby and Belvoir produced the highest yields. The coefficient of variation was higher for spring wheats, 26.2%, than winter wheats, 15.5%, only spring barley had a higher CV. This suggests that the spring wheats are not as stable and show a higher degree of variability than the other species. This reflects the more difficult agronomy with these varieties, particularly in terms of weed control on some of our sites. And, in common with other spring cereal species, despite apparently large differences between varieties, it is differences between sites and seasons that dominate.

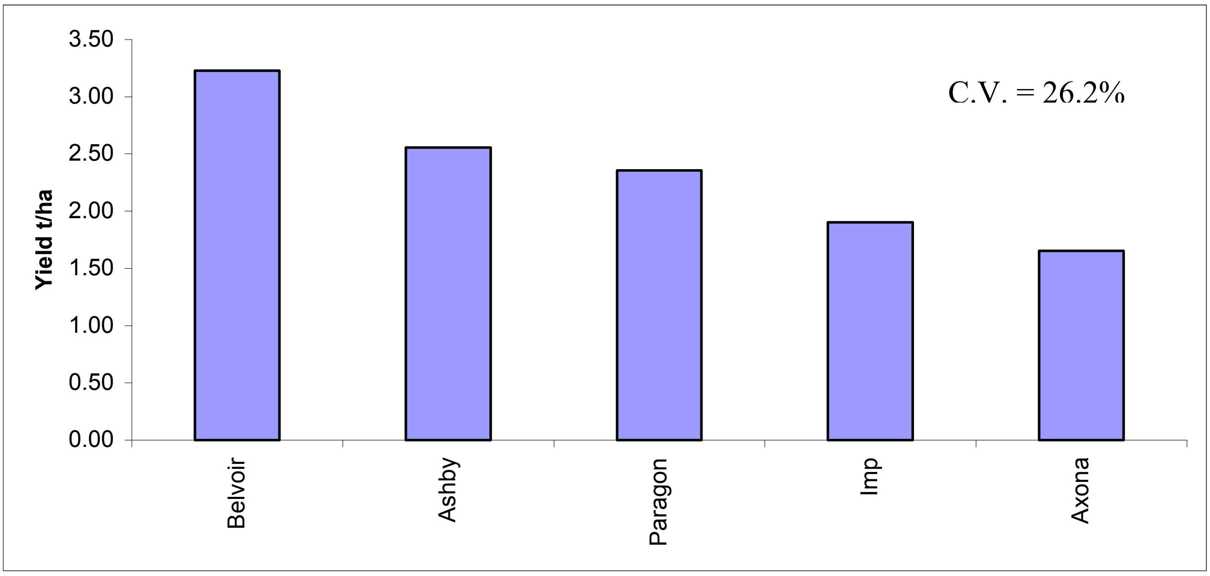

Figure 7. The mean yield (t/ha) of all spring wheat varieties grown over the four-year trial (data combined across sites & years).

6.1.5. Performance – Overall.

6.1.5.1. Figures 2 to 7 show that winter oats and triticale performed best under organic conditions yielding between 5 and 5.5t/ha for oats and 4 to 5 t/ha for triticale. Winter wheat, spring barely and spring oats were the next best yielders producing in the region of 3 - 4 t/ha. Spring wheat performed poorly. Any differences between varieties with this combined data set were not statistically significant.

6.1.5.2. Stability of yields can be estimated by the coefficient of variation. Winter oats and triticale showed the most stability across the years and sites, as demonstrated by their very low CV's, 5.5% and 11.9% respectively. The high and stable yields of oats and triticale can be partly explained by the competitiveness of these two species with weeds, illustrated by Figure 8 below. Generally winter cereals were more stable across sites and over time (predictable performance) than spring cereals, winter cereals therefore tend to be less risky especially winter oats and triticale.

6.1.5.3. Highly significant statistical differences amongst the winter wheats illustrate that Hereward is consistently the best yielding bread making wheat and Claire is consistently the best yielding wheat overall. This highlights one of the reasons that variety choice is so crucial when growing winter wheat organically. Some of the winter wheat varieties out of European low input breeding programmes show promising yield consistency in organic systems.

6.1.5.4. The wheat plant ideotype is a good example of a plant designed for monoculture. Wheat plants that perform well in monoculture interfere minimally with their neighbours under high fertility conditions, where all ameliorable factors are controlled. The aim of this design is to provide a crop community that makes best use of light supply to the best advantage of grain production. This design has produced wheats with a high proportion of seminal roots, erect leaves, large ears and a relatively dwarf structure. This 'pedigree line for monoculture' approach is highly successful, but it has delivered crop communities that do best where light is the only, or the main, limiting factor for productivity: therefore the products of this approach to breeding require inputs to raise fertility, and to control weeds, pests and diseases. This breeding effort, coupled with the increasing convenience of monoculture, now dominates modern farming but the restrictions involved have led some people to question the value of this approach to farming and breeding.

Figure 8. Oats and Triticale at Sheepdrove in 2001 illustrating the importance of the ecological interaction between crop and weed, the poppies are able to occupy any space unoccupied by the oats and triticale, two crop species that have good shading abilities.

6.1.5.5. The dwarfing genes in wheat have not been developed in other cereal species and is one development that leads to the instability of wheat yields in organic systems, due to the increased interference of weeds. However, wheat continues to be the more desirable species. This project has therefore begun to illustrate neatly the need for a specific wheat-breeding programme for organic producers (see Breeding Programmes on page 19). The data also highlights the desperate need to develop markets for robust and profitable cereals other than wheat.

6.1.5.6. The adaptation of wheat for conventional systems is not so heavily reflected in the other species, although, all species are not suitable for the development of ecological production systems. Ecological production systems are reliant on diversity to buffer against variability, but all cereal species have been bred for monocultures, so there is a need in all species to select varieties that perform well under organic conditions and that have good ecological combining abilities both with other varieties and with other species i.e. under-sowing (see Breeding Programmes on page 18).

Figure 9. Winter wheat at Bowden Farm in 2001. This situation contrasts with the oats and Triticale in Figure 10, as the wheat was unable to compete successfully with rayless mayweed (*Matricaria discoidea*).

6.1.5.7. Figures 11 to 14 highlight the overall instability of both spring and winter wheat varieties over sites and years. This is confirmed by the lower coefficient of variation for both spring and winter wheats across years, 17.2% and 15.3% respectively, than across sites, spring wheats 27.4% and winter wheats 19.7%. This suggests that differences within organic production systems (between sites) are of greater influence on cereal yields than differences in weather between seasons (between years). This illustrates the risk of suggesting that one particular variety performs well in all organic systems; as individual organic systems have different weather, soil, weed, pathogen, disease and nutrient profiles and so different varieties will respond in different ways depending on conditions at the site.

Differences in approaches to conventional and organic variety testing.

The distinction between determining the mean performance of a variety at different sites and in different years (adaptability) and the potential of a variety under optimum conditions (adaptation) is the crux of organic variety testing. In conventional variety trials it is the potential of varieties that is explored because all weeds, pests and diseases can be controlled. But in organic systems it is the mean performance that is more important as organic farmers need a far better idea of risk than conventional producers. We have begun to develop a new way of testing varieties that is more appropriate for organic producers, this is known as a ‘Participatory approach’ to variety testing.

6.1.5.8. Of the winter wheats Claire and Hereward exhibit consistent and high yields across both sites and years, the spring wheat Chablis also demonstrates this. This shows that although wheat varieties are not well adapted to organic production they do have a degree of adaptability, which is a very important principle for breeding. However, we believe that wheat yields in organic production systems could be further increased and stabilised by producing varieties with a high degree of adaptation to the system and adaptability to deal with variability within the system.

Figure 10. Wheat and oats at Wakelyns Agroforestry 2003. Note the difference in height between the wheat with dwarfing genes in the foreground and the tall variety (Maris Widgeon) in the background.

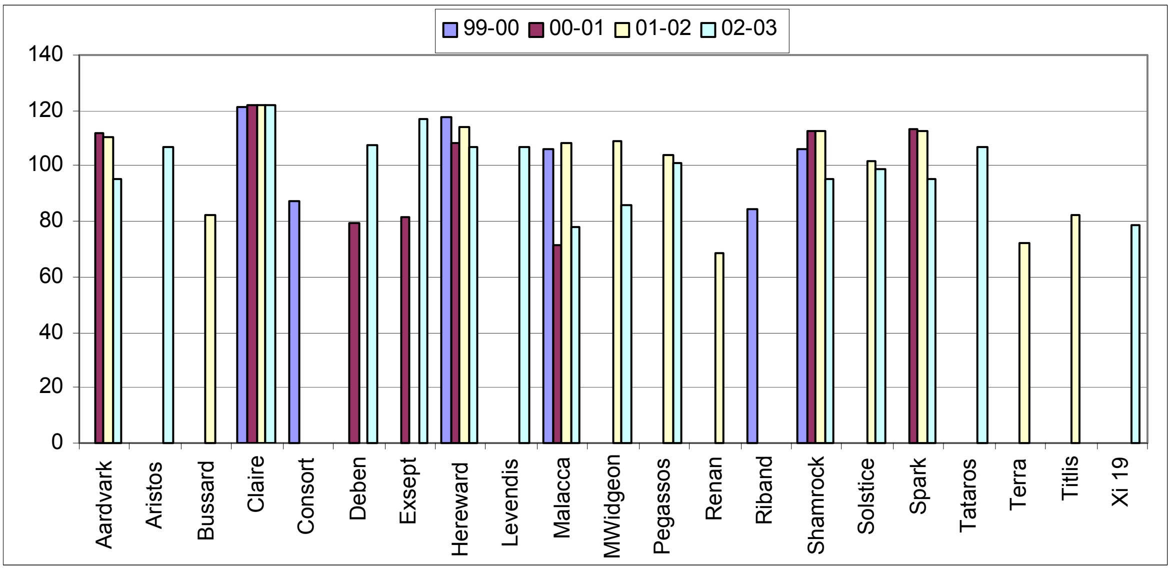

Figure 11: Relative yield performance of winter wheats across years.

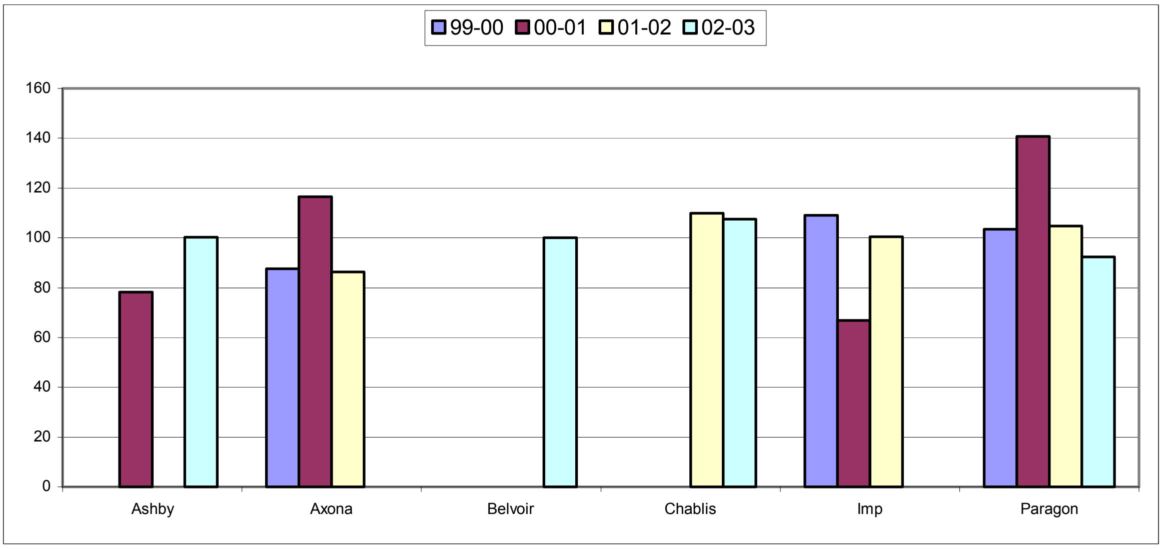

Figure 12. Relative yield performance of spring wheats across years

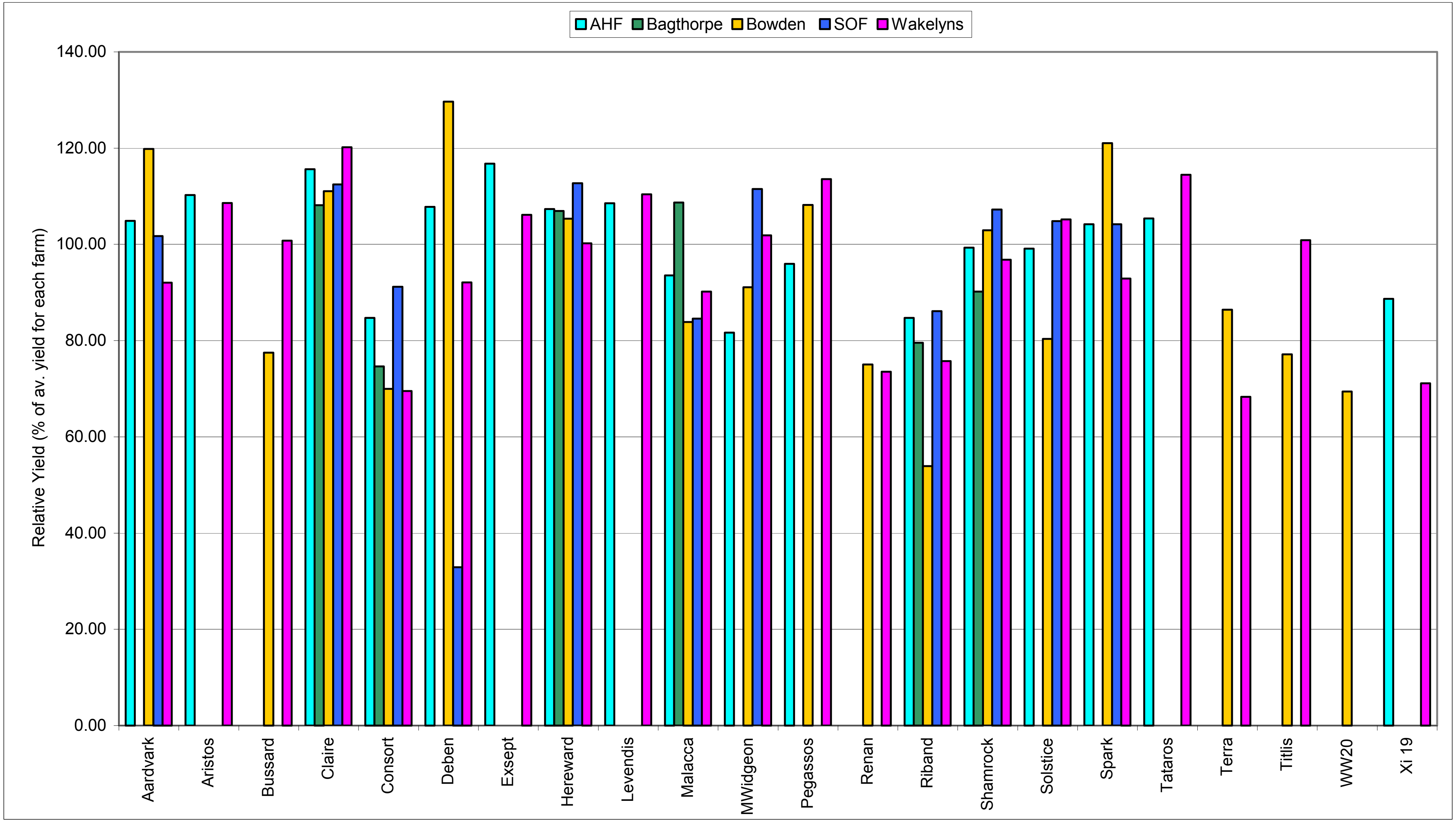

Figure 13: Relative yield performance of winter wheats across sites (all years combined), Relative Yield = the average yield for the variety expressed as a percentage of the average yield for all winter wheats across sites and years combined, therefore showing the performance of the variety relative to the performance for winter wheats.

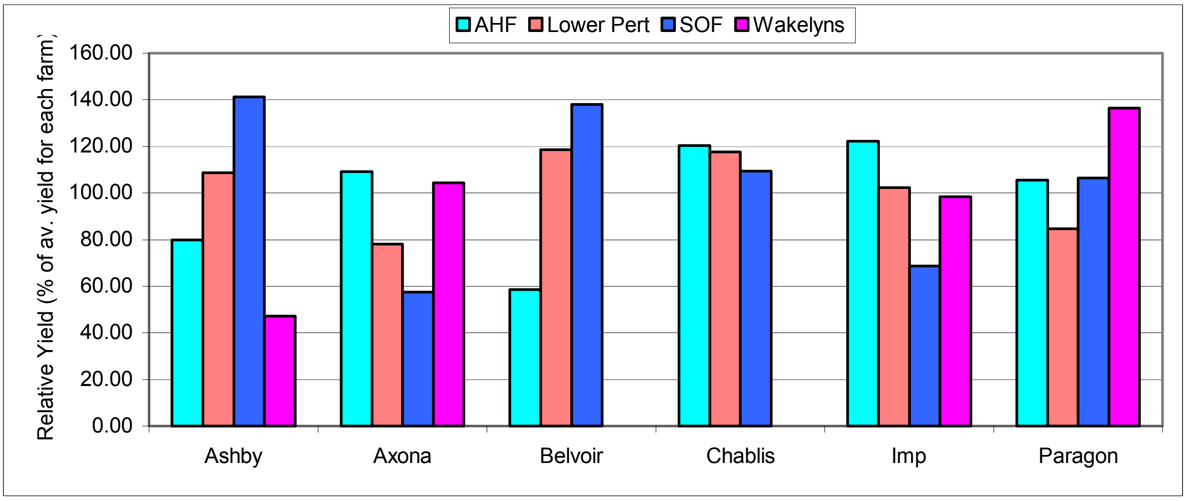

Figure 14: Relative yield performance of spring wheats across sites.

Breeding Programmes.

The above results have supported the development of innovative breeding programmes for winter wheat and oats. Furthermore, careful analysis of the performance of different varieties, coupled with stability analysis of variety mixtures should provide a well argued scientific case for these innovative programmes in organic systems.

We have produced some composite cross populations of wheat and have molecular markers for important quantitative traits. These populations are still in early generations and are on four farms across the UK. Composite crosses are generated by crossing varieties with diverse evolutionary origins, bulking the F1s and then exposing the population to continuous selection in farming systems. This approach should produce wheats with the appropriate adaptation to individual systems and the adaptability to be able to deal with variability in those systems (the two problems highlighted above).

We have also noted that oats, triticale and barley perform well under organic systems. Therefore these species offer an important option in organic cropping rotations. However, the desirability of these species is limited by their usefulness and marketability. Again, using molecular markers we are developing oat varieties that are more appropriate for animal feed (particularly for chickens) and that will grow well in variety mixtures and when grown in species mixtures (particularly with clover).

6.1.6. Performance – Conventional versus Organic.

Table 3: EFRC & HGCA yields and grain quality data for some winter wheat varieties

BASIC AGRONOMIC DATA											
WINTER WHEAT ONLY	**Nabim Group 1**			**Group 2**	**Group 3**		**Others**				
	Hereward	**Xi19**	**Malacca**	**Solstice**	**Deben**	**Claire**	**Maris Widgeon**	**Shamrock**	**Exsept**	**Spark**	**MEAN (t/ha)**
Yield											
EFRC = Average annual yield from 2000-03	4.3	3.3	3.4	4.0	3.6	4.7	3.7	4.1	4.4	4.2	4.0
HGCA = Fungicide treated grain yield as % of treated control yield (10.3t/ha), from 2004/05 recommended list	9.4	10.5	9.9	10.3	10.7	10.3	-	-	-	-	10.2

Grain Quality (EFRC calculated at 4 sites in 2003, HGCA taken from the 2004/05 recommended list)	**Nabim Group 1**						**Group 2**		**Group 3**			
	Hereward		**Xi19**		**Malacca**		**Solstice**		**Deben**		**Claire**	
	EFRC	**HGCA**	**EFRC**	**HGCA**	**EFRC**	**HGCA**	**EFRC**	**HGCA**	**EFRC**	**HGCA**	**EFRC**	**HGCA**
Protein Content (%) (<10.5 poor)	10.9	13.1	11.2	11.7	10.5	12.1	9.8	12.1	10.5	11.1	9.7	11.6
Hagberg Falling Number(<200 poor)	211	243	171	280	307	305	194	263	215	196	218	238
Specific Weight (kg/hl) (<72 poor)	75	79.5	72.7	76	70.3	75.6	72	78.4	73.8	76.4	69.1	76.8

6.1.6.1. Table 3 shows that yields from the EFRC organic trials were only 39% of yields from the conventional trials for winter wheat. Table 3 also shows that the ranking of the varieties is different for the two systems. For instance, Hereward is the best yielding bread making wheat under organic conditions but the poorest, of those varieties listed, under conventional conditions. Grain quality characteristics are closely correlated with yield characteristics and so it is not surprising that the relative ranking of the varieties under the two systems is also different for grain quality characteristics. Furthermore, the generally low quality achieved by organic wheats is illustrated in Table 3.

7. Objective 2: To determine whether growing mixtures of selected varieties compared with growing pure stands alone results in better performance.

7.1. Background - Wheat Mixtures

7.1.1. Mixtures of crop species have been common for thousands of years. Where they have been investigated in indigenous agriculture, the choice of components, and of their frequencies, was deliberate. The main advantage recognised by farmers was stability of overall production – confirmed from records of mediaeval agriculture in England. Such practices have continued widely not only in tropical countries but also in temperate regions. For example, there is extensive use of barley/oat mixtures in Ontario, Canada (400,000 ha) and of barley/oat and wheat/barley/oat mixtures in Poland (1.4 million ha).

7.1.2. More recently, with the emergence of pure line varieties, it also became evident that variety mixtures could be more productive than pure lines. A major reason for this is restriction of disease development. Plant pathogens find it more difficult to spread through a heterogeneous crop population (a polyculture) than through a crop made up from identical individual plants – a monoculture. This has now been shown for many crops including coffee, apple, rape, potatoes and cereals, and for many different pathogens, particularly those spread by wind, such as rusts and mildews.

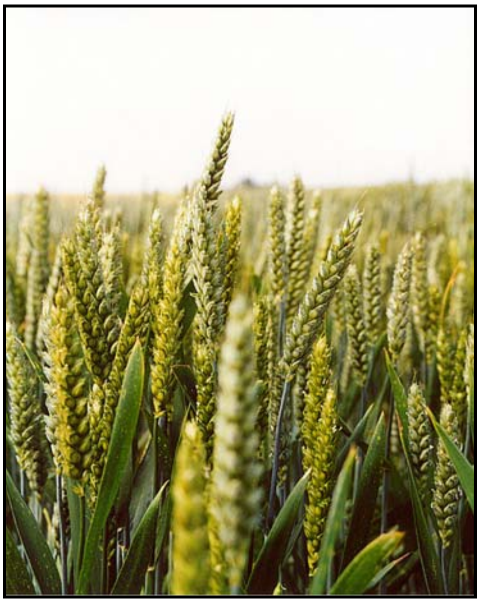

Figure 15: Hereward, Malacca and Shamrock Variety Mixture at Sheepdrove in 2001

Results and discussion -Yield.

7.1.3. Figure 16 shows the majority of yields for variety mixtures to be over 3t/ha. The winter oats perform well with all yields above 5t/ha except for DuJaKi, the majority of the winter wheat mixtures achieve above 4t/ha. The spring wheat mixtures deliver the poorest yields with all three mixtures producing less than 2.5t/ha. The winter oats mixture of Jalna, Kingfisher and Solva achieves a very high yield, 5.83t/ha, this performance is matched by that of the Solva pure stand, 5.50t/ha.

Key to Mixtures Name Abbreviations.

Spring Barley	Spring Wheat	Spring Oats	Winter Oats	Triticale	Winter Wheat
Ce= Cellar Ch= Chariot Op= Optic	Ax= Axona As= Ashby Ch= Chablis Pa= Paragon Im= Imp	Am= Amigo Ba= Banquo Fi= Firth Me= Melys	Ki= Kingfisher Mi= Millennium Ja= Jalna Du= Dunkeld So= Solva	Eg= Ego Fi= Fidelio Ta= Taurus Tr= Tricolor Pa= Partout	Aa= Aardvark Ar= Aristos Cl= Claire Co= Consort De= Deben He= Hereward Le= Levendis Ma= Malacca Pe= Pegassos Ri= Riband Sh= Shamrock So= Solstice Sp= Spark

7.1.4. Figure 17 shows the relative yields for the variety mixtures grown during the four-year trial. The winter wheats appear to give the most consistent performance with most of the mixtures achieving above average yields. Overall the relative yields for the mixtures seem to be pulled down by a few poor performances, such as ChOp, ClCoRi and DuJaKi, the rest of the mixtures appear to perform close to or above the average. It is clear from Figure 17 that some variety combinations perform much better as mixtures than other variety combinations, they have different ecological combining abilities. Some mixtures were offering around a 20% yield advantage above the overall average and most mixtures offered some yield advantage. However, if biodiversity is not functional, or the varieties do not ‘nick’ well together, then there may not be any yield advantage from mixing varieties and possibly even a yield penalty.

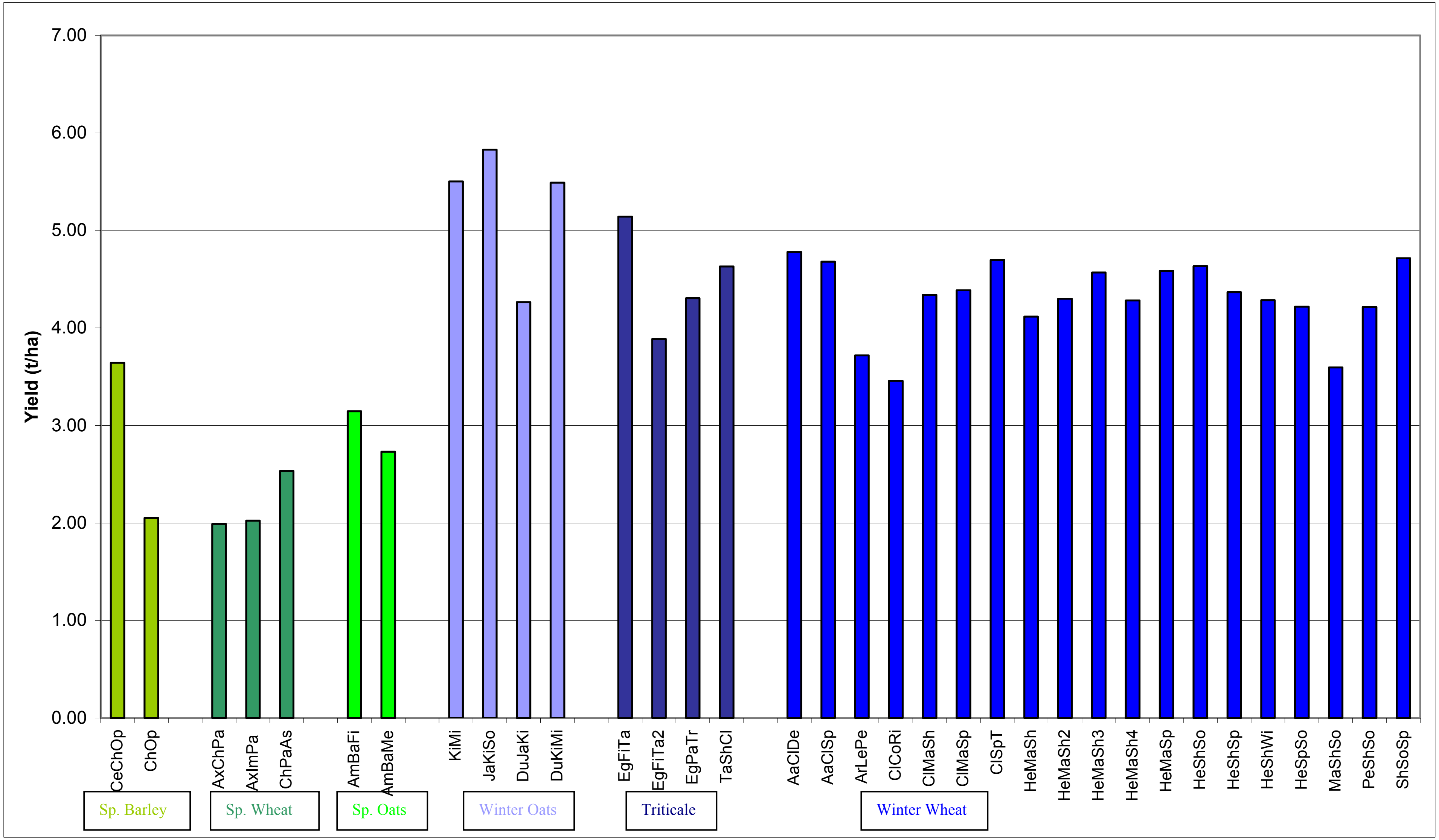

Figure 16. Bar Chart to show the average yield of all varietal mixtures grown over the four-year trial (data across sites & years combined)
(See Key To Mixture Name Abbreviations on page 23 for explanation of names on x-axis)

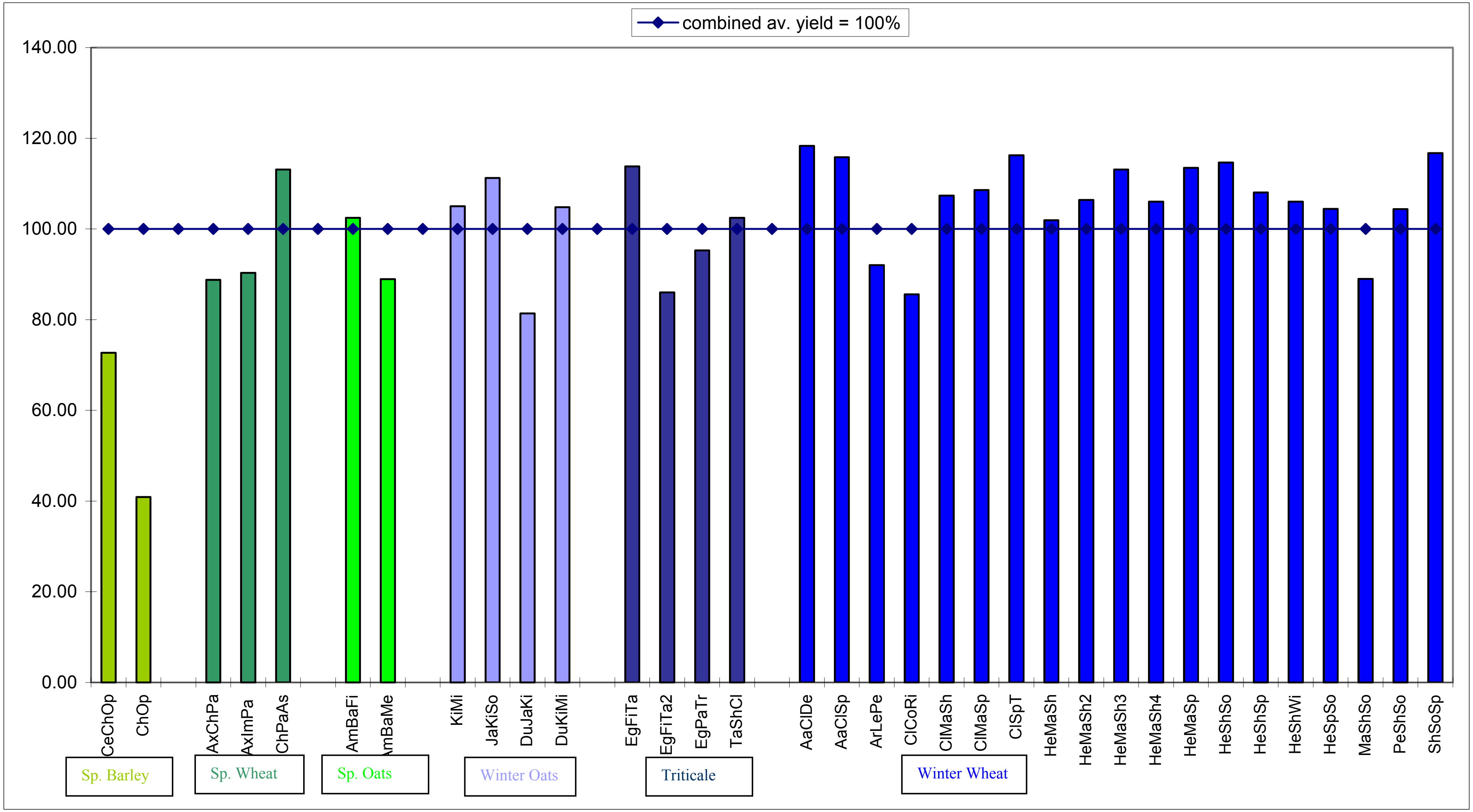

Figure 17. Relative Yield performance of variety mixtures through out the trial period. Relative Yield = the average yield of the mixtures expressed as a percentage of the average yield for that species across sites and years combined, therefore showing the performance of the mixtures relative to the performance of the pure stands for that species. (See Key To Mixture Name Abbreviations on page 23 for explanation of names on x-axis)

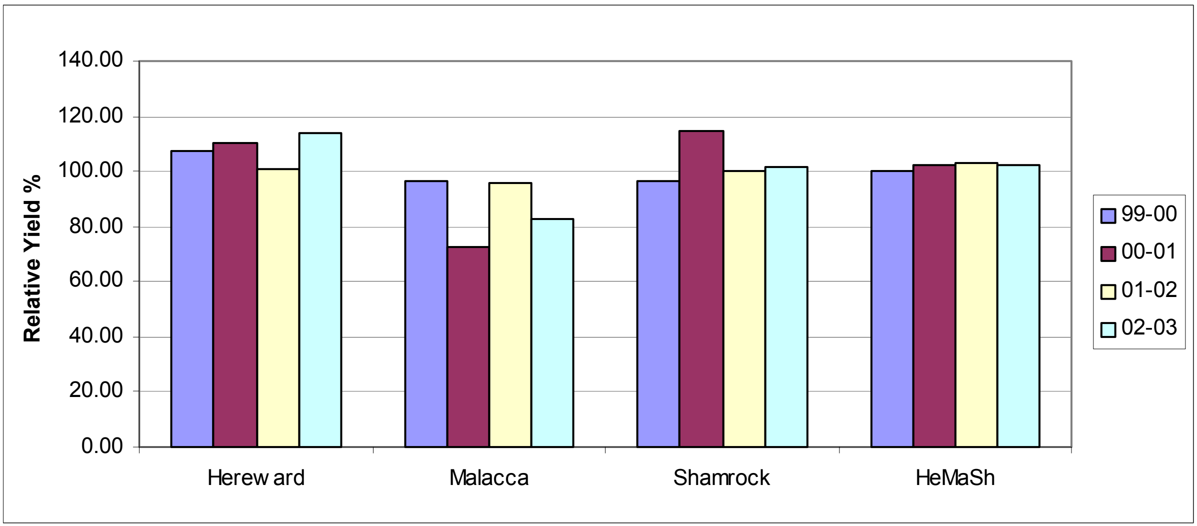

Figure 18: The relative yields of a mixture of Hereward, Malacca and Shamrock and its pure stand components over four years and across all sites.

7.1.5. Figures 18 highlights the most important quality of variety mixtures, providing yield stability, this visual observation is confirmed by the coefficient of variation data shown in Table 4. Figure 17 shows that the mixture of Hereward, Malacca and Shamrock does not provide the large yield advantage of other mixtures, but HeMaSh is a mixture that was used across all sites and years. However, the performance of HeMaSh does illustrate the yield stability of the mixture compared to the pure stands and indicates that the optimum combination of varieties (i.e. AaClDe in Figure 17) can produce improved yields at high degrees of stability.

7.1.6. The stability of performance illustrated in Figure 18 often translates into stability in grain quality as the compensation and complementation operating between varieties in mixtures has implications for grain quality parameters. Therefore, in organic systems that provide large degrees of variability in nutrient resources and pest, weed and disease interactions (see section 7.4 & 7.5), the mixing of the correct combinations of varieties can provide stable high yields of consistent quality products (Sarandon and Sarandon, 1995).

Table 4: Table showing a comparison of the coefficient of variation between the pure stands and mixtures for different species, lowest %CV therefore most stable highlighted red.

	% CV	
Species	**Pure Stand**	**Mixture**
Spring Barley	47.4%	39.6%
Spring Wheat	26.2%	14.0%
Winter Wheat	15.5%	8.8%
Spring Oats	13.3%	10.0%
Winter Oats	5.5%	13.1%
Triticale	11.9%	11.8%

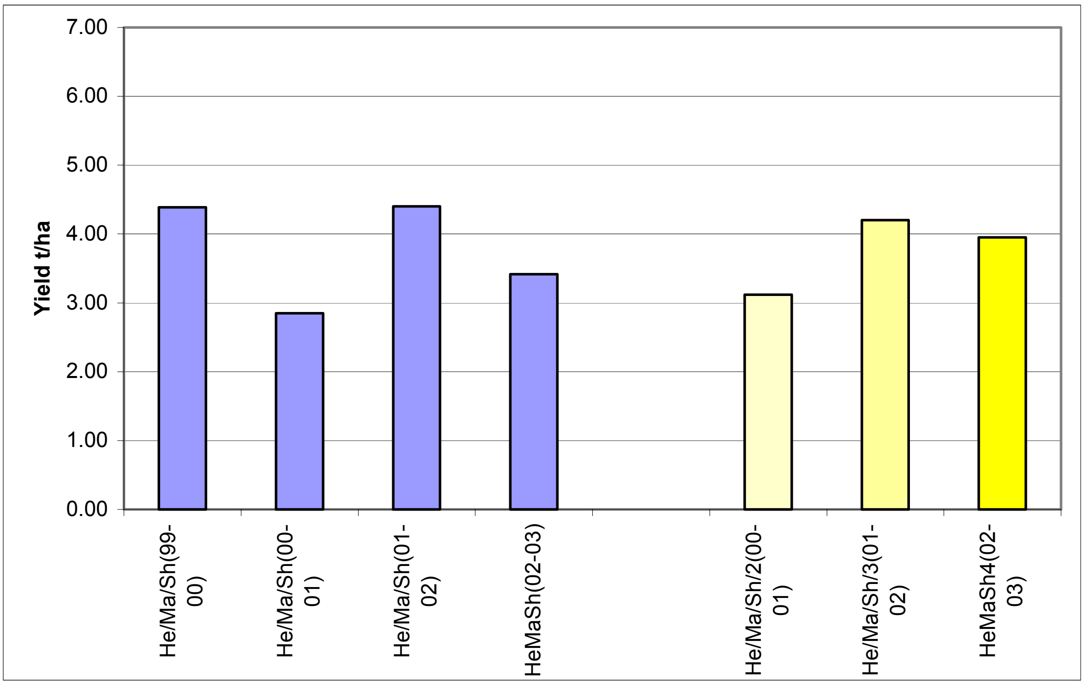

Figure 19. The mean yields (t/ha) of HeMaSh at Wakelyns over all years, re-sown seed mixtures are shown on the right hand side of the figure. HeMaSh/2 was formed from re-sowings over two seasons, HeMaSh/3 was re-sown over three seasons and HeMaSh/4 was re-sown over four seasons.

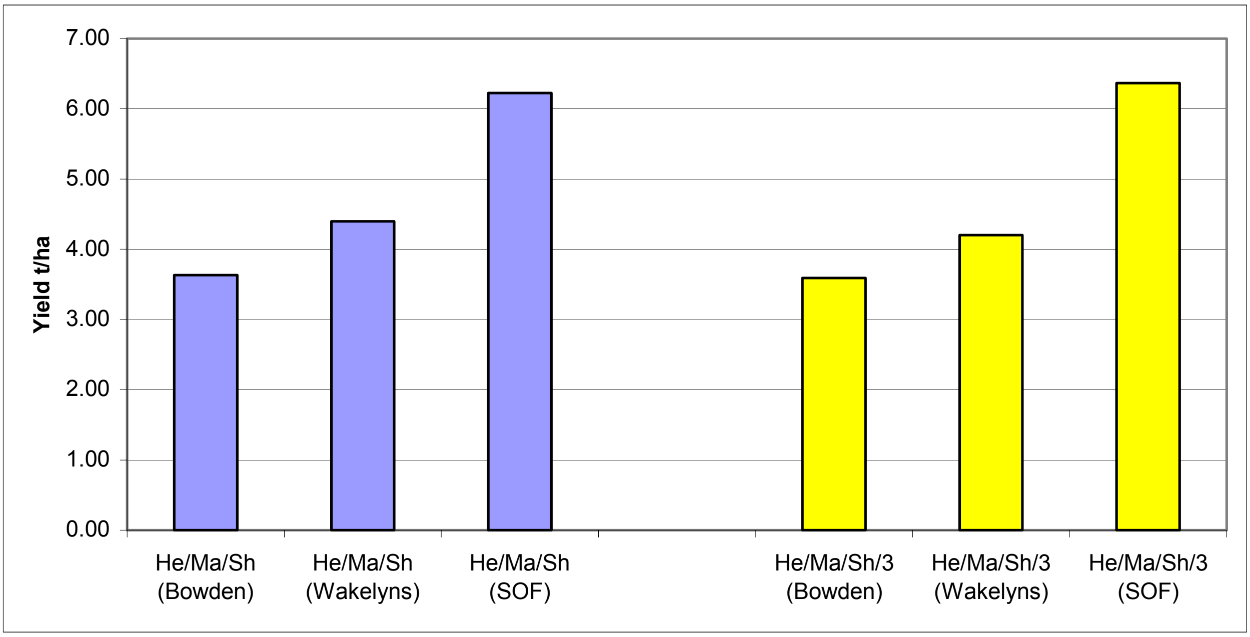

Figure 20: The mean yields (t/ha) for HeMaSh in the 2002 harvest season across three sites. Columns on the left of the Figure show newly created mixtures and columns on the right show mixtures that had been re-sown for three seasons.

7.1.7. The improved quality of buffering against seed-borne disease by re-sowing variety mixtures as opposed to pure stands was seen both in different seasons and at different sites. This is shown in Figure 19 as there was no difference between newly created mixtures and mixtures re-sown for 2, 3 or 4 years. This suggests that although there may have been some deterioration in seed quality over time this was not found in yield data even after four seasons of re-sowing. Part of the reason for this may be that mixtures buffer against the suite of biotic and abiotic challenges (risks) posed by growing cereals in different organic systems and in different seasons. Hence, although one of the constituents may have suffered from seed-borne diseases, poor establishment of that variety in a mixture may have been compensated by improved establishment of the other varieties in the mixture.

7.1.8. We compared the performance of newly created mixtures from new seed with re-sowings of a mixture from farm-saved seed. We saw a build up of soil-borne diseases, particularly *Microdochium nivale* on the farm-saved seed. However yields were no different from those seen with the same mixture newly created each season. Our hypothesis for this situation is that the mixture permits a similar degree of dynamism and compensation against seed-borne disease as you see against foliar diseases. So, the evidence presented here that if one of the varieties suffers from an unpredictable seed-borne disease then growing a variety mixture provides a buffer against this risk that would be unacceptable in varieties re-sown in pure stands.

Results and discussion - Grain Quality (for pure stands only).

7.1.9. Tables 5 to 7 shows the range and values of grain quality results.

7.1.10. Bread making wheats.

7.1.10.1. **Specific weight (kg/hl):** A specification of 76 kg/hl specific weight is usually required of wheat for bread making purposes. No variety consistently met this specification although Hereward and Shamrock did in single years. Most of the winter wheats were within the moderate specification however the spring wheats produced poor specific weights.

7.1.10.2. **Hagberg Falling Number:** In UK bread making, a Hagberg Falling number of >250 is generally defined as the accepted level, there may be some flexibility in this figure for organic growers. Most of the varieties tested performed well and achieved either good or high Hagbergs.

7.1.10.3. **Crude protein (% dry matter):** Conventionally grown grain aims to achieve at least 13% protein on a dry matter basis, however standards for organic bread are more usually >12% protein (although >10.5% is sometimes acceptable depending on season and demand). On this basis none of the samples produced high proteins and many provided poor protein levels.

7.1.11. Biscuit Making Wheats

7.1.11.1. In contrast to bread making wheats, biscuit making requires soft endosperm with lower protein levels and Hagberg Falling Numbers of at least 180. Very few specifications are applied to feed wheats, but samples low in fibre with high specific weights (an indication of high carbohydrate) and high in protein are most desirable.

7.1.11.2. **Specific weight (kg/hl):** The samples tested were confined to providing moderate or poor specific weights.

7.1.11.3. **Hagberg Falling Number:** The samples tested were generally in the high range.

7.1.11.4. **Crude protein (% dry matter):** The samples tested were not consistent and although all were acceptable, none was good.

Winter Wheat

Bread Makers

	>76 GOOD <72 POOR				>250 GOOD <200 POOR				>12 HIGH <10.5 POOR			
	Specific Weight				**Hagberg Falling Number**				**Crude Protein (%DM)**			
Variety	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**
Hereward	77.03	71.63	75.80	75.00	289.86	210.33	313.30	210.50		10.14		10.94
Malacca	71.73	74.17	70.50	70.32	372.25	237.67	443.00	307.00		11.38		10.45
Shamrock	74.05	71.53	76.00	74.22	307.50	258.00	299.70	163.00		10.82		10.22
HeMaSh	74.03	73.85	74.20	71.32	299.75	190.00	328.30	187.50		11.60		10.23

Biscuit Makers

	>76 GOOD <72 POOR				>180 GOOD <140 POOR				>12 HIGH <9 POOR			
	Specific Weight				**Hagberg Falling Number**				**Crude Protein (%DM)**			
Variety	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**
Claire	72.85	69.37	72.50	69.14	320.75	127.00	324.30	218.00		9.77		9.70
Consort	69.18				287.75							
Deben		72.70		73.77		213.00		214.50		9.99		10.50
Riband	68.80				296.75							
ClCoRi	70.30				309.25							
AaClDe		73.93		72.17		269.33		172		11.41		10.09

Spring Wheat (primarily high quality bread making wheats)												
	>76 GOOD <72 POOR				>250 GOOD <200 POOR				>12 HIGH <10.5 POOR			
	Specific Weight				**Hagberg Falling Number**				**Crude Protein (%DM)**			
Variety	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**
Axona	72.60		64.20		226.00		521.00					
Chablis			63.20	72.00			437.50	316.33				11.74
Imp	71.80		61.80		285.00		475.50					
Paragon	71.00		61.95	70.89	276.00		421.50	326.33				12.27
AxImPa	71.40				249.00							
AxChPa			62.9				451					

Table 5: Table to show the grain quality results for Spring and Winter Wheats. Good and Poor results highlighted

7.1.12. Triticale

7.1.12.1. Triticale is a hybrid of wheat and rye. As such it benefits from desirable characteristics of both parents, producing high quality grain, notable for high lysine content, under low input systems and over a wide range of conditions. Markets for this crop are not yet fully developed, its main use being feed grain, or as whole crop silage. It occupies a position in the rotation very similar to rye, and like rye, can be used as a green manure for soil protection and nitrogen retention.

7.1.12.2. **Specific weight (kg/hl):** An indication of carbohydrate, specification given is same as for wheats. The samples tested were mostly in the poor specification with a few in the moderate.

7.1.12.3. **Hagberg Falling Number:** The samples tested were all in the poor specification.

7.1.12.4. **Crude protein (% dry matter):** This parameter reflects the desirability of 'own-farm' produced protein. The samples tested were mostly in the poor specification with a few in the moderate.

7.1.13. Oats

7.1.13.1. **Specific weight (kg/hl):** The samples of winter oats tested were mostly in the good specification and a smaller number in the moderate. While the spring oats produced product in the good specification in one year and poor in the subsequent year.

7.1.13.2. Winter oats appear to meet the requirements for flaking while spring varieties struggled.

7.1.14. Barley

7.1.14.1. **Specific weight (kg/hl):** High specific weight indicates good carbohydrate content. The samples tested were all within the moderate specification.

Triticale												
	>76 GOOD <72 POOR				>250 GOOD <200 POOR				>10 HIGH <8 POOR			
	Specific Weight				Hagberg Falling Number				Crude Protein (%DM)			
Variety	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**	**99-00**	**00-01**	**01-02**	**02-03**
Ego	70.20	69.70	72.60	69.93	190.67	63.00		70.50		11.01		9.32
Fidelo	69.05	65.75			62.00	62.00				14.09		
Partout			69.90	71.14				62.00				10.15
Taurus	68.75	68.80	72.00	69.78	169.50	63.00		63.50		11.83		10.50
Tricolor			71.20	69.88				62.00				9.48
EgFiTa	68.65	65.00			62.00	62.00				11.70		
EgPaTr			72.00	69.48				62.00				9.44

Table 6: Table to show the grain quality results for Triticale. Good and Poor results highlighted

Winter Oats				
	>50 GOOD <45 POOR			
	Specific Weight			
Variety	**99-00**	**00-01**	**01-02**	**02-03**
Dunkeld		51.2	53.4	
Jalna	55.30	49.70		
Kingfisher	54.85	48.90	52.20	
Millennium		48.00	61.00	
Solva	51.45	48.00		
JaKiSo	53.45			
DuKiMi		48.7	52.6	

Spring Oats				
	>50 GOOD <45 POOR			
	Specific Weight			
Variety	**99-00**	**00-01**	**01-02**	**02-03**
Amigo	53		39.7	
Banquo	54.80		40.25	
Firth			38.80	
Melys	56.70			
AmBaMe	53.00			
AmBaFi			41.00	

Spring Barley				
	>70 GOOD <60 POOR			
	Specific Weight			
Variety	**99-00**	**00-01**	**01-02**	**02-03**
Cellar			63.5	60.52
Chariot	63.00		64.70	
Dandy			64.30	63.67
Hart	65.10			
Optic	64.50			62.70
ChHaOp	64.30			
CeChOp			63.40	

Table 7: Table to show the grain quality results for Spring and Winter Oats and Spring Barley. Good and Poor results highlighted

Results and discussion - Disease.

7.1.15. The EFRC cereal trials have highlighted the significance of mixtures in preventing air-borne fungal diseases with the important observation that, in some wheat mixtures, three diseases were being restricted simultaneously – powdery mildew, brown rust and *Septoria tritici*, leading to a 15% yield increase for the mixture. Recent work on rice in China (see section 4.6) shows that the bigger the area of mixtures, the better they work in damping down disease over the whole area.

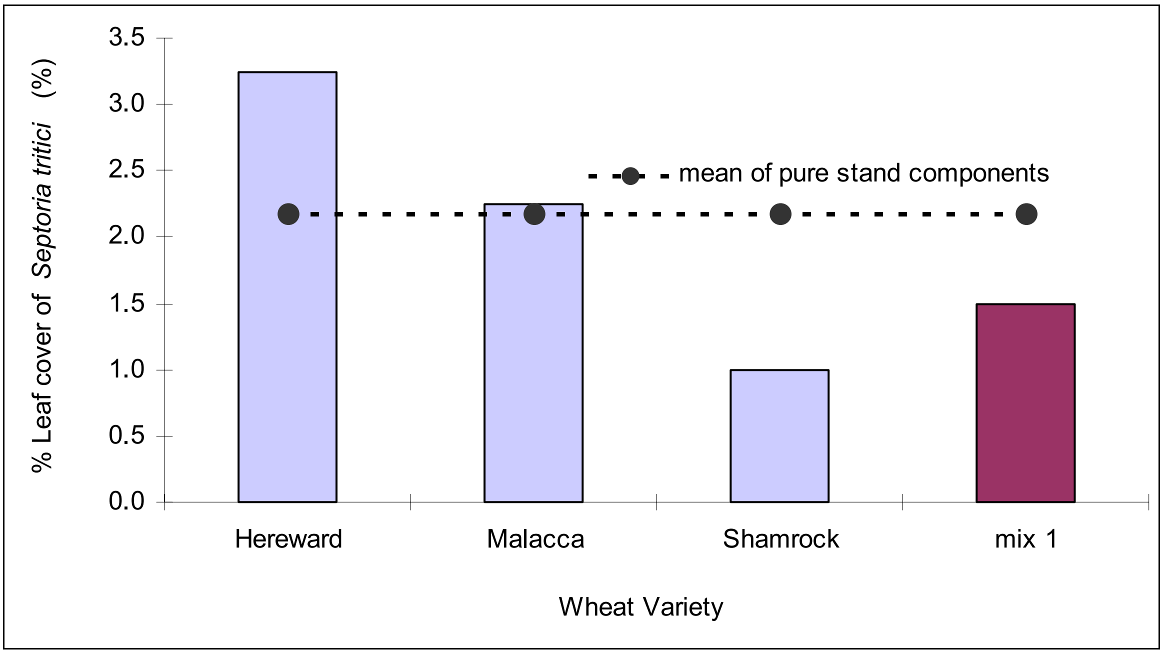

Figure 21: Graph using data from 1999-2000 illustrates the reduction of disease due to the "mixture" effect.

7.1.16. Figure 21 shows the severity of *Septoria tritici* in a mixture of Hereward, Malacca and Shamrock compared with the severity of the disease in the pure stands. In common with many other foliar diseases, the heterogeneity created by mixing varieties of wheat has been seen to be useful in preventing many of the more important pathogens during the lifetime of this project.

Results and discussion - Weeds

7.1.17. The vigorous growth habits of triticale and oats enabled them to compete effectively with weed populations, as demonstrated by the results from 1999-2000, shown in Figure 22 below. Winter wheat, spring wheat and spring barley were less competitive and therefore experienced higher weed infestation levels (Figure 22 and 23).

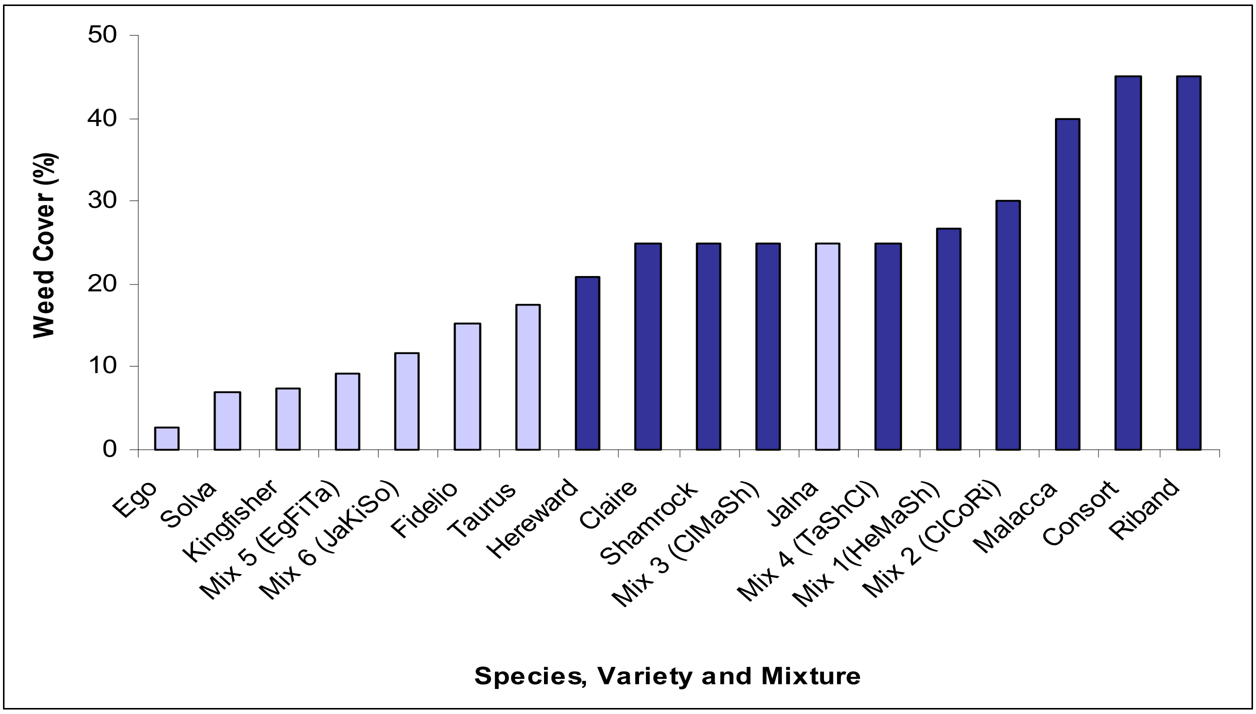

Figure 22. The effect of winter cereal species, variety and varietal mixtures on weed cover (%) at SOF (Assessed July 2000). Winter wheat is shaded dark blue; triticale and oats are light blue.

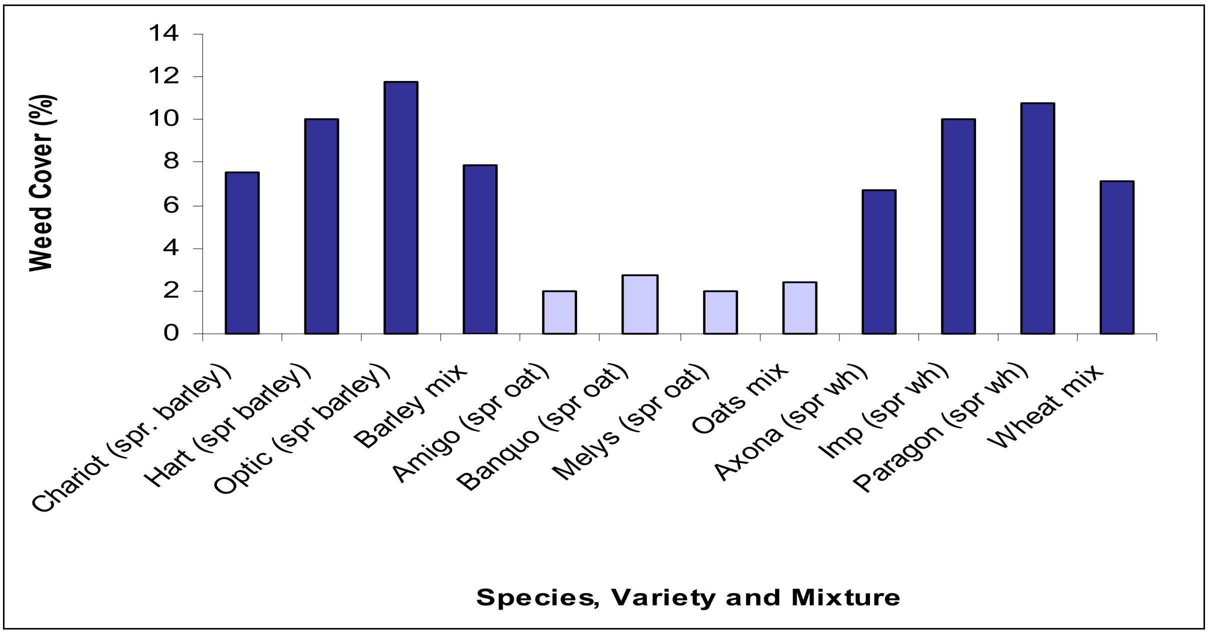

Figure 23. The effect of spring cereal species, variety and varietal mixture on weed cover (%) at Lower Pertwood (Assessed June 2000). Wheat and barley are shaded dark blue and oats are shaded light blue.

7.1.18. Figure 22 shows that the percentage weed cover was much greater amongst the wheat varieties than the oat and triticale varieties. We have seen this effect at all stages of crop growth. This effect is likely to be related to the growth characteristics of the different species above ground, but also, and importantly (especially early in the season) is the different competitive abilities of the crops below ground.

7.1.19. Figure 23 illustrates the large differences between spring cereal species in terms of their competitive abilities against weeds. This again highlights the need to develop more appropriate wheat genotypes. In this way we have begun to realise the need to develop wheat genotypes that thrive both above and below ground at all stages of crop growth under variable and low fertility conditions, thereby buffering against the risks of weeds. This relationship between breeding towards a particular crop physiology and ecological interactions with other plants and species is an important focus of EFRC's cereals research programme.

8. Conclusions.

8.1. It is clear that current cereal varieties (most of which have been bred for conventional production) perform less well within organic systems. They generally yield between 25 and 75 *per cent* of the conventional yield. The trials confirmed that the performance of cereals in organic systems, both in terms of yield and conventional measures of grain quality was much lower than would be expected in conventional systems. This may be because the UK varieties have been bred for monocultural production systems that rely on synthetic inputs to provide high fertility and control pests, weeds and diseases.

8.2. The results from the four seasons of trials show that different types and species of cereals have different yield potentials under organic conditions. For instance, triticale was consistently the best yielding cereal species, with wheats showing low and unstable yield potential. Through the course of the project we have begun to elucidate the reasons why this is the case and initiated projects to address these problems as far as is possible.

8.3. The first objective of the work was to determine the relative performance of modern cereal varieties grown under organic conditions.

8.3.1. Winter Oats: Dunkeld, Jalna, Kingfisher, Millennium and Solva were all trialled and their yields were not significantly different. Therefore the project cannot make a specific recommendation for Winter Oats. They are all as good as each other.

8.3.2. Spring Oats: Again there was large variation in the data and there were no significant differences between the varieties. However, Winston had a greater mean yield and greater yield stability than the other varieties.

8.3.3. Triticale: Ego and Fidelio performed the best.

8.3.4. Winter barley: These results were from one year on one site and the three varieties that were trialled, Diamond, Leonie and Pearl all had similar mean yields.

8.3.5. Spring barley: Decanter performed the best (although with large amounts of variation) followed by Cellar.

8.3.6. Winter wheat: Claire was the best performing feed wheat and Hereward was the best performing bread-making wheat.

8.3.7. Spring wheat: This is a poorly yielding and generally risky cereal crop with Ashby and Belvoir performing best, although high grain quality and premiums are more easily achieved with spring wheats than winter wheats.

8.4. Variety mixtures appear to provide some compensation between varieties for problems with seed-borne disease using farm-saved seed. This was seen in mixtures that were re-sown on sites as opposed to regenerated from new seed each season, this has important implications for farmers wishing to save their own seed or for breeding from composite cross populations.

8.5. Variety mixtures also provided the expected benefit of preventing air-borne foliar diseases and there was some evidence for improved weed competition in variety mixtures compared to the pure stands.

8.6. Through complementation and compensation between varieties, when the ecological combining abilities between mixtures is optimised then they can provide high and stable yields compared with the mean of the components in pure stands. However, mixing varieties bred for monocultural production systems is unlikely to optimise mixture responses.

8.7. Variety mixtures also stabilised grain quality in certain mixtures; however, the need to choose varieties carefully when designing mixtures was highlighted. Furthermore, the unsuitability of varieties bred for industrialised monoculture in ecological systems, for instance in variety and species mixtures, was highlighted, as was the difficulties associated with marketing products grown in ecological systems.

8.8. Variability in the data sets illustrates the difficulty in defining organic systems and in the lack of adaptability in cereal varieties. This work has underpinned two EFRC initiatives, the development of participatory variety trials to deal with differences between organic systems and the development of breeding programmes to deal with a lack of adaptability in currently available cereal varieties.

9. References.

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