Project Report No. 474 October 2010 £13.00

Better Organic Bread: Integrating raw material and process requirements for organic bread production

October 2010
Cost £13.00

Project Report No. 474

Better Organic Bread: Integrating raw material and process requirements for organic bread production

by

Richard Stanley[1] and Stephen Wilcockson[2]

[1]Campden BRI, Chipping Campden, Gloucestershire, GL55 6LD

[2]Newcastle University, Nafferton Ecological Farming Group, Stocksfield, Northumberland NE43 7XD

This is the final report of a 57 month project (RD-2004-3022) which started in October 2005. The work was funded by the Sustainable Arable LINK Scheme and a contract for £32,800 from HGCA (Project No LINK LK 0960, HGCA 3022).

CONTENTS

1. ABSTRACT

This project aimed to develop agronomic strategies and optimise milling and baking processes which enable more UK produced organic wheat to be used for breadmaking. Spring wheat trials were established on three organic farms in England from 2006 to 2009 inclusive, to evaluate variety and fertility management treatments: type and rate of manure/compost application, rhizobial inoculation of pre-crop clover to influence N-fixation/supply, and targeted micronutrient supplementation to enhance grain selenium levels. Yield, agronomic and disease assessments were supplemented with evaluation of bread making performance of the wheat samples. Results indicate that variety choice is a pre-requisite for achieving milling grade and that spring varieties Paragon, Tybalt, Granary, Fasan and Amaretto can produce adequate protein levels in different regions. Composted farm yard manure (cattle) and composted green waste applications can increase yield significantly ($p \leq 0.0001$) by up to 0.5 t/ha where lower fertility conditions exist. However, where rotations maintain adequate fertility and a two year grass/clover ley precedes spring wheat, significant yield benefits from these composts are unlikely. Applications of composted chicken manure permitted by organic farming standards significantly ($p \leq 0.0001$) increased yield by up to 0.5t/ha only at sites with lower soil fertility. Grain protein content was increased significantly by up to 1%. Milling and baking trials showed that loaf volume was not increased by variety choice, farm yard manure and green waste compost treatments, but chicken manure compost increased loaf volume by 3%. However, the cost benefit of using this type of organic fertiliser is dependent on the input cost of such products and an adequate premium for milling grade organic wheat.

The use of microbial inoculants to enhance nitrogen fixation by preceding clover crops coupled with compost application to improve soil N retention provided some significant ($p \leq 0.05$) yield benefits (0.79t/ha) on land recently converted to organic production in spring wheat in a preliminary trial harvested in 2005. However, in more extensive trials of similar treatments on the three organic farms in 2008 and 2009, no increase in spring wheat yield or protein content due to inoculation of the preceding clover was observed. The food industry partners evaluated selected milling and baking approaches using test and plant bakery conditions. This showed that protein supplementation and dough recipe modification can result in wholemeal loaves of acceptable quality from commercial samples of UK grown organic Paragon, Amaretto and Tybalt.

2. SUMMARY

The organic breadmaking sector in the UK has been unable to meet market requirements without utilising imported high protein organic wheat to augment the lower protein content of the home grown crop. This project was established to identify routes to improve wheat protein and breadmaking quality which could be adopted at each stage of the supply chain by the farmer, miller and baker.

This project evaluated the effect of variety choice and fertility inputs on agronomic performance, grain quality and breadmaking performance of organically grown spring wheat in the UK. Additional objectives were to identify the effect on loaf quality of process variables, i.e. milling and baking phases, and evaluation of these variables under commercial conditions by the industry partners. Investigations of soil supplementation to raise selenium levels of wheat grain and the suitability of wheat for use as wholegrain flakes for muesli were also included.

The project was led by Campden BRI and comprised field trials to evaluate variety and fertility inputs. These were established by The Nafferton Ecological Farming Group of the University of Newcastle upon Tyne at three sites on organic farms managed by project partners located in Berkshire, Norfolk and Northumberland. The project consortium included companies from all stages of the organic breadmaking food chain, including organic farmers, grain merchants, millers and bakers. Field trials were conducted in each of four years between 2006 and 2009. Agronomic data for the field performance of the trials were supplemented by evaluation of the breadmaking performance of the wheat samples by Campden BRI.

The multisite field trials examined a range of variety and fertility effects, as well as the effects of rhizobial inoculation on N reserves, targeted micro nutrient supplementation on selenium levels in wheat, and field applied sulphur treatments.

2.1 Multisite Field Treatments

- Years:2006,2007,2008,2009.
- Sites:
  - Sheepdrove (Berkshire); Courtyard (Norfolk); Gilchesters (Northumberland).
- Varieties (spring wheat):
  - Paragon (UK), Tybalt (UK), Fasan (D), Monsun (D), Amaretto (D), Zebra (Norway/Sweden), Granary (UK) & AC Barrie (Canada).
- Fertility input & management:
  - Farmyard manure (FYM); green waste compost (GWC); chicken manure pellets (CMP).
  - Pre-crop clover management (rhizobial inoculation).
  - Sulphur (foliar) application (2008 at Courtyard only).

2.2 Spring wheat varieties

Paragon: a nabim Group 1 variety which is the most popular spring variety grown for milling and bread making in both conventional and organic systems because of its high quality grain. It has long straw and shows good resistance to yellow and brown rust. (Included in a preliminary trial in 2005 and in the project trials in 2006, 2007, 2008 and 2009).

Tybalt: a nabim Group 2 variety, with high yield potential relative to other spring varieties when sown in spring. Protein content tends to be low but baking performance is fair and the variety exhibits good disease resistance (especially to mildew and brown rust and average for yellow rust). (Included in the project trials in 2006, 2007, 2008 and 2009).

Fasan: a long-straw German variety bred specifically for high baking quality. (Included in a preliminary trial in 2005 and in the project trials in 2006, 2007, 2008 and 2009).

Monsun: a short-straw German variety bred for intensive farming systems. (Included in a preliminary trial in 2005 and in the project trials in 2006 and 2007 but not in 2008 and 2009 because seed of this variety was not available).

Amaretto: a German variety, not listed in the UK, but is on other European lists. Similar quality and yield characteristics to Paragon with good disease resistance and used by some millers of organic grain in the UK. (Included in the project trials in 2006, 2007, 2008 and 2009).

Zebra: a long-straw Scandinavian variety bred specifically for high baking quality wheat production in Norway. (Included in a preliminary trial in 2005 and in the project trials in 2006, 2007, 2008 and 2009).

Granary: a high yielding nabim Group 2 variety first listed in 2009. Slightly lower yielding than Tybalt but with a higher protein content and specific weight and good disease resistance. (Included in the project trials in 2007 when it first became available and 2008 and 2009).

AC Barrie: a Canadian red wheat variety with outstanding quality characteristics of interest to some conventional growers and millers in the UK. However, it was highly disease susceptible, particularly to mildew, at all three sites and was only included in one year (2007).

2.3 Sites

At Gilchesters in Northumberland, North Eastern England, soils are heavy, moisture retentive, clay loams. In spring, cereal establishment may be delayed leading to a late harvest and grain quality may suffer if weather conditions deteriorate. Water stress is rare and temperatures are lower than at southerly sites leading to a higher yield potential. Soil fertility was intermediate between the other two sites. At Courtyard Farm in Norfolk, Eastern England, soils are very well-drained, coarse, calcareous, light loams formed in chalk. Sowing and harvest of spring cereals is usually early, but water stress often limits yield. Some fields are low in fertility but others have benefited from manure inputs from outdoor pig enterprises. At Sheepdrove Farm, Berkshire, Southern England, the silty clay loam soils over chalk are well-drained facilitating early sowing in spring. Available water held in the chalk relieves water stress to some extent in low rainfall conditions. The soils at Sheepdrove were the most inherently fertile of the three sites.

2.4 Field Trials

The trials in 2006 and 2007 comprised a variety trial evaluating the field performance of selected varieties under organic conditions at each site, and a fertility trial evaluating the effect of different rates of farmyard manure (FYM) and green waste based composts (GWC) and chicken manure pellets (CMP) on the variety Paragon at each site. Drilling and harvest dates are shown in Table 1.

Table 1. Field trial establishment and harvest dates for multisite variety and fertility trials

Year	Site					
	Sheepdrove		Courtyard		Gilchesters	
	Drilling	Harvest	Drilling	Harvest	Drilling	Harvest
2006	20/3	15/8	28/3	10/8	10/4	30/8
2007	21/3	29/8	28/3	31/8	2/4	12/9
2008	18/3	16/9	1/4	17/9	25/4	23/9
2009	18/3	11/9	2/3	27/8	2/4	9/9

The trials in 2008 and 2009 at all three sites were designed using information obtained from the previous two years (2006 and 2007) and the results of a preliminary trial on rhizobial inoculation of pre-crop clover at Gilchesters in 2005. These trials comprised six varieties treated with selected fertility treatments of combinations of pre-crop clover rhizobial inoculation and FYM based compost. They were made at two sites, Sheepdrove and Gilchesters, in 2008 and all three sites, Sheepdrove, Courtyard and Gilchesters, in 2009. Courtyard was excluded from this rhizobial inoculation trial in 2008 because of rotational constraints. At Courtyard in 2008 a single trial was established to test the effects of foliar applications of sulphur on yield and protein content of the same six varieties of spring wheat grown in the rhizobial inoculation trials in 2008 and 2009.

2.5 Fertility treatments

- Fertility inputs & management:
  - Organic production standards require that on an individual farm, N input from organic manures is limited to 170kg/ha with a maximum of 250kg/ha on any one area.
  - A commercial organic fertiliser – composted chicken manure pellets (CMP) - had approximately twice the amount of N than either FYM or green waste compost and ten times more readily available N (Table 2).

- FYM compost and GWC were ploughed in before drilling; CMP were applied post crop emergence.
- Fertility inputs were applied at 125 and 250kg/ha N in 2006 and 2007, and 170kg/ha N in 2008 and 2009.
- Rhizobial inoculation of pre-crop clover to increase N availability.
- Sulphur application by foliar spray (2008 at Courtyard only).

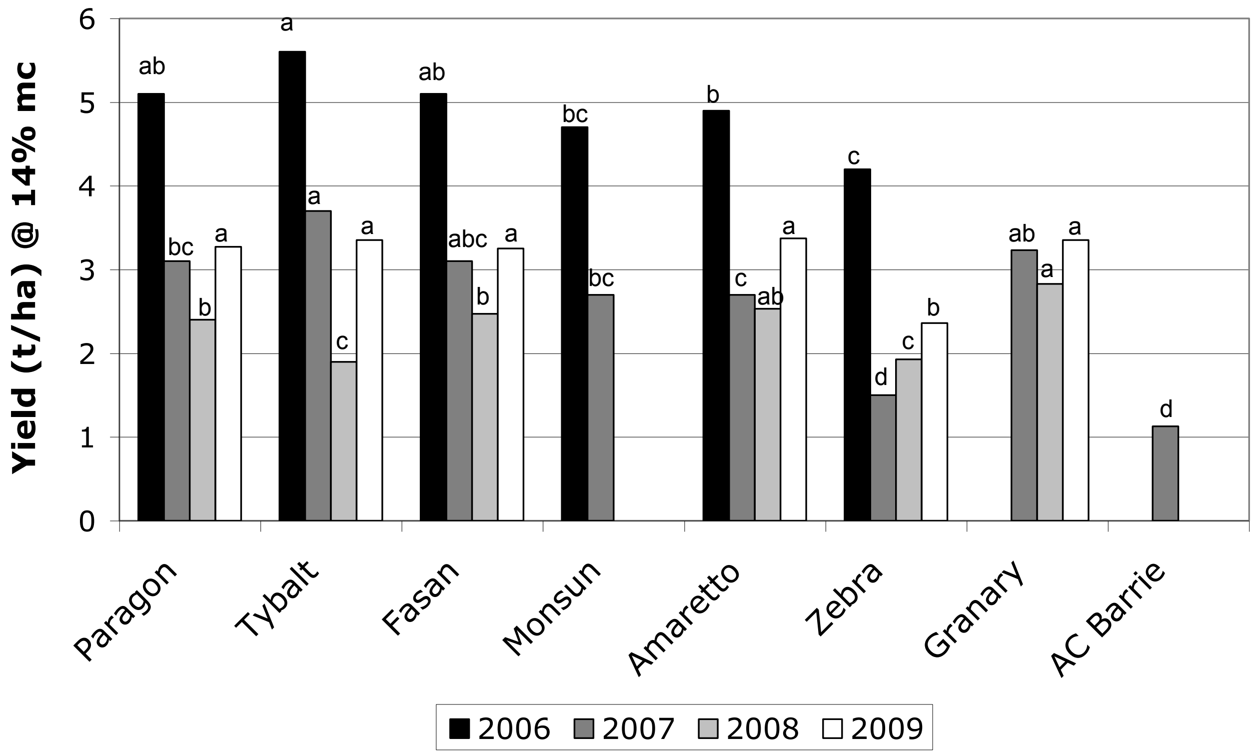
Table 2. Typical manure nutrient analyses (dry matter basis)

	%N	NO_3 mg/kg	NH_4 mg/kg
FYM Compost	2.4	342	351
Greenwaste Compost	2.2	159	242
Chicken manure pellets	4.0	5481	359

2.6 Rhizobial inoculation treatment

A preliminary field trial commencing in 2003 investigated the effect of rhizobial inoculation of fertility building clover crops and compost amendment on the yield and protein content of four varieties of spring wheat grown in an organic, stockless system at Gilchesters. The clover crop was established (with and without inoculum treatment) in 2003 two years prior to ploughing out for spring wheat sown in 2005 and green waste compost had been applied to the clover sward before ploughing. Spring wheat grown in 2005 following the clover inoculation treatments and pre-ploughing compost application gave a higher yield and protein content compared to untreated plots. However, when this inoculum treatment was investigated again at 3 sites in 2008 and 2009, there was no significant increase in either yield or protein content in the plots treated where the preceding clover had been inoculated with *Rhizobium*.

Figure 1. The effect of wheat variety and season on grain yield (t/ha at 14% moisture content (mc)) averaged over sites. (Within a year, yields of varieties with the same letter were not significantly different (p<0.05) according to Tukey's HSD test)



Footnote: Monsun seed unavailable in 2008, 2009; Granary first became available for inclusion in 2007 trials and was included on the HGCA Recommended List in 2009; AC Barrie included in 2007 but excluded subsequently because of high susceptibility to mildew.

2.7 Results of field trials for four years and three sites

- There were large effects of site and season on the performance of variety and fertility treatments (data not shown).
- Highest yields of all varieties were recorded in 2006 when growing conditions were most favourable. In 2007, 2008 and 2009 yields of all varieties were significantly lower because of poor seasonal conditions, with frequent heavy rainfall and dull conditions in July.
- Averaged over sites, within the same year, the four varieties Paragon, Fasan, Amaretto and Granary (not included in 2006) gave similar yields (Figure I). Within three of the years (2006, 2007 and 2009) Tybalt yielded as well as, or better than these four varieties. In 2008 however, the potential of Tybalt was limited by poor quality of the seed lot that was used at all three sites which resulted in low

germination and establishment of this variety at all three sites. In twelve field trials over the four years, Tybalt was the top ranking yielder on five occasions, Granary and Fasan on three occasions and Paragon twice. (However, the top ranking variety never significantly outyielded the second ranking variety, but significantly outyielded the lowest ranking variety ($p \leq 0.05$ to $p \leq 0.0001$), except in 2009 at Gilchesters where the were no significant yield differences between varieties).

- Although Zebra and Fasan had longer straw and a longer distance from the flag leaf to the base of the ear than other varieties, this did not protect against the effects of disease as they were infected with yellow rust to a greater extent than other varieties. Zebra was extremely susceptible to yellow rust leading to premature death of the flag leaf, and levels of septoria in the ear were also greatest in this variety. AC Barrie was so severely infected with mildew at all sites in 2008 that yields were very low.
- Crops treated with the highest rate of CMP were taller and greener than those with lower fertility inputs. The increased height did not result in lodging and the more persistent canopy did not always affect yield.
- Fertility management treatments had no marked effects on incidence of disease, irrespective of variety.
- Significant yield benefits were recorded in response to some but not all fertility treatments and at particular sites as follows:
  - CMP at Courtyard 2008 (+ ~0.5t/ha ($p \leq 0.0001$) compared with no application).
  - FYM and GWC compost at Sheepdrove 2007(+ ~1.5t/ha ($p \leq 0.0001$) compared with no application).
  - FYM at 170kg/ha N at Sheepdrove and Courtyard 2009(+ ~0.3t/ha and +0.5 t/ha ($p \leq 0.0001$) respectively, compared with no application).
  - Rhizobial treatments showed non-significant effects on yield in 2008/9.
  - There were no effects of foliar applied sulphur on yield, grain quality or disease of the varieties grown at Courtyard in 2008.

The main findings of the field trials are:

- Variety choice is influential on yield and quality and is the primary consideration for growing spring wheat in organic systems for bread-making, as is the case in conventional systems.
- The extent to which the chosen variety achieves its potential yield and quality depends on environmental conditions (weather, site effects including soil fertility and its management and disease profiles).

- Site specific, significant ($p \leq 0.0001$) yield benefits of the order of 0.5 to 1.5t/ha may be obtained in some years when growing conditions are unfavourable, by increasing N rate, using CMP and using FYM based compost.
- The economic benefit of the manure or compost application will depend on the cost per kg of N x quantity applied, relative to the improvements in grain yield and/or quality achieved and depending on the responsiveness of the site: this is of particular significance where bought-in manures are involved.
  - The full economic benefits may extend beyond the current milling wheat crop further into the rotation although they may be difficult to quantify.
- Effects of Rhizobial inoculation of pre-crop clover and compost amendments are not clear: whilst preliminary trials showed good yield responses in two spring wheat varieties, multisite trials on spring wheat in 2008 and 2009 gave no significant effects.
- Yield responses to fertility treatments applied pre-sowing or post-emergence in the current season may be absent or small and insignificant. This may be because their effects are masked by soil fertility built up over previous years of rotations. Moreover, a relatively small fraction of the N contained in the fertility inputs may be readily available to the crop in the year of application and organic N becomes mineralised over the rotation.

2.8 Enhancement of wheat selenium levels

The effect of amending soils with micronutrient mixtures designed to remedy chronic micronutrient deficiencies in organically managed soil was determined in field trials established at Nafferton Farm.

Results of trials by agronomy partner, Field Science, showed that when compared with untreated samples, wheat from plots treated with the micronutrient formula contained significantly increased selenium levels.

2.9 Results for protein content and loaf volume

Wheat protein analysis, and milling and baking of the trial samples were undertaken at Campden BRI. A large amount of data was generated from the different trials. In order to maximise the information obtained from these trials, the results were grouped into three data sets which were analysed to identify the main effects of the treatments. Each data set comprised the same treatments from trials in any site and in any year. The three sets were:

1. All fertility treatments using compost and CMP.
2. All fertility treatments using rhizobial treatments.
3. All wheat varieties grown in untreated plots.

These data were statistically analysed using a General Linear Model. This technique tests a large but unbalanced data set to identify the fitted mean differences in protein content or loaf volume attributable to the treatments.

The results of the analysis of the 3 data sets are:

- For the fertility treatments
  - Site and year effects showed significant differences.
  - CMP gave a significant increase in protein content of about 1% at Sheepdrove and Courtyard.
  - When baked into white loaves, CMP gave a significant increase in loaf volume of 2.8% compared to untreated.

- For rhizobial fertility treatments in 2008 and 2009
  - Site and year effects showed significant differences.
  - There were no significant effects of fertility treatment on protein content or loaf volume.
  - Variety differences were significant; Paragon, Tybalt, Granary and Zebra contained up to 1% more protein compared to Amaretto. Variety differences for loaf volume showed a significantly larger volume for Paragon which was 5% greater compared with other varieties.

- For variety data taken from all untreated plots
  - Site and year effects showed significant differences.
  - Paragon and Zebra contained significantly higher protein than other varieties.
  - When baked into white loaves, variety showed no significant effect on loaf volume. (Variety effect on loaf volume was confounded by low Hagberg Falling Number, which reduced baking performance, particularly in 2007).

The results of protein analysis of the trial samples using size exclusion high performance liquid chromatography (SE-HPLC) give an indication of flour protein quality. These data identify the relative proportions of large polymeric and smaller monomeric protein components, which can be related to dough strength and to baking potential. The resolved components are classified into five main fractions (F1-F5) according to molecular weight. Improved baking performance is generally associated with a higher proportion of the F1 fraction, representing the largest polymeric protein complex enriched in the high molecular weight subunits of glutenin. The F2 fraction contains mainly the low molecular mass glutenin polymers, while F3 and F4 contain mainly monomeric gliadin proteins. The results of the analysis of the trials samples indicate that:

- Protein quality data presented as a function (F3+F4)/F1 showed a weak correlation (r=0.265) with loaf volume.
- There was an effect of variety, site and season on the variation in molecular weight distribution of glutenin components, which can be related to dough strength and baking potential in the absence of added gluten.
- Protein quality data from these organic trials shows a similar classification of protein fractions as the results in published data collected from conventionally grown wheat samples.

2.10 Milling and baking variables

Trials at Campden BRI examined the influence of different milling and baking variables on the performance of individual varieties of wheat to produce bread. The effect on loaf quality was measured during the project.

Summary results for these trials indicate that:

- When white flour is milled at 72% extraction, loaves produced have an 8% greater loaf volume than white flour at 78% extraction.
- Increasing flour protein by 2% by adding gluten could increase white loaf volume by 3.3% and wholemeal loaf volume by 8.2%.
- Dough work input had a non significant effect on white loaf volume, but for wholemeal flour changing energy input at the dough mixing stage from 13 to 9 watt hours/kg produced a small but significant 3% increase in loaf volume.

- Wholemeal flour with small bran particles produced 4.5% greater loaf volume than flour with larger bran particle.

2.11 Commercial baking trials

A series of test bakes and commercial trials were carried out by the project partners.

- For wholegrain products, the variety Fasan with higher specific weight produced wheat flakes more suitable for use in muesli products.
- For baked products, roller milled wholemeal flour was observed to consistently produce a better quality loaf than stoneground wholemeal flour from the same wheat. This could be explained by a greater variability in particle size distribution in stoneground flours.
- Trials conducted by industry partners using plant bakery equipment with spiral and high speed pressure vacuum mixing indicate that an acceptable loaf can be produced when using low protein organic flour, provided modifications to the dough recipe are made. Recommended adjustments include: the addition of gluten to increase flour protein content from 10% to 12%, an increase in dough conditioner levels by 25%, and an increase in palm shortening levels by 100%. The consequence of these changes was estimated to add 8% to raw material costs.

2.12 Conclusions

The project conclusions are, that wheat variety choice offers potential for achieving yield and breadmaking quality, the varieties Paragon, Tybalt, Granary, Fasan and Amaretto are capable of producing adequate protein levels when grown in different regions. However, it should be recognised that seasonal differences can have a large influence on the suitability of UK spring organic wheat for breadmaking.
The use of composted materials based on farm yard manure and green waste, and supplementary organic fertility inputs based on chicken manure can increase both yield and protein content in lower fertility conditions.

The use of microbial inoculants to increase the benefits of nitrogen fixation by preceding clover crops can provide some yield benefits on land which is in conversion to organic production. However, in more extensive trials no increase in crop yield or wheat protein content was observed from this treatment on established organic farms.

In baking trials, loaf volume was not consistently increased by variety choice or compost treatment but was increased by chicken manure treatment. The effect of site and season resulted in large variation in hectolitre weight and Hagberg values caused by environmental factors with large effects on loaf volume.

The food industry trials undertaken by the partners showed that protein supplementation and dough recipe modification can result in acceptable quality wholemeal loaves from commercial samples of UK grown organic Paragon, Amaretto and Tybalt. Test baking of wholemeal flour using traditional sourdough techniques produced loaves with good flavour. Evaluation of wheat variety samples for use in muesli products showed Fasan to produce the best flaked product.

3. TECHNICAL DETAIL

3.1. Introduction

The total area of land in the UK used for organic cereal production is about 55,000 Ha which comprise 22,000 Ha of organic wheat, 15,000 Ha of organic barley, with the remainder consisting of oats and other grains (Defra 2009). The organic wheat sector supplies hard wheats for breadmaking, and soft wheats for biscuit and general food use as well as animal feed.

The production of bread in the UK is dependent on a supply of wheat flour containing sufficient protein to produce gluten with enough strength for the dough to rise and retain adequate structure in the finished baked product. This is achieved by using wheat varieties selected to contain high protein content, which are grown with input of supplementary nitrogen fertiliser to optimise grain protein. A similar approach is used for the organic wheat crop in the UK, but due to the limited options for providing additional fertility inputs in organic systems, organic farmers are unable to regularly meet the requirements of the baking market (Gooding, 1993). As a result millers add imported high protein organic wheat to the grist to augment the lower protein content of the home grown crop. The Better Organic Bread project was established to identify routes for improvement of wheat protein content and breadmaking quality of spring wheat which could be adopted at each stage of the supply chain by the farmer, miller and baker.

The agronomy component of the project evaluated the effect of fertility inputs and variety selection on agronomic performance, grain quality and breadmaking performance of organically grown spring wheat in the UK. The effect of selenium and sulphur on wheat quality was also investigated. The processing objectives were to identify the effect of process variables at the milling and baking phases on loaf quality and to evaluate wheat as a wholegrain flake ingredient in muesli products. These variables were validated under commercial conditions by the industry partners.

3.2 Field Trials

Field trials to evaluate the effects of variety and fertility management on yield and quality of spring wheat were established by Nafferton Ecological Farming Group of Newcastle University at three sites on organic farms managed by project partners located in Berkshire (Sheepdrove), Norfolk (Courtyard) and Northumberland (Gilchesters). Trials were conducted in each of four years between 2006 and 2009. Agronomic data for the field performance of the trials were supplemented by evaluation of the bread making performance of the wheat samples by Campden BRI. The field trials comprised multisite trials which examined variety and fertility effects (Experiment 1 and Experiment 2) and the effect of rhizobial inoculation of the preceding clover crop and pre-sowing compost application (Experiment 3). Subsidiary trials were made to evaluate the effects of foliar applications of sulphur on yield and quality at Courtyard in 2008 (Experiment 4) and targeted micro nutrient supplementation on selenium levels in wheat at Nafferton Farm in 2006 and 2007 (Experiment 5). The trials in 2006 and 2007 (Experiment 1) comprised a variety trial evaluating the field performance of selected varieties under organic conditions at each site (six varieties in 2006, 2008, 2009 and eight varieties in 2007) and a fertility trial (Experiment 2) evaluating the effect of selected organic fertility inputs on the variety Paragon at each site. The trials in 2008 and 2009 (Experiment 3) were designed using information obtained from the previous two years (Experiments 1 and 2) and the results of previous experiments on rhizobial inoculation at Gilchesters (Wilkinson *et al*., 2006; Wilkinson *et al*., 2007). These trials comprised six varieties treated with selected fertility treatments of combinations of rhizobial inoculation and FYM based compost. They were made at two sites, Sheepdrove and Gilchesters, in 2008 and all three sites, Sheepdrove, Courtyard and Gilchesters, in 2009. Courtyard was excluded from this rhizobial inoculation trial in 2008 because the two-year grass/clover ley fertility of the rotation was established one year later than at the other two sites. At Courtyard in 2008 a single trial (Experiment 4) was established to test the effects of foliar applications of sulphur on yield and protein content of the same six varieties of spring wheat grown in the rhizobial inoculation trials in 2008 and 2009. Sowing and harvest dates in experiments 1 to 4 are shown in Table 3.

Details and results of experiment 5, investigating targeted micro nutrient supplementation on selenium levels in spring wheat variety Paragon which was made at a different site (Newcastle University's Nafferton Farm) in 2006 and 2007 by agronomy partner Field Science, are presented in Section 7 Appendix A.

Table 3. Field trial establishment and harvest dates of the multisite variety and fertility trials (Experiments 1, 2, 3 and 4)

Year	Site					
	Courtyard		Sheepdrove		Gilchesters	
	Drilling	Harvest	Drilling	Harvest	Drilling	Harvest
2006[e]	28/3[ab]	10/8[ab]	20/3[ab]	15/8[ab]	10/4[ab]	30/8[ab]
2007[e]	28/3[ab]	31/8[ab]	21/3[ab]	29/8[ab]	2/4[ab]	12/9[ab]
2008	1/4[d]	17/9[d]	18/3[c]	16/9[c]	25/4[c]	23/9[c]
2009	2/3[c]	27/8[c]	18/3[c]	11/9[c]	2/4[c]	9/9[c]

Where:

[a]Experiment 1: 2006 and 2007, variety evaluation trial at three sites

[b]Experiment 2: 2006 and 2007, fertility input trial (input type and rate) at three sites

[c]Experiment 3:2008 and 2009, rhizobial inoculation of pre-crop clover and pre-sowing compost

[d]Experiment 4: 2008, foliar sulphur application trial at Courtyard site only

[e]Experiment 5: 2006 and 2007, micronutrient supplementation trial at Nafferton Farm (see Section 7 Appendix A).

3.2.1 Site characteristics

The three farms in England were certified according to organic production standards. They contrasted in terms of soil type, local climate and disease pressure and hence yield and quality potential. At Gilchesters in Northumberland, North Eastern England, soils are of the Brickfield and Dunkeswick Associations (Jarvis *et al*.,1984). These tend to be heavy, moisture retentive, clay loams. Risk of damaging soil structure when the soil is wet limits opportunities to cultivate and establish cereal crops. Sowing in spring can be delayed, leading to a late harvest, which may compromise grain quality as weather conditions deteriorate. Temperatures are lower than at the southerly sites but water stress is rare, leading to a higher yield potential. Previous experiments examining the effects of fertility management and variety choice on yield and baking quality of organic spring wheat have been done at this site (Wilkinson *et al*., 2006; Wilkinson *et al*., 2007). At Courtyard Farm in Norfolk, Eastern England, the soil type is Newmarket 2 Association. Coarse calcareous loams formed in chalk are light and very well drained, and can be cultivated soon after rainfall (Hodge *et al*., 1984). Early sowing of cereals is possible in spring and harvest is early. Shallow rooting coupled with drought frequently restricts growth and yield. Some fields are low in fertility but others have benefited from manure inputs from outdoor pig enterprises.

At Sheepdrove Farm, Berkshire, Southern England, the silty clay loam soils belong to the Andover 1 Association formed over chalk (Jarvis *et al*.,1984). Well-drained, they dry rapidly after rain, facilitating early cultivation and sowing in spring. In drought conditions, effects of water stress on crop growth and yield may be alleviated by available water held in the chalk.

Soil nutrient analyses prior to drilling and manure/compost application showed differences in inherent fertility in terms of % N between the sites, with Courtyard being the lowest, Sheepdrove the highest and Gilchesters intermediate (Table 4). On this basis, Courtyard would appear to have a greater potential to respond to applied fertility inputs than Sheepdrove or Gilchesters, although this was not always borne out in the trial results.

Table 4. Soil nutrient analyses – average of 2006 - 2008

Site	% N	% C	P mg/kg	K mg/kg
Courtyard	0.2	1.7	54.6	144
Sheepdrove	0.6	8.0	28.6	243
Gilchesters	0.3	3.1	22.2	131

3.2.2 Variety trials

Bread making quality characteristics are determined to a large extent by variety. Group 1 varieties are preferred although Group 2 varieties may be included in bread making grists (nabim, 2010*)*. The extent to which varieties achieve their potential quality depends upon seasonal conditions and local micro-climate, soil type, crop nutrition and pest and disease pressure. All of these factors varied throughout the course of this research programme.

Table 5 shows the varieties included in Experiments 1, 2 and 3. All were spring varieties, sown in spring, with different yield, agronomic, disease resistance and quality characteristics spanning the range of performance currently available. These included: well-established varieties, e.g. Paragon, already popular in UK organic production systems; more recently introduced varieties, e.g. Granary and varieties from abroad with potential; and some in need of further testing under organic production systems.

Paragon: RAGT Seeds Ltd, Cambridge. First listed 1999, this Group 1 variety is the most popular grown for milling and bread making in accordance with organic standards. Although yields are generally lower than other spring varieties, they are compensated by very good bread making qualities. The straw is relatively long but stiff (resistance to lodging score = 6) and the variety shows good all-round disease resistance (mildew = 7 or moderately resistant; Yellow rust = 9 or resistant; Brown rust = 7 or moderately resistant; *Septoria tritici* = 6 or moderately resistant) (HGCA, 2010). Paragon accounted for about 16% of spring wheat supplies from 2009 harvest, whilst the Group 2 varieties Tybalt and Granary accounted for about 24% and 11% respectively (NIAB, 2010). This variety was included in the trials in 2006, 2007, 2008 and 2009.

Tybalt: Zelder, Netherlands. First listed in 2003, Tybalt is a nabim Group 2 variety, with high yield potential relative to other spring varieties when sown in spring rather than late autumn. It has weak straw and good disease resistance. Although weak straw varieties may have a tendency to lodge, in organic systems because fertility is generally lower than in conventional systems, lodging is less of a risk. As a Group 2 variety, Tybalt's protein content and specific weight is usually lower than Group 1 varieties such as Paragon. This variety was included in the trials in 2006, 2007, 2008 and 2009.

Fasan: Lochow Petkus, Germany. Fasan is a long straw variety bred specifically for high baking quality wheat production in Germany and used in a preliminary experiment in 2005 (Wilkinson *et al*., 2006; Wilkinson *et al*., 2007). Long straw varieties such as Fasan and Zebra are more competitive against weeds in organic systems, may have a more vigorous root system and are able to exploit a greater volume of the soil profile to extract nutrients to greater depth than with less vigorously rooting varieties. In both Fasan and Zebra, the length of the peduncle (stalk bearing the ear) between the flag leaf's ligule and base of the ear is longer than in most varieties. This characteristic should afford some protection for the ear against foliar diseases infecting the flag leaf, such as *Septoria tritici*, transmitted upwards by rain splash. This variety was included in the trials in 2006, 2007, 2008 and 2009.

Monsun: Lochow Petkus, Germany. A short straw spring wheat variety bred for intensive farming systems in Germany and used in a preliminary experiment in 2005

(Wilkinson *et al*., 2006; Wilkinson *et al*., 2007). This variety was included in the trials in 2006 and 2007 but not in 2008 and 2009 because seed was unavailable.

Amaretto: Saatzuchtgesellschaft Streng's. Amaretto is not listed in the UK but is on the European Common Catalogue of wheat varieties. It is considered to be an alternative to Paragon, with similar quality and yield characteristics and good disease resistance. Some millers of organic grain use Amaretto. This variety was included in the trials in 2006, 2007, 2008 and 2009.

Zebra: Swallof-Weibull, Sweden. Zebra is a long straw variety bred specifically for high baking quality wheat production in Norway and also used in a preliminary experiment in 2005 (Wilkinson *et al*., 2006; Wilkinson *et al*., 2007). This variety was included in the trials in 2006, 2007, 2008 and 2009.

Granary: KWS, UK, Cambridge. Granary was first listed in 2009 on the HGCA Recommended list (HGCA, 2010). It is a high yielding Group 2 variety with a higher protein content and specific weight, but lower Hagberg Falling Number (HFN) than Tybalt and suited to spring sowing. Granary has good disease resistance, especially to *Septoria tritici.* This variety was included in the trials in 2007, 2008 and 2009.

AC Barrie: Dr R.M. DePauw, AAFC, Box 1030, Swift Current, SK, CANADA S9H 3x2. This is a long-straw, Canadian red wheat variety with extremely good quality characteristics (protein, specific weight and HFN), exceeding those of varieties commonly grown in the UK. Indeed, crops of this variety are currently grown under contract to major millers and bakers. However, the variety is very disease susceptible and consequently not recommended for organic systems, although it was included in one season (2007) because of its reputation for quality. Mildew infection was so high at all three sites that it was not included again.

The variety trials in Experiments 1 and 2 were randomised complete block designs with four replicates and the varieties included in 2006, 2007, 2008 and 2009 are shown in Table 5. Plots were 30m long by 8m wide and a strip of between 2 and 3m wide by 30m long was harvested with a small plot combine for yield and quality assessments.

3.2.1 Fertility trials

Protein content of wheat for milling in organic systems is often 20 to 40% below that grown in conventional systems (Taylor and Cormack, 2002). In both systems, variety choice sets the potential grain quality for milling and baking, but fertility management affects the extent to which this potential is achieved. Manufactured fertilisers are widely used in conventional production to influence grain yield and quality. In both winter and spring milling wheats, late applications of nitrogen at the start of the grain filling period may be applied to increase grain protein: 40kg/ha N applied as fertiliser prills at the end of May (flag leaf emergence) may increase protein by 0.5 to 0.7% and yield by 0.1 to 0.2 t/ha. Foliar urea applied at 40kg/ha N may increase protein by 0.75 to 1% but not affect yield (HGCA, 2009; Defra, 2010). As these inputs are not permitted according to organic standards, fertility management depends on building fertility in the rotation with grass/clover leys, green manures, grain legumes and animal manures and composts, e.g. composted green waste, farm yard manure (FYM) from cattle, sheep, pigs and poultry (in some cases subject to certain restrictions or requirements (Soil Association, 2009)). The amount of N that can be applied in the form of 'organic' manures is restricted to 170kg/ha N averaged over the whole farm area and a maximum of 250kg/ha N on any one field.

Although the total quantity of N applied to spring wheat may be the same irrespective of fertility input type, e.g. 170kg/ha N, different manures provide different concentrations of total and readily available N for rapid crop uptake. For example, poultry manure contains ~16–30 kg N/t (30-45% of which is readily available N) compared with FYM (cattle) ~6kg N/t (20-25% readily available) (Defra, 2010). However, potential losses of N by volatilisation and leaching are greater for poultry manure than other forms of FYM and composts. Compared with mineral fertilisers such as ammonium nitrate, organic N in manures is much less available to the crop to which it is applied and becomes potentially available as a result of mineralisation over months and years.

Table 5. Summary of evaluation of varieties in the multisite variety trials (Experiment 1)

		Field Trial				Single plot sample milled and baked				Protein content and Quality			
Site	Variety	2006	2007	2008	2009	2006	2007	2008	2009	2006	2007	2008	2009
Courtyard	Paragon	Y	Y	Y	Y		Y	Y		Y	Y	Y	Y
	Tybalt	Y	Y	Y	Y		Y	Y		Y	Y	Y	Y
	Fasan	Y	Y	Y	Y		Y	Y		Y	Y	Y	Y
	Monsun	Y	Y				Y			Y	Y		
	Amaretto	Y	Y	Y	Y		Y	Y		Y	Y	Y	Y
	Zebra	Y	Y	Y	Y		Y	Y		Y	Y	Y	Y
	Granary		Y	Y	Y		Y	Y			Y	Y	Y
	AC Barrie		Y				Y				Y		
Gilchesters	Paragon	Y	Y	Y	Y					Y		Y	
	Tybalt	Y	Y	Y	Y					Y		Y	
	Fasan	Y	Y	Y	Y					Y		Y	
	Monsun	Y	Y							Y			
	Amaretto	Y	Y	Y	Y					Y		Y	
	Zebra	Y	Y	Y	Y					Y		Y	
	Granary		Y	Y	Y							Y	
	AC Barrie		Y										
Sheepdrove	Paragon	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y
	Tybalt	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y
	Fasan	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y
	Monsun	Y	Y			Y				Y	Y		
	Amaretto	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y
	Zebra	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y
	Granary		Y	Y	Y			Y	Y		Y	Y	Y
	AC Barrie		Y								Y		

Y indicates that data was collected for the variety site indicated

3.2.2 Fertility management

At each site, the spring wheat crop was preceded by a fertility building grass/clover ley of two years duration. At Gilchesters, winter wheat then winter barley was followed by a two-year red clover ley that was cut frequently and mulched. At Courtyard, wheat, a grain legume, wheat then barley was under sown with grass/white clover to establish a two-year ley for grazing. At Sheepdrove, two cereal crops, either two wheats, or wheat followed by spring barley preceded a two-year grass/clover ley that was grazed. In Experiment 2, different levels of nitrogen inputs were applied in spring shortly before the leys were ploughed for the wheat crops, using a range of permitted fertility inputs based on the results of a nutrient analysis. FYM and composts were applied mechanically with a small-scale manure spreader in February or March, but CMP were applied by hand post-emergence in early to mid-May. The design was a randomised complete block with four replicates. Experimental treatments were fertility input type (FYM- farm yard manure; CMP-chicken manure pellets; a mixture of FYM and CMP; GWC – green waste compost) and fertility input level, 125 and 250kg/ha N, and were accompanied by an untreated control. In both years, each of the fertility input types applied at the three sites was obtained from a single, homogenous batch, and so was identical in composition. FYM and green waste compost was supplied by Sheepdrove Farm. The CMP were a proprietary brand (Greenvale Ltd, Yorkshire) made from composted chicken manure formed into small, 3mm diameter pellets and approved for restricted use by organic farming standards. Analytical composition of the three organic manures (determined by Natural Resource Management Ltd, Bracknell, Berkshire) and quantities applied to achieve the different N-input levels are shown in Table 6. Plots were 8m long by 30m wide, and a strip of either 2.2m or 3m was harvested with a small plot combine for yield and quality assessments.

Table 6. Typical analytical composition of farm yard manure (FYM) and green waste compost (GWC) and chicken manure pellets (CMP) on a dry matter basis 2006 and 2007

	2006			2007		
	FYM	GWC	CMP	FYM	GWC	CMP
Dry matter (%)	22.9	40.0	92.0	53.2	40.7	86.2
Total nitrogen (% w/w)	3.18	1.54	3.82	1.70	2.94	4.24
Total carbon (% w/w)	38.1	20.3	38.6	17.2	35.5	39.7
C:N ratio	12:1	13.1	10:1	10.1	12.1	9.5:1
Nitrate nitrogen (mg/kg)	305	159	404	63	1508	313
Ammonium nitrogen (mg/kg)	298	126	5383	502	357	5579
Total phosphorus (P) (mg/kg)	6727	2583	10200	3150	10600	13600
Total potassium (K) (mg/kg)	23675	5850	13560	7040	17100	36900
Total copper (Cu) (mg/kg)	14.0	23.1	22.6	38.1	60.1	133
Total zinc (Zn) (mg/kg)	90	143	71	178	300	885
pH	8.69	7.80	n/a	7.35	7.31	n/a
Applications (t/ha fwt) to achieve						
170 kg/ha N	23.4	27.6	4.5	18.8	14.1	4.0
250 kg/ha N	34.4	40.6	6.5	27.6	20.8	5.9

3.2.3 Rhizobial inoculation treatments, Gilchester site only (Experiment 3)

Fertility management may be further refined by improving the N fixing capacity of forage legumes preceding the more exploitative cereals crops. For example, the effects of natural inoculation of red clover with endemic soil *Rhizobia* can be enhanced with further inoculation of the seed at drilling. However, there is a risk that some of the additional fixed N which is mineralised may be lost by leaching from the system following ploughing. However, by applying a high ratio C:N compost onto the clover before ploughing, microbial activity should help to retain the extra N as it is incorporated into the organic fraction and be available during subsequent seasons. This approach was initially tested in a preliminary trial at Gilchesters. A field trial was established to investigate the effect of rhizobial inoculation of fertility-building clover crops supplemented with green waste compost (GWC) on the yield and protein content of four varieties of spring wheat established in March 2005. The clover crop was established two seasons before the spring wheat plots were established with and without inoculant treatment on the organic, stockless farm. Long straw varieties of spring wheat – Fasan and Zebra - (but not short straw varieties – Paragon and Monsun) grown on the trial plots given the clover inoculation treatments produced significantly ($P \leq 0.05$) higher yields than uninoculated treatments with an increase of ~0.65t/ha for both varieties. However, effects on grain protein content depended on variety and clover inoculation and compost amendment. In the short straw varieties, the combination of *Rhizobia* inocula and compost significantly increased protein contents, whilst applying compost without previous clover inoculation reduced protein contents. On the other hand, in long straw varieties, *Rhizobium* inoculation without compost reduced protein content of Fasan, but for Zebra, the combination of *Rhizobia* inocula and compost amendment increased protein contents (Table 7). These results were used to design the fertility inputs used in the multisite trials established in 2008 and 2009. The results of the inoculation trials are reported in Wilkinson *et al*. (2006) and Wilkinson *et al*. (2007).

Table 7. The effects of pre-crop clover inoculation with *Rhizobium (-/+ Rhizobium*) and green waste compost amendment (-/+ compost) on yields (t/ha) and protein (%) of spring wheat varieties grown at Gilchesters 2005 (Within a row, means with the same letter are not significantly different (P≤0.05) according to Tukey's HSD test)

	Without *Rhizobium* inoculum		With *Rhizobium* inoculum	
	- compost	+compost	-compost	+compost
Variety				
Yield t/ha				
Paragon (SS)[a]	5.86a	5.75a	5.64a	5.71a
Monsun (SS)	7.02a	6.79a	6.86a	6.75a
Fasan (LS)[b]	6.97a	6.42b	7.34a	7.32a
Zebra (LS)	7.69b	7.63b	7.95b	8.72a
Protein (%)				
Paragon (SS)	12.10a	11.72b	11.68b	12.32a
Monsun (SS)	12.15b	11.85c	11.82c	12.62a
Fasan (LS)	11.97a	12.00a	11.07b	11.6ab
Zebra (LS)	11.05b	11.40ab	11.53a	11.73a

[a]SS; short straw variety; [b]LS; long straw variety
(Wilkinson et al., 2006)

A similar approach was taken in 2008 and 2009 as mentioned in section 2. These trials comprised six varieties treated with selected fertility treatments of combinations of rhizobial inoculation and FYM compost at Sheepdrove and Gilchesters in both 2008 and 2009 and at Courtyard in 2009 only. The trial at Courtyard was delayed by a year compared with the other two sites because the rotation there required that the clover ley was established a year later than at Sheepdrove or Gilchesters.

3.2.4 Post-emergence sulphur application treatments, Courtyard site only 2008 (Experiment 4)

At Courtyard in 2008, the effect of foliar application of sulphur on yield and protein content of six spring wheat varieties was investigated. Two foliar applications of sulphur, each 4kg/ha elemental sulphur, were applied with water by knapsack sprayer. The first application was on the same date that CMP were applied post-emergence, and the second was one month later. The total amount of sulphur that may be applied under organic standards is 8kg/ha.

3.2.5 Micronutrient treatments, Nafferton site only 2006 and 2007 (Experiment 5)

The effect of amending soils with micronutrient mixtures designed to remedy chronic micronutrient deficiencies in organically managed soil was determined in field trials established at Newcastle University's Nafferton Farm, Stocksfield, Northumberland.

Results of trials by agronomy partner, Field Science showed that:

i) The micronutrient formula employed can enhance the selenium level of milling wheat from 0.17mg/kg to 6.98mg/kg.
ii) Treatment with compost and micronutrients had a limited influence on wheat yield following clover.
iii) Treatment with micronutrients in a second wheat had a significant yield influence.
iv) The quantity of micronutrient at 25kg/ha has an operational advantage compared to bulkier inputs including compost.
v) The addition of micronutrients gave no significant advantage in terms of fungal resistance or chlorophyll levels.
vi) From parallel experiments conducted by Field Science on conventionally grown milling wheats, it is concluded that selenium (Se) enhancement is possible to similar levels in this system, but fertilisers need to be chosen carefully to avoid blocking plant Se uptake.

A more detailed report of this trial is given in Section 7 Appendix A.

3.2.6 Methods: agronomy trials

Crop establishment

Seed bed preparation and drilling was done with the commercial equipment available at each farm. Certified organic seed was sown at rates of 350 seeds/m^2 as soon as soil conditions allowed at each site: Gilchesters was always the last site to be drilled, sometimes up to 4 weeks later than the sites in the south and south-east. In the fertility experiments in 2006 and 2007, the whole experimental area was sown with Paragon and superimposed onto the previously fertilised plots, each 8 metres wide and a minimum of 30 metres long, and the experiments were surrounded by commercial crops of spring wheat.

In the variety trials in 2006 and 2007, 170kg/ha N was applied in the form of FYM over the whole trial area, prior to ploughing out the grass/clover leys and drilling the plots. In 2008 at Courtyard, the six varieties were established after ploughing out the grass/clover ley. No basal manure treatment was applied but CMP and sulphur applications were made post-emergence to the soil and foliage respectively. In 2008 and 2009, in the Variety x *Rhizobium* trials, the grass/clover swards were established with clover seed inoculate or not, and grown for two years. Prior to ploughing out in spring, applications of FYM were made to the designated areas. After ploughing and seed-bed cultivations, the varieties were drilled. The experimental design was a split plot with main plots (+ or - inoculation) split for fertility treatment (+ or – FYM compost), and varieties sown in strips at right-angles across the *Rhizobium*/compost treatments.

Disease and leaf chlorophyll assessment protocols

At intervals and different wheat growth stages (Zadok *et al*., 1974), visual assessments were made using standard protocols (Anon., 1976) of infection with foliar and ear diseases (mildew, yellow and brown rust, *Septoria tritici*). Chlorophyll contents of the upper leaves were assessed with a Konica-Minolta model SPAD-502 chlorophyll meter (Spectrum Technologies Inc., Plainfield, Illinois, USA). This measures the absorbance of leaves in the red/far-red wavelength regions of the light spectrum. Numerical SPAD values are calculated which are proportional to the chlorophyll contents of leaves and indicative of the nitrogen concentrations in the leaf blades. Ten measurements per plot were made on randomly selected flag leaves.

Harvest and grain sampling procedures
Crops were harvested with a plot combine harvester (CLAAS, Germany) with a 2.4m wide cutter bar, and fresh weights were determined immediately after harvesting. From each plot an area was harvested that was sufficient to provide samples large enough for the various quality and baking tests. Subsamples were taken to assess grain moisture content, by drying at 80°C using a forced-draught drying-oven (Genlab Ltd., Widnes, UK). Where necessary, the remainder of the samples were placed in sacks and dried using forced-draught ventilation.

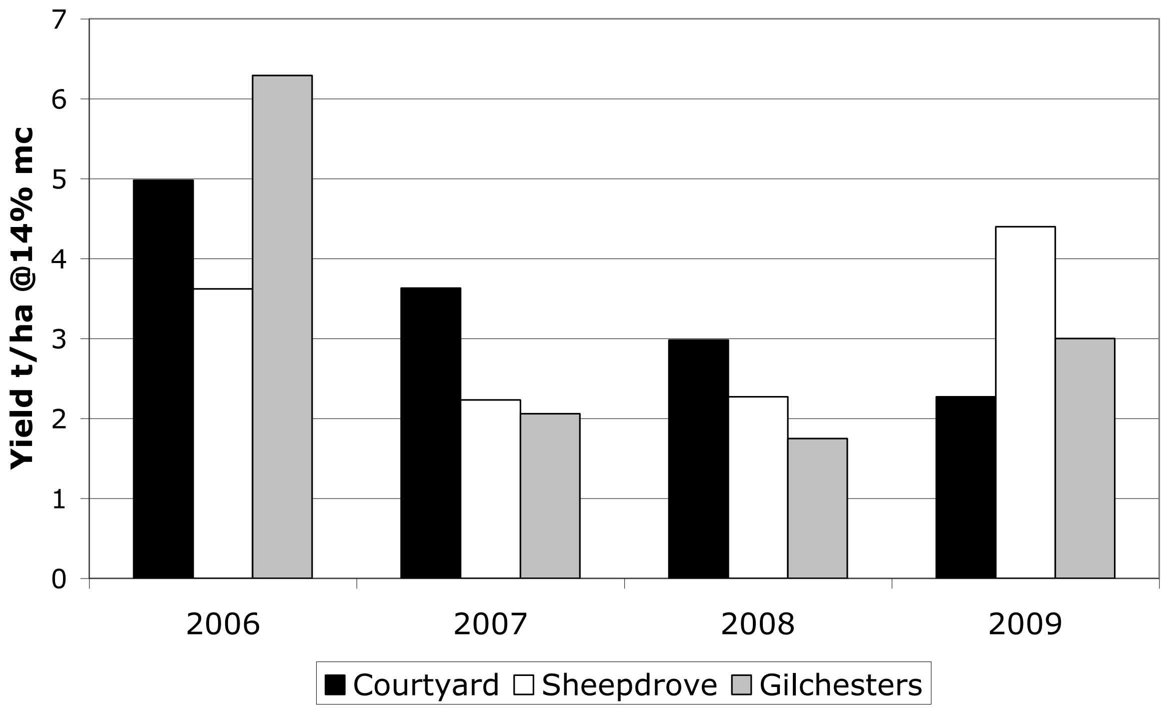
Data analysis
Data were analysed by one-way (variety trial 2006 and 2007), two and three-way (fertility management types and levels 2006 and 2007), two-way (sulphur x compost Courtyard 2008) and split-plot/split block ANOVA (variety, clover inoculation and compost amendment), comparing the effects and interactions between treatments. Individual means of crops grown at individual sites with different varieties and/or different fertility inputs were compared by Tukey's Honest Significant Difference Test (THSD). ANOVA and THSD test were performed using 'R' software (R; R Foundation for Statistical Computing, Vienna, Austria 2005).

3.2.7 Results of agronomy trials

The effects of site and season on crop performance
Figure 2 shows the effects of site and season on grain yield averaged over varieties included in the variety trial in each year from 2006 to 2009.

In general, within a season, the weather conditions at the three sites reflected the national situation and to some extent explain the differences between years in crop performance. In 2006, May was wet and warm, June was warmer than normal, and July exceptionally so; both these months were dry and brighter than normal. August was wet and potentially detrimental to yield, particularly when harvesting was delayed. In 2007, a very warm (with record temperatures and sunshine hours in April), dry spring was followed by unsettled, wet weather from May until August. June and July were extremely dull and wet: nationally rainfall exceeded 150% of average leading to high levels of disease, lodging and harvest delays in cereals although conditions improved in August and September. Consequently, grain quality was very variable and lower than in 2006: availability of milling wheat was severely restricted, resulting in high premiums for good quality samples (Defra, 2007 and 2008). As in 2007, weather conditions in 2008 and 2009 were also less favourable for growth of spring wheat, leading to disappointing yields. In 2008 the spring was wet, which delayed sowing. Average monthly temperatures were about normal, but July and August were wet (and August dull as a consequence) leading to delayed harvest and implications for grain quality. Over 5 and 6 September 2008, very localised, torrential rain fell in north-east England, close to Gilchesters, totalling 150mm rain. The 2009 season was notable for dry conditions in spring. Whilst this enabled early drilling, growth on the light soil at Courtyard was particularly adversely affected by water stress lasting throughout May and the crop never recovered. There was a brief heat-wave at the beginning of July; the remainder of July was very wet, but August and September were dry. This facilitated early harvest in good conditions but led to difficulties with subsequent cultivations and root-crop harvesting in many situations.

Figure 2. The effects of site (Courtyard, Sheepdrove and Gilchesters) and season (2006 to 2009) on grain yield (t/ha at 14% moisture content (mc)) averaged over six varieties.



Annual yields averaged over all treatments were 5.0, 2.6, 2.3 and 3.2t/ha in 2006, 2007, 2008 and 2009 respectively. Gilchesters produced the highest average yield of

6.29t/ha in 2006 (Figure 2) (with a maximum yield of 6.85t/ha for Paragon) reflecting favourable growing conditions in that season at that site. Furthermore, in 2006, Gilchesters produced the highest grain protein content of all the trials from 2006 to 2009 (with an average of 15.4% for Paragon in Experiment 2) as shown later in this report (see section 3.3.1). In both 2007 and 2008 summer was cooler, duller and wetter and particularly wet later in the season. This had negative effects on yield at Gilchesters (the northern site, late sowing/harvest) but earlier harvesting at Courtyard and Sheepdrove avoided the adverse conditions. As mentioned previously, in 2009, spring was very dry and followed by a short-lived heat wave in early July which decreased yield potential at Courtyard compared with the other two sites, despite a very wet July.

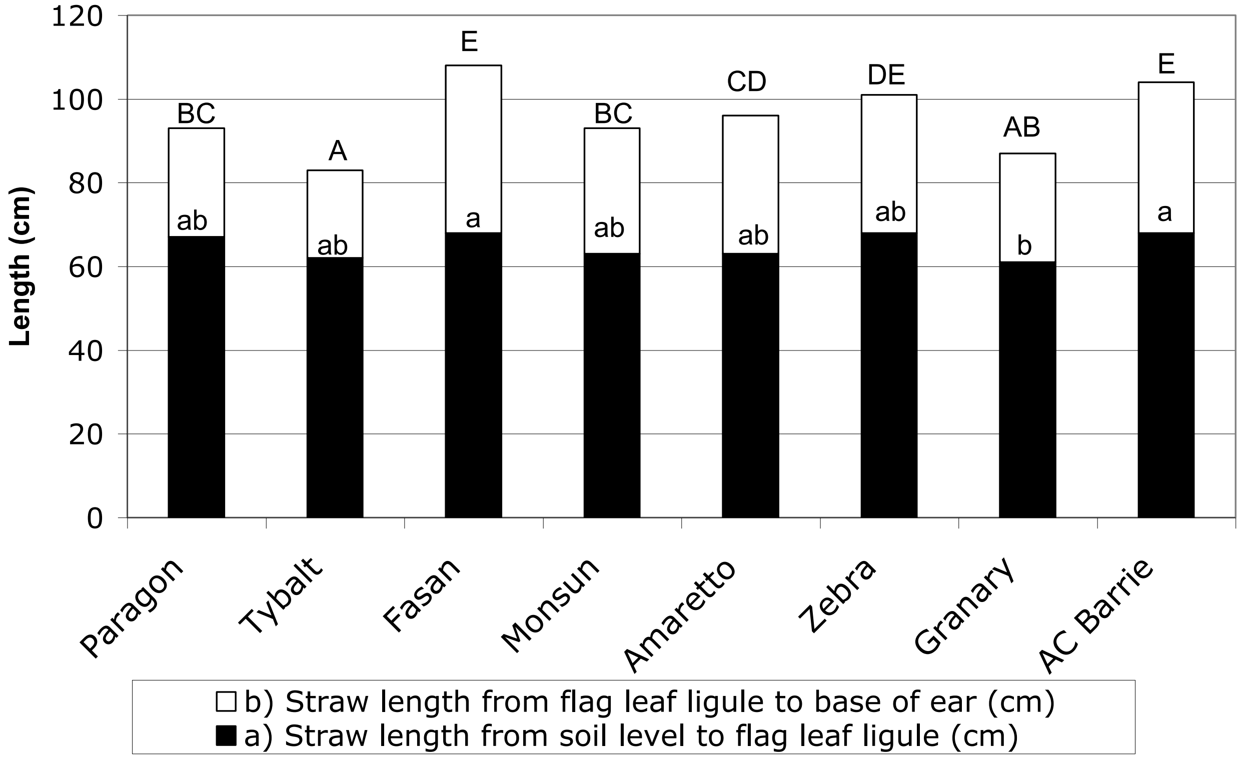
Crop performance at the individual sites reflected different soil type and local micro-climatic influences on agronomic factors such as sowing and harvest dates and biological factors such as crop growth, development of diseases and pests and rates of soil N mineralisation. Therefore, relative performance of treatments changed from site to site and from season to season. For example, drilling was always earliest, and harvesting usually early, at Courtyard and Sheepdrove. At Courtyard in 2006, yellow rust was more prevalent than at the other two sites and the combination of dry spring conditions coupled with the light textured soil-type at Courtyard decreased yields to a greater extent than at the other two sites.

The effects of variety on crop performance and yield

Six different varieties of spring wheat were grown at all three sites in 2006 and 2007 and eight in 2007. In 2006 and 2007 they were grown with a single fertility treatment but in 2008 and 2009 they were grown with a range of fertility input treatments.

In general in each year, percentage establishment was similar for all varieties grown at an individual site. However, very dry conditions at the Gilchesters' site in 2007, coupled with some damage from rooks, decreased plant and tiller populations compared with the other two sites. In 2008, although the stock of Tybalt seed was certified, germination was lower than expected and so percentage establishment was uniformly lower for Tybalt compared with the other varieties at all three sites. This resulted in a more open canopy leading to more vigorous weed growth and potentially greater competition (plots of Tybalt were easily identified in the trials because of weed infestation, but no quantitative assessments were made of weed populations, species composition or cover in any of the trials or treatments). It was assumed that in 2008, the combination of lower plant populations and more intense weed competition decreased yield of this variety relative to the other varieties: within a year, the overall average yield of Tybalt expressed as a percentage of the overall average annual yields for 2006, 2007, 2008 and 2009 was 114%, 140%, 81% and 106% respectively. (More detailed results showing the ranking order of varieties, their yields and the significance of differences between varieties at each site in each year are shown later in the report, in Figure 4 and Tables 9 and 10). Weed populations, mainly broadleaved species, were relatively low at both Courtyard and Sheepdrove in all four years. At Courtyard, this reflected a history of organic seed (certified) crop production and regular roguing. At Gilchesters, weed control was satisfactory in 2006 and 2007, but in both 2008 and 2009, there were infestations of wild oats. It was apparent at Gilchesters, the most northerly site, that establishment was better for commercial crops of organic winter wheat sown in October that were being grown adjacent to the spring wheat trials and that wild oats were much less evident. As expected, length of straw differed from site to site and season to season and varieties also differed. Fasan, AC Barrie and Zebra were taller than the other varieties. Whilst long-straw crops are potentially more prone to lodging than short ones, this problem is unlikely in organic crops because growth is usually less vigorous than in well-fertilised, conventional crops which almost invariably receive growth regulators to shorten the straw. Certainly, lodging did not occur in any of the trials or treatments. The distance between the flag leaf ligule and base of the ear also differed between varieties, which could have affected the potential for spread of fungal pathogens from flag leaf to ear, e.g. *Septoria tritici,* by rain splash. The risk of transfer would be expected to be lower the greater the distance. Whilst the heights of the ligules of the flag leaf were similar for all varieties, the distance between ligule and base of the ear were different. Figure 3 shows a typical example: for Fasan this distance was about 40cm compared with about 20cm for Tybalt. However, this did not seem to give any advantage in terms of disease resistance.

Figure 3. The effects of variety on length of straw (cm) from (a) soil level to the flag leaf ligule (b) flag leaf ligule to the base of the ear and total length of straw (a+b); Courtyard 2007. (Straw lengths (a) and (b) of varieties with the same small case or capital letter respectively were not significantly different (p<0.05) according to Tukey's HSD test)



Disease infection

Disease infections differed between sites, seasons and varieties. Several assessments were made in each season, but those made on the flag leaf GS 75 and ear are shown as an example in Table 8. Infection with mildew was invariably rare, except in 2007 when the susceptible variety AC Barrie was grown: flag leaf area infection was 17.5% at Courtyard, 51.3% at Sheepdrove and 41.3% at Gilchesters, resulting in very low yields at all sites of about 1t/ha, which was 50 to 75% lower than the other varieties. Although AC Barrie is a good milling and baking quality variety, fungicide treatments are essential to achieve a reasonable yield. In general, flag leaf infection with yellow rust was low at all sites in 2006, 2007 and 2009 and high in 2008. Zebra was consistently the variety most infected with yellow rust, even when disease pressure was relatively low, but in 2008, the flag leaf was almost killed off by the disease at GS75 at all three sites and the disease was frequently observed in the glumes of the ear. Yellow rust was mainly responsible for the low yields of this variety. Fasan was also infected with yellow rust at all sites in all seasons but other varieties were less infected. Flag and ear infection with *Septoria* was also most prevalent in 2008. Table 8 shows that the effects of variety on both *Septoria* and yellow rust were very highly significant ($p \leq 0.0001$) at all three sites and the results for percentage infection indicate the relative resistance of the varieties to these diseases. Paragon, Tybalt and Granary were the least infected. There was no relationship between the distance from the flag leaf to the ear and infection of the ear with *Septoria*. (Note: in Zebra, the apparently low level of *Septoria* infection of the flag leaf and much higher infection of the ear was because flag leaves were almost completely infected with yellow rust). Readings made with a Kinoca-Minolta SPAD-502 meter on the flag leaves gave SPAD values, which indicated chlorophyll content and hence nitrogen status and the effects of variety were very highly significant ($p \leq 0.0001$). These were lower for Zebra and Fasan than the other varieties (even though measurements avoided infected areas of the leaf) which would reflect premature senescence caused by disease.

Table 8. The effects of variety on a) infection of the flag leaf and the ear with *Septoria* (% leaf or ear area infected) and b) Yellow rust and SPAD units of the flag leaf at GS 75 at Courtyard (Court.), Sheepdrove (Sheep.) and Gilchesters (Gilch.) in 2008.([a]SPAD units: arbitrary units indicating chlorophyll content of the flag leaf; higher values indicate a higher chlorophyll content).

a)

Variety	Flag leaf *Septoria* (%)			Ear *Septoria* (%)		
	Court.	Sheep.	Gilch.	Court.	Sheep.	Gilch.
Paragon	31.3±2.21	13.13±1.76	60.63±5.18	5.6±0.55	3.93±0.57	14.69±2.10
Tybalt	33.8±2.72	11.25±1.41	45.31±3.64	6.6±0.90	2.06±0.39	8.81±0.83
Fasan	20.0±1.58	6.88±3.50	0	5.5±0.91	9.44±1.90	7.50±0.84
Amaretto	31.9±3.15	23.13±1.98	16.88±4.10	12.6±1.55	11.19±1.32	12.63±1.01
Zebra	0.0±0.0	1.88±1.88	0	51.9±3.19	75.94±4.36	83.13±2.23
Granary	30.6±2.32	25.00±2.89	48.44±4.69	9.19±1.75	8.19±4.80	8.12±1.18
ANOVA p-values	p≤0.0001	p≤0.0001	p≤0.0001	p≤0.0001	p≤0.0001	p≤0.0001

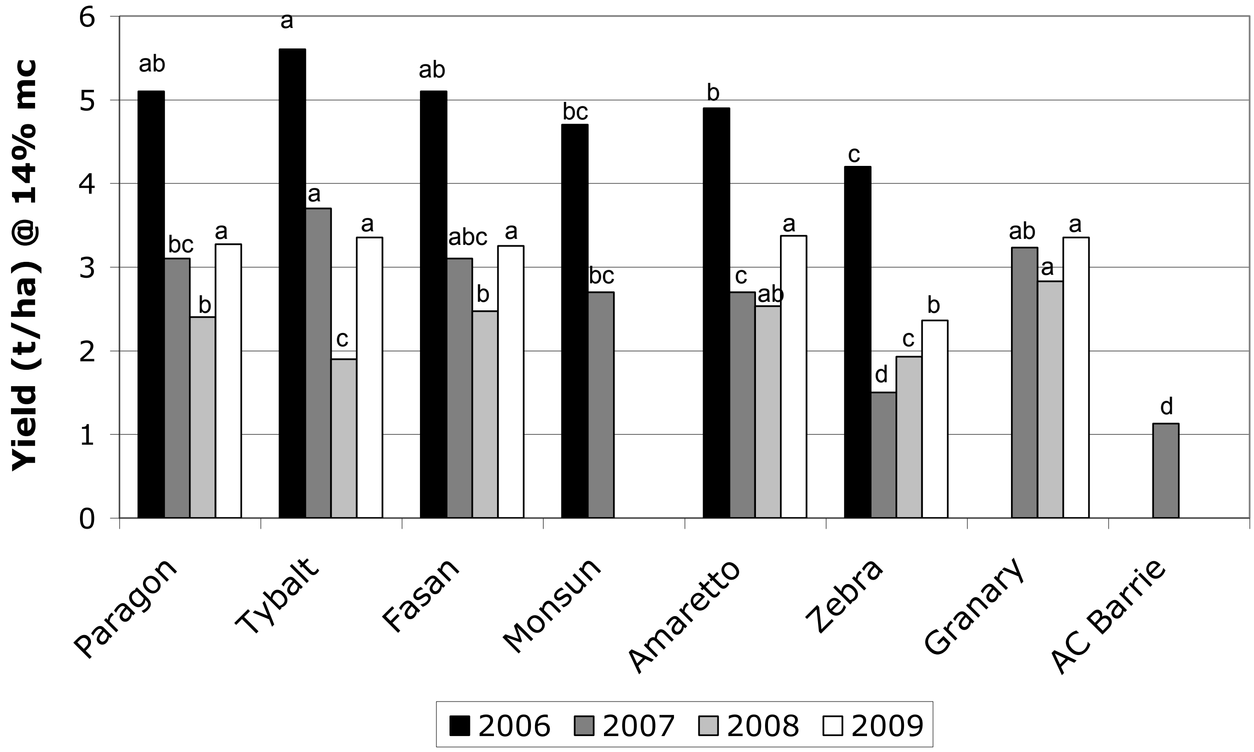
b)

Variety	Flag leaf Yellow rust (%)			Flag Leaf SPAD (units)		
	Court.	Sheep.	Gilch.	Court.	Sheep.	Gilch.
Paragon	0	2.00±1.35	0.31±0.31	37.3±1.97	36.6±0.97	43.2±1.02
Tybalt	0	2.88±0.77	1.88±0.63	40.4±1.64	41.8±0.88	41.1±0.93
Fasan	46.6±4.49	75.06±6.97	95.56±0.75	31.1±1.13	26.1±1.60	34.1±1.24
Amaretto	4.3±0.85	14.50±4.23	69.06±5.67	39.3±1.53	33.5±1.87	36.5±1.41
Zebra	100.0±0.00	94.69±4.99	99.69±0.31	23.6±1.74	17.12±2.17	27.1±1.23
Granary	0.1±0.06	10.13±6.04	2.56±0.78	37.4±1.85	33.9±1.62	37.0±1.43
Anova p-values	p≤0.0001	p≤0.0001	p≤0.0001	p≤0.0001	p≤0.0001	p≤0.0001

Variety yields

Figure 4 shows the effect of variety on grain yield, averaged over the sites in all four years and averaged over the different fertility treatments.

Figure 4. The effect of variety and season on grain yield (t/ha at 14% moisture content (mc)) averaged over sites. (Within a year, yields of varieties with the same letter were not significantly different (p<0.05) according to Tukey's HSD test)



Generally, the ranking order of different varieties' yields was similar from season to season and site to site and over the various fertility treatments. Occasionally, there were interactions between site and variety, indicating that the relative performance of varieties differed between sites. This is a frequent and well-established observation and differences in regional yields are identified in the NIAB pocket guide to varieties of cereals, which indicates suitability of varieties for different regions (NIAB, 2009). However, the best varieties at the top of the list in one region are also the best in another although the ranking order of the individual varieties may change slightly. For example, in the NIAB spring wheat regional yields 2005 – 2009, Tybalt is the second highest in both the East and South, Granary is third in the East but fourth in the south, and Paragon is sixth in both regions (NIAB, 2009).

Several varieties gave similar yields, e.g. Paragon, Tybalt (low yield in 2008 in Tybalt at all three sites was a result of poor seed lot leading to low plant population and weed competition), Granary, followed by Fasan, Monsun and Amaretto. Zebra and AC Barrie invariably yielded least because of yellow rust and mildew infection respectively, causing premature senescence. Yield and disease resistance of Paragon, Tybalt and Granary were consistent with figures given in the HGCA recommended lists (HGCA, 2010). The low yield of Zebra from 2006 to 2009 was in complete contrast to its performance at Gilchesters in 2005 when its yield averaged 8.0 t/ha compared with 5.7 t/ha for Paragon (Wilkinson *et al*., 2007).

Table 9 shows the ranking order of yields of varieties at each site and in each season and Table 10 shows the yields.

Table 9. The ranking order of yield of spring wheat varieties grown at Courtyard (Court.), Sheepdrove (Sheep.) and Gilchesters (Gilch.) 2006 – 2009

Rank Order	2006			2007		
	Court.	Sheep.	Gilch.	Court.	Sheep.	Gilch.
1	Tybalt	Tybalt	Paragon	Tybalt	Tybalt	Paragon
2	Fasan	Amaretto	Amaretto	Granary/Fasan	Granary/Paragon	Fasan
3	Paragon/ Monsun	Paragon	Fasan/Tybalt	-	-	Granary
4	-	Fasan	-	Monsun	Amaretto	Tybalt
5	Zebra	Monsun	Monsun	Paragon	Fasan	Monsun
6	Amaretto	Zebra	Zebra	Amaretto	Monsun	Amaretto
7	-	-	-	Zebra	Zebra	AC Barrie
8	-	-	-	AC Barrie	AC Barrie	Zebra
	2008			2009		
	Court.	Sheep.	Gilch.	Court.	Sheep.	Gilch.
1	Fasan	Granary	Granary	Fasan	Tybalt/Granary	Fasan
2	Granary	Amaretto	Amaretto	Amaretto	-	Paragon
3	Amaretto/ Paragon	Zebra/Paragon	Fasan	Tybalt	Amaretto	Granary/ Amaretto
4	-	-	Paragon	Granary	Paragon	-
5	Zebra	Tybalt	Tybalt	Paragon	Fasan	Tybalt
6	Tybalt	Fasan	Zebra	Zebra	Zebra	Zebra

Table 10. The yields (t/ha) of spring wheat varieties grown at Courtyard (Court.), Sheepdrove (Sheep.) and Gilchesters (Gilch.) 2006 – 2009 (Within a column, means with the same letter are not significantly different (p<0.05) according to Tukey's HSD test)

	2006			2007		
Variety	Court.	Sheep.	Gilch.	Court.	Sheep.	Gilch.
Paragon	4.8±0.82b	3.6±0.12b	6.9±0.30a	3.7±0.25bc	2.9±0.21bc	2.7±0.57c
Tybalt	6.1±0.62a	4.3±0.29a	6.3±0.81a	5.2±0.22a	3.4±0.33b	2.4±0.30c
Fasan	5.4±0.51ab	3.5±0.26bc	6.3±0.72a	4.4±0.26ab	2.4±0.14c	2.6±0.26c
Monsun	4.8±0.21b	3.4±0.22c	6.1±0.82a	3.9±0.24b	2.1±0.06c	2.2±0.38cd
Amaretto	4.2±0.50b	3.9±0.10ab	6.8±0.89a	3.5±0.18bc	2.5±0.21bc	2.0±0.33cd
Zebra	4.7±0.57b	2.4±0.12d	5.5±0.47a	2.8±0.24c	0.9±0.09d	0.9±0.07d
Granary	x	x	x	4.4±0.19ab	2.9±0.26bc	2.5±0.26c
AC Barrie	x	x	x	1.3±0.25d	0.8±0.06d	1.2±0.09cd
ANOVA p-values	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

	2008			2009		
Variety	Court.	Sheep.	Gilch.	Court.	Sheep.	Gilch.
Paragon	3.1±0.16ab	2.2±0.14b	1.9±0.15a	2.2±0.12b	4.6±0.18a	3.0±0.32
Tybalt	2.2±0.16c	2.1±0.14b	1.4±0.11b	2.4±0.09ab	4.9±0.15a	2.7±0.39
Fasan	3.5±0.18a	1.9±0.15b	2.0±0.14a	2.6±0.09a	4.1±0.15b	3.1±0.28
Monsun	x	x	x	x	x	x
Amaretto	3.1±0.09ab	2.4±0.12ab	2.1±0.15a	2.5±0.09ab	4.8±0.13a	2.9±0.26
Zebra	2.6±0.90bc	2.2±0.23ab	1.0±0.06c	1.6±0.08c	3.2±0.13c	2.3±0.22
Granary	3.4±0.19a	2.9±0.08a	2.2±0.15a	2.3±0.13ab	4.9±0.19a	2.9±0.28
AC Barrie	x	x	x	x	x	x
ANOVA p-values	<0.0001	0.003	<0.0001	<0.0001	<0.0001	0.188

The effects of fertility management on crop performance and yield

Background

With several variables involved: site and season, varieties and types and levels of fertility inputs (and confounding effects of different sowing dates and harvest dates, and different levels of weed control etc.), responses to fertility treatments varied. Consequently, it is very difficult to establish general, unifying principles from the results.

In all years, at all sites according to the fundamental principle of building fertility in organic farming systems, spring wheat crops followed 2 to 3 year grass/clover leys (and at Courtyard, these occasionally had supported outdoor pigs), ploughed out in spring. Moreover, the 3 sites had a history of long term organic management. This results in high SNS (Soil Nitrogen Supply) index of ~3 to 5 in the first year after ploughing out (or ~81-100 to 161 – 240kg N/ha), according to Defra (2010) and high residual fertility, which may influence the effectiveness of organic fertility inputs, e.g. manures and composts applied prior to ploughing out the leys.

Supplementary organic manure inputs were made with materials permitted under organic farming standards: green waste compost, FYM (cattle) compost, poultry manure compost (note: applied as CMP for practical reasons, i.e. availability, uniformity and ease of application). Each manure provides different concentrations of N and amounts of readily available N, potentially available for rapid crop uptake: e.g. typically, poultry manure ~16 – 30 kg/t (30-45% readily available) vs. FYM (cattle) ~6kg/t (20-25% readily available) – poultry manure having more leaching potential and volatilisation (Defra, 2010). Organic N in manures is much less available and becomes potentially available as a result of mineralisation over months and years. According to organic standards, N input from organic manures is limited to 170 kg/ha over the farm with a maximum of 250 kg/ha on any one area.

The build up of fertility during the grass/clover ley phase may be affected by the nitrogen-fixing activity of clover nodule bacteria and the subsequent retention of fixed nitrogen within the rooting zone: applying a high C:N compost prior to ploughing out of the grass clover ley should limit the amount of N potentially lost from the system post-ploughing. The first field trial investigating effects of rhizobial inoculation of fertility-building clover crops on the yield and protein content of four varieties of spring wheat (varieties Paragon, Monsun, Fasan and Zebra) grown in an organic, stockless system commenced at Gilchesters in 2003 (Wilkinson et al., 2006; Wilkinson et al., 2007). The clover crop was established (with and without inoculant treatment) two years prior to ploughing out for spring wheat sown in 2005 and green waste compost had been applied to the clover sward before ploughing. Spring wheat tested in 2005 grown on the trial plots given the inoculation treatments produced an increased yield and protein content compared to untreated plots. A similar strategy was tested in these trials using a bigger range of spring wheat varieties in 2008 and 2009.

Results

a) Effects of type and level of fertility inputs 2006 and 2007

In 2006 and 2007, yield of Paragon did not invariably respond to the applied fertility inputs (type or level). This was probably because fertility previously built up over several years of 'organic' management and also the pre-crop grass/clover ley and the availability of N available from all sources (residual + supplementary from applied manures) varied. The latter is affected by factors such as soil temperature and water supply (N mineralisation from organic to 'inorganic' forms is slower when conditions are cool and/or dry, whilst soluble, inorganic N may be leached in wet conditions), ability of the crop to take up N, and weed competition (although competition was generally low). In 2006, which was generally a very much drier season than 2007, there were no significant yield differences between any of the different types and levels of fertility inputs. On the other hand, in 2007 there were significant differences at Sheepdrove but not at Courtyard or Gilchesters (Table 11). At Sheepdrove, the zero control treatment which received no supplementary manure or compost yielded least (1.5 t/ha) whilst other treatments yielded significantly more, approximately 3t/ha with the exception of treatments which included CMP at either 125 or 250kg/ha N. The yield of these treatments was about 2t/ha which was significantly lower than all FYM and GWC treatments, but not significantly different from the zero control. The reasons for the lower yields with CMP are difficult to explain as there was no lodging and no differences in weed competition or disease infection between treatments. Phytotoxicity of CMP might be a possible explanation, but is unlikely because the yield of the treatment combination of 125kg/ha N FYM + 125kg/ha N CMP was 3.1t/ha and amongst the highest yields and significantly higher than were CMP were used alone.

b) Effects of chicken manure pellets (CMP) and foliar sulphur applications on spring wheat varieties at Courtyard 2008

The effects of variety, averaged over fertility input and sulphur application treatments in 2008 at Courtyard, were shown previously in Table 10 and there were highly significant differences between variety yields. Tybalt gave the lowest yield which was considered to be mainly due to the low plant populations caused by a seed lot with low germination % as mentioned previously. No other variety was affected.

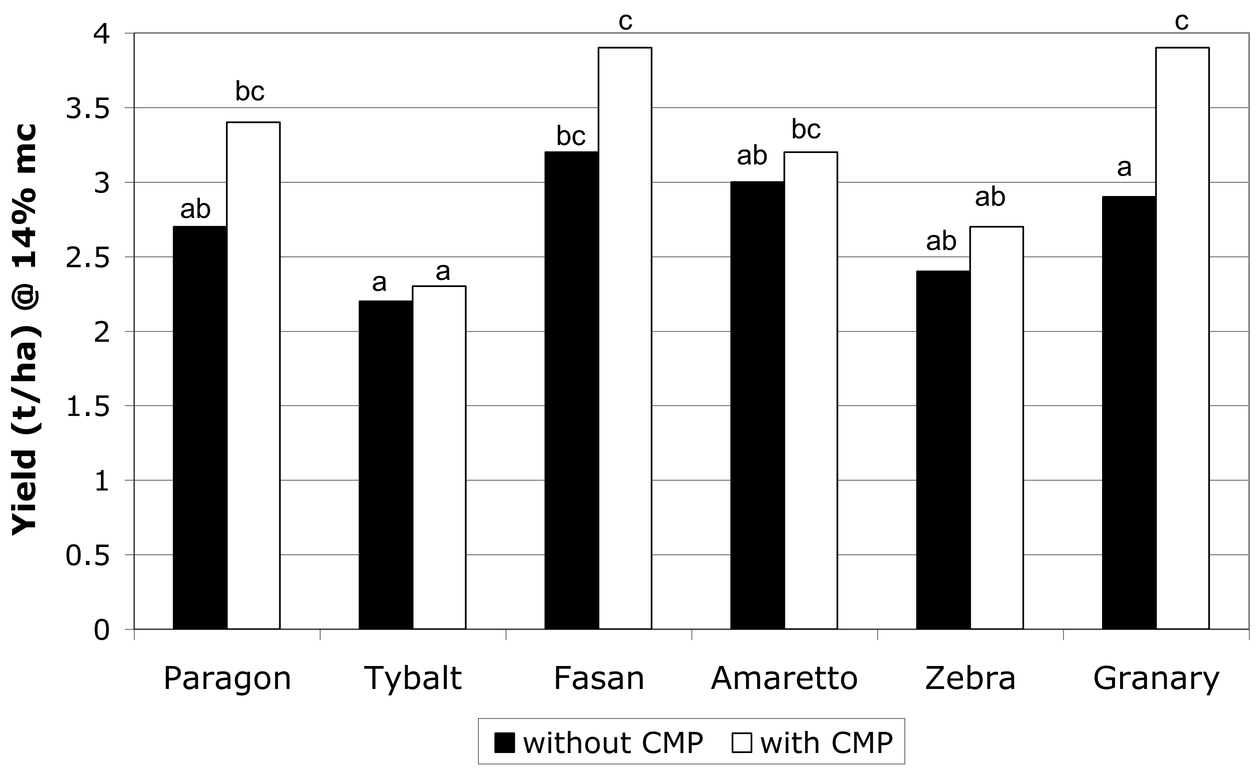
Foliar applications of sulphur to potentially further improve grain (protein) quality had no significant effects on yield or levels of disease in any of the varieties (Paragon, Tybalt, Fasan, Amaretto, Zebra, Granary). There were no significant interactions between any of the treatments on grain yield or on any other of the characteristics that were assessed.

Where CMP were applied, the length of straw increased by about 6cm or 10% on average, but there were no effects on the distance from the flag leaf to the ear. SPAD readings of the flag leaf were also increased by CMP from about 30 to 40 SPAD units or 25%, which indicated higher chlorophyll content and hence that the N status of the CMP treated crops was higher than non-treated. Averaged over the varieties, there was a very highly significant ($p \leq 0.0001$) effect of compost application (in the form of CMP at 170kg/ha N).: Although the variety x compost interaction was not statistically significant, the magnitude of the response to CMP differed between varieties – it ranged from a non-significant difference of +0.1t/ha for Tybalt (whose performance probably suffered from low plant populations) to a significant ($p \leq 0.05$) difference of 1t/ha for Granary (Figure 5).

Table 11. The effects of fertility input type (farmyard manure compost = FYM; chicken manure pellets = CMP; green waste compost = GWC and no supplementary fertility input = CTRL) and nitrogen rate (kg N/ha) on grain yield (t/ha at 14% moisture content) in 2006 and 2007 (For yields at Sheepdrove in 2007, means with the same letter are not significantly different ($p<0.05$) according to Tukey's HSD test; there were no significant differences between means of yields within all sites in 2006 and Courtyard and Gilchesters in 2007))

		2006			2007		
		Court.	Sheep.	Gilch.	Court.	Sheep.	Gilch.
Type	Rate						
FYM	250	4.1±0.7	3.7±0.2	5.9±0.7	3.2±0.0	3.0±0.2 abc	2.6±0.4
FYM/CMP	250	4.5±0.4	3.7±0.2	5.0±0.4	2.9±0.5	3.1±0.2 a	2.3±0.5
CMP	250	4.5±0.6	3.5±0.2	5.7±0.4	2.2±0.2	2.1±0.3 bcd	2.7±0.5
GWC	250	4.5±0.3	3.7±0.4	5.1±0.6	3.2±0.2	3.2±0.1 a	1.9±0.9
FYM	125	3.8±0.6	3.8±0.3	5.4±0.5	3.3±0.3	3.0±0.3 abc	3.0±0.8
FYM/CMP	125	3.9±0.9	3.8±0.4	5.6±0.5	3.1±0.2	2.6±0.2 abc	1.9±0.2
CP	125	4.1±0.9	3.6±0.3	5.9±0.8	3.2±0.1	2.0±0.2 cd	2.9±0.2
GWC	125	4.3±0.2	3.7±0.3	5.7±0.4	3.3±0.2	3.0±0.1 abc	3.1±0.4
CTRL	0	4.2±0.3	3.7±0.2	5.7±0.6	3.1±0.3	1.5±0.2 d	1.9±0.1
ANOVA -p values		0.1543	0.8308	0.1534	0.1010	0.0001	0.1980
Type		0.1907	0.4466	0.2058	0.0961	0.0001	0.2458
Rate		0.0106	0.1844	0.2537	0.0527	0.1736	0.3939
Type*Rate		0.7382	0.9335	0.0720	0.2781	0.5163	0.2815

Figure 5. The effects of variety and chicken manure pellets (CMP) at 170kg/ha N on grain yield (t/ha ay 14% moisture content (mc)) at Courtyard 2008. (Means with the same letter are not significantly different (p<0.05) according to Tukey's HSD test)



c) Effects of pre-crop *Rhizobia* inoculation and fertility inputs on spring wheat varieties 2008 and 2009

In 2008 (Gilchesters and Sheepdrove) and 2009 (Gilchesters, Sheepdrove and Courtyard), the 6 varieties were grown following grass/clover leys +/- *Rhizobia* inoculation and +/- FYM cattle manure compost at 170kg/ha N. In 2008 there were no significant differences in yield between any of the *Rhizobia* or fertility treatments and no interactions between inoculation and FYM compost input. Furthermore, there were no significant interactions between either or both of these treatments with variety (Table 12). However, there was a significant ($p \leq 0.001$) site x variety interaction: Tybalt, Granary and Zebra performed relatively less well at Gilchesters compared with Sheepdrove.

In 2009, it was difficult to draw any firm conclusions from the trial at Gilchesters because whilst there were yield differences between treatments, there was no discernible pattern with regard to treatment effects. Yields were significantly (p≤0.0001) higher at Sheepdrove than Courtyard and about twice as high (~4t/ha compared with ~2t/ha) reflecting differences in growing conditions between the sites. At both Courtyard and Sheepdrove, whilst rhizobial inoculation had no significant effect on yield, application of FYM compost significantly (p≤0.0001) increased yield on average by the order of 0.5t/ha and 0.3t/ha at the sites respectively (Table 2.10). There was no significant interaction between site and compost application, but the greater response at Courtyard may have been a reflection of lower soil fertility compared with Sheepdrove in 2009. There was a significant (p≤0.0001) interaction between site and variety with Fasan performing relatively better at Courtyard than at Sheepdrove (Figure 6). Fertility management treatments had no marked or significant effects on levels of disease infection irrespective of variety (Data not shown).

Figure 6. The effect of variety and FYM compost at 170kg/ha N (C- = without compost; C+ = with compost) on grain yield (t/ha at 14% moisture content (mc)) averaged over *Rhizobium* inoculation treatments at Courtyard and Sheepdrove 2009. (At Courtyard, mean y

(At Courtyard, for individual varieties, means with the same letter are not significantly different (p<0.05) according to Tukey's HSD test. At Sheepdrove, for individual varieties there were no significant differences between compost treatments)

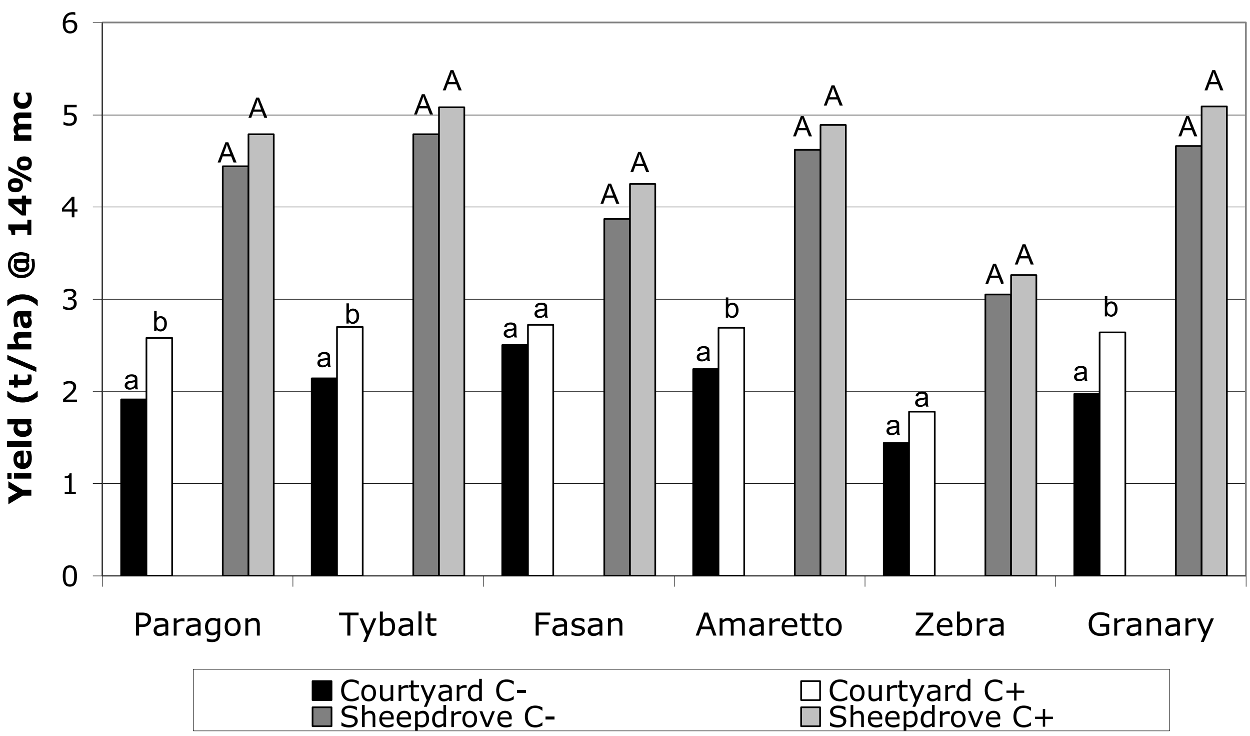


Table 12. The effect of pre-crop clover inoculation with *Rhizobia* and FYM compost application and variety on grain yield (t/ha at 14% moisture content) at Courtyard (Court.), Sheepdrove (Sheep.) and Gilchesters (Gilch.), 2008 and 2009 (Within a column, means with the same letter are not significantly different (p<0.05) according to Tukey's HSD test)

Treatment	2008	2008		2009	2009	2009
	Sheep.	Gilch.		Court.	Sheep.	Gilch.
Paragon	2.18±0.137b	1.86±0.146a		2.24±0.117b	4.61±0.181a	3.03±0.315
Tybalt	2.06±0.141b	1.39±0.109b		2.42±0.094ab	4.94±0.151a	2.68±0.386
Fasan	1.93±0.146b	1.96±0.138a		2.61±0.088a	4.06±0.153b	3.11±0.279
Amaretto	2.39±0.116ab	2.09±0.145a		2.47±0.091a	4.75±0.129a	2.88±0.256
Zebra	2.19±0.226b	1.01±0.064c		1.61±0.078c	3.16±0.128c	2.30±0.216
Granary	2.86±0.083a	2.20±0.145a		2.31±0.129ab	4.88±0.185a	2.88±0.276
Anova - p value	0.003	<0.0001		<0.0001	<0.0001	0.188
-Rhizobia	2.25±0.098	1.77±0.093		2.32±0.074	4.33±0.125	2.90±0.182
+Rhizobia	2.29±0.091	1.74±0.096		2.23±0.072	4.47±0.128	2.72±0.157
Anova - p value	0.815	0.658		0.165	0.125	0.270
- Compost	2.27±0.095	1.73±0.096		2.03±0.63	4.23±0.126	2.94±0.152
+Compost	2.27±0.094	1.77±0.093		2.52±0.66	4.56±0.123	2.68±0.183
ANOVA – p value	0.950	0.617		<0.0001	<0.0001	0.136

3.2.8 Field trials discussion

Variety choice

The results of the trials in this programme confirm that variety choice is the primary consideration for growing spring wheat in organic systems for bread-making as it is in conventional systems. The variety or varieties to be grown should be chosen on the basis of their known characteristics, including yield, quality, agronomic characteristics and disease resistance as described in publications such as the HGCA Recommended List for cereals and oilseeds (HGCA, 2010) and their suitability to meet the requirements of the millers and bakers. Currently available varieties such as the nabim Group 1 variety Paragon continue to meet these requirements in organic as well as conventional systems of production, although yield is lower than most other varieties such as Tybalt and Granary (nabim Group 2). Moreover, such varieties maintain their position over a wide range of weather conditions, geographic locations and fertility management strategies.

Organic manure inputs (type and rate)

Just as in conventional systems, significant increases in yield in response to fertiliser inputs are not guaranteed. However, in the trials that assessed the effects of type and level of fertility inputs that may be used in organic systems of production, yields of spring wheat were improved in some cases. Site specific yield increases of the order of 0.5 to 1.0t/ha were obtained by increasing N rate, using FYM based compost and chicken manure pellets. At Sheepdrove in 2007 a yield response of ~1.0t/ha to 125 and 250kg/ha N was recorded (except where CMP had been applied); it was ~ 0.5 – 1t/ha to CMP applied at a rate of 170kg/ha N at Courtyard in 2008, and ~ 0.5t/ha to FYM compost at 170kg/ha N at both Courtyard and Sheepdrove in 2009. Whether a response is recorded, and the magnitude of the response, will depend on several factors: the inherent or residual fertility of the soil to which the fertility input is applied; the amount of N present in the soil which is readily available (NO_3^-, NH_4^+) for crop uptake in the current season; and the potential for mineralisation of soil N, which will depend upon soil microbiological activity and be influenced by soil temperature and soil water supply. Indeed, the responsiveness to applied fertility inputs is likely to be influenced by the general growing conditions and expected to be better when they promote vigorous growth (although a counter-argument is that when growth is suppressed by adverse conditions, supplementary fertiliser should stimulate it). In three of the four years of the experimental programme – 2007, 2008 and 2009 – overall, yields were generally low because conditions were less than optimum: this may have limited the effectiveness of the fertility inputs in increasing yield.

The fundamental principle of fertility management in organic systems is to build soil fertility within the rotation over the long term. This would include, for example, grass/clover leys, forage and grain legumes and manure/compost inputs, preferably generated within the system rather than 'brought-in'. This would maintain a closed nutrient cycling system as far as possible and at strategic points, support more exploitative crops in the rotation such as wheat (HGCA, 2008). Therefore, the cumulative effects of the fertility management strategies are productivity drivers: crops later in the rotation should benefit from current fertility inputs. For example, a spring wheat crop immediately following a grass clover ley may not respond significantly to current inputs of manures or composts at rates of 170kg/ha N (or up to a maximum of 250kg/ha N on a single field) because of inherent fertility built up previously over the rotation, but cumulative effects should benefit later crops in the rotation as organic N becomes mineralised. This represents a long term strategy aimed at the rotation as a whole, rather than a short-term one focussed specifically on an individual cash crop e.g. milling wheat within a rotation, which often appears only once every 5 or more years.

Pre-crop clover treatment and manure input

Rhizobium inoculation of clover in the ley preceding spring wheat gave no significant yield benefits in either 2008 or 2009 at any of the sites. However, there was a significant ($p \leq 0.0001$) effect of FYM compost at Courtyard and Sheepdrove with increases of ~0.5t/ha and ~0.3t/ha respectively. There was no interaction between *Rhizobium* inoculation and FYM compost application. This was in contrast to the results of the trials at Gilchesters in 2005. *Rhizobium* inoculation of red clover seed significantly ($p<0.05$) increased establishment of clover and the number and size of root nodules on clover plants: yields of the subsequent wheat crops were increased.. There were significant ($p<0.05$) interactions between fertility management practices (*Rhizobium* inoculation x green waste compost) in spring wheat. For the spring wheat variety Zebra only, there was a positive interaction. Without *Rhizobium* inoculation, yield was unaffected by compost amendment: 7.69t/ha without compost and 7.63t/ha with compost. Where *Rhizobium* inoculation was combined with compost amendment, yields were 7.95t/ha without compost and 8.72t/ha with compost.

Economic analysis: benefits of manure/compost applications

The economic benefit of the manure or compost application will depend on cost per kg of N x quantity applied, relative to the improvements in output, i.e. grain yield, and/or quality achieved and depending on the responsiveness of the site: this is of particular significance where brought-in manures are involved.

The full economic benefits may extend beyond the current milling wheat crop further into the rotation, although they may be difficult to quantify.

In the gross margin analysis of organic crop production enterprises, where farm-sourced manures or composts are applied on a rotational basis, a standard cost is allocated to the fertility input to cover manure, and brought-in fertiliser and phosphate and potassium amendments (for example £50/ha, but some may be allocated to other costs, Lampkin *et al.,* 2008). Where manure or compost is brought in and may be costed as £/t or p/kg N, a partial budget is an appropriate economic analysis. Partial budgeting is a technique that can be used to evaluate the change in an agronomic practice, e.g. change of manure or compost input. A partial budget is shown in Table 13. The example is based on a situation where a brought-in purchased fertility input is used instead of, or as a supplement to, a farm-sourced input. Yield and quality responses to applied fertility inputs presented are of the magnitude recorded in the trials, i.e. 0.5 and 1.0t/ha and 1% protein. At 70p/kg N, a yield increase of 0.5t/ha or 1% protein is insufficient to cover the cost of the 'novel' fertiliser (-£5 and -£70/ha respectively) but a 1t/ha yield improvement gives a margin of £110 over the cost of fertiliser N. At 50p/kg N, a 0.5t/ha yield increase increases output over cost by £30/ha and 1.0t/ha by £145/ha. However, a 1% protein content increase still does not cover the cost of fertiliser. Break-even costs for N for +0.5t/ha, +1.0t/ha and +1% protein would be 67p/kg, 135p/kg and 29p/kg N. Therefore, fertiliser bought more cheaply would give a positive margin. There may be other benefits from the 'novel' fertiliser. For example, if the N concentration is higher than the traditional fertiliser, application costs would be less because a lower rate of the 'novel' fertiliser would need to be applied. There would also be residual effects as more of the N would become available by mineralisation over time. This is difficult to estimate, although an attempt has been made in Table 13.

Table 13. Partial budget for a change in fertility input application prior to spring wheat production from the standard to a 'novel' input

LOSSES (£)	GAINS (£)
Income lost: £0	**Extra income:** (1) +0.5t/ha grain @ £230/t = £115 (2) +1.0t/ha grain @ £230/t = £230 (3) + 1% protein/t @ £10/t = £50
Extra costs: 170kg/ha N as 'novel' manure @ (1) 70p/kg N = £120	**Costs saved:** Cost of substituted manure = £0
Net gain (if any): (1) -£5 (2) +£110 (3) -£70 (assuming a yield of 5t/ha)	**Net loss (if any):** £0
Non-quantifiable losses: Negative effects of 'novel' manure e.g. contaminants/toxicity (not expected) Possible physical damage if top-dressed	**Non-quantifiable gains:** Residual fertility for succeeding crops in the rotation (Estimate: assuming N off take in a 5 t/ha spring wheat crop = ~ 100kg/ha 170kg/ha N applied – 100kg/ha off take = 70kg/ha N Value = 70kg/ha N @ 70p/kg = £49/ha)

Assumptions: 5t/ha spring wheat crop; Organic milling wheat @ £230/t and £10 premium for +1% increase in protein (Nigel Gossett, Norton Organic Grain Ltd. Personal communication).

Cost of N taken as 70p/kg, based on current, conventional fertiliser ammonium nitrate price (June 2010). For a brought-in FYM or compost organic fertiliser with an analysis of 2% N w/w costing £10/t, the N cost would be 50p/kg.

3.3 Evaluation of field trial samples

Samples of wheat from the field trials were evaluated for suitability for breadmaking using a series of tests carried out at Campden BRI. In each year of the trials samples from each plot in each trial at all sites were analysed for protein content determined by a near infrared (NIR) method. In addition the proportion of component proteins of different molecular weight was determined using a size exclusion high performance liquid chromatography (SE-HPLC) technique to give a measure of protein quality. Samples from each plot of one site were selected for assessment of baking performance and were milled and baked into white loaves at Campden BRI. In 2006 duplicate samples from the same trial site were also milled and baked into wholemeal loaves by W. H Marriage at their Chelmsford mill.

Baking tests produced good results in 2006; however, in 2007 although protein content was at a reasonable level (mean 13.43% protein), baking performance was poor as Hagberg falling numbers were low (range between 141-266 seconds) due to the higher than average rainfall. In the 2008 and 2009 seasons protein levels were also lower than optimum and baking performance was not good.

3.3.1 Methods: wheat analysis

Protein content of wheat samples was determined by NIR reflectance. This is based on the absorption of NIR energy at specific wavelengths, by peptide linkages between amino acids of protein molecules, by OH groups in starch molecules and by OH bonds in water molecules. Measurements at reference wavelengths and mathematical manipulation of the data were used for background correction.

Wheat samples were ground using a Falling Number KT 3100 mill and tested using a Perten 8611 NIR instrument according to FTWG method 14 (Campden BRI, 2010). Flour protein content (N x 5.7) was corrected to a dry matter basis. The NIR calibrations used were based on Dumas protein values (FTWG method 19, Campden BRI, 2010).

SE-HPLC protein analysis

The proportion of the large glutenin polymers is an important determinant of wheat end use quality as it is related to functional properties such as dough elasticity and strength (Singh et al., 1990). Size-exclusion (SE)-HPLC was used to determine changes in the glutenin polymer size distribution in the harvest grain samples. This method uses sonication in SDS solution to solubilise all glutenin polymeric proteins and resolve them into five major fractions (F1-F5) according to their molecular size. F1 corresponds mainly to high molecular mass polymers, enriched in HMW subunits of glutenin; F2 corresponds mainly to low mass glutenin polymers, F3 and F4 mainly to the various classes of monomeric gliadin proteins, and F5 mainly to non-gluten proteins (albumins and globulins). This form of protein quality assessment was made following the Profilblé® method that was developed in France jointly by ARVALIS and INRA (Dachkevitch and Autran, 1989; Morel *et al*., 2000). The protocol was used as described by Millar (2003). Flour (160mg) is combined with 20ml of 1% SDS in phosphate buffer to extract soluble wheat proteins. Following controlled sonication (Misonix Microson XL2000) and centrifugation, the supernatant is resolved by SE-HPLC analysis. This was performed using a Jasco HPLC system with a TSKgel G4000SW analytical column in conjunction with a TSKgel SW guard column. The chromatograms were integrated using methods provided by ARVALIS. All values are quoted as a percentage of the total response of the column, i.e. as a percentage of total protein. The response for each sample was normalised using the results from a control flour. Both daily and column specific checks were undertaken to ensure the linearity of response**.**

Hagberg falling number

Alpha-amylase activity in wheat samples was determined by the Hagberg Falling Number test which is based on the rapid gelatinisation of an aqueous suspension of flour and its subsequent liquefaction by endogenous *alpha*-amylase. Flour Falling Number was measured according to FTWG method 06 (Campden BRI, 2010) using a Perten 1700 Falling Number instrument. The wheat sample was ground to a fine wholemeal, and mixed with the required quantity of water in a viscometer tube to produce a uniform suspension. Falling Number was recorded as the time in seconds from immersion of the viscometer tube in the boiling water bath until the stirrer dropped sufficiently to stop the timer.

3.3.2 Methods: milling and baking

On receipt, wheat samples were checked for moisture content using a Sinar moisture meter, then cleaned to remove extraneous material such as weed seeds, small grains, stones, insects and ergot using a Carter Day dockage tester fitted with appropriate slotted riddles. Cleaned samples were dried to a maximum moisture of 15% before short term storage. For optimum milling performance the wheat was conditioned to 16% moisture by controlled addition of water prior to milling. Flour was prepared using a correctly configured Bühler mill. For each of flour type, white and wholemeal, the process was adjusted to produce flour containing the required components of the whole wheat (white flour being 72% extraction and wholemeal flour being 100%).

Table 14. Dough mixing and baking by the Chorleywood Bread Process (CBP)

	White bread % of flour weight	Wholemeal bread % of flour weight
Flour	100.0	100.0
Yeast	2.5	2.5
Salt	2.0	2.0
Fat (slip point 38°C- 45°C)	1.0	2.0
Ascorbic acid	0.01	0.01

Flour samples from each batch were mixed to form a dough using the following ingredients added to a PC controlled Morton mixer (Table 14). Fungal *alpha*-amylase was added as required to improve dextrin production, which allows the yeast to work continuously during dough fermentation. The amount required (1.5CU/g) was calculated from flour results using the Campden BRI Bake Workbook. Water was added as required, based on the flour water absorption values as determined by the Brabender Farinograph (600 Line).

The first proof was at ambient bakery temperature for 10 minutes; the dough was then formed using a Sorensen moulder, producing single dough piece weighing 400g.The second proof was at 43° C to attain a specified dough height. The risen dough was baked in a direct fired 12 tray oven at 244°C for 25 minutes, followed by ambient cooling and overnight storage before assessment.

Loaf volume
The volume of loaves was determined by a seed displacement method. The equipment used was calibrated by establishing the weight of seed displaced by a fibreglass dummy loaf of known volume. The loaf to be tested was placed in a rigid container which was filled with dried pearl barley. Measurement of the weight of seed required to fill the container enables the volume of the loaf to be calculated.

C-Cell
The appearance, dimensions and cell structure of slices of bread were measured objectively using the C-Cell (Calibre). The bread was sliced to thickness of 15mm using a Graef rotary slicer and placed in the instrument. The slices were illuminated obliquely to accentuate the cell structure and the image was captured using a CCD camera and the crumb structure assessed by the C-Cell software. The parameters determined by C-Cell were:

- Number of cells/slice area.
- Slice brightness.
- Cell wall thickness.
- Cell diameter.

3.3.3 Results of evaluation of field trials samples

Protein Content
Protein analysis was carried out on individual plot samples from the variety and fertility trials from each year. Statistical analysis of the data from each trial revealed significant effects of site and season on protein content. In order to obtain the maximum amount of information about the effect of the agronomic field treatments on wheat protein content, a different analysis was carried out using data from all trials which included common treatments. This was achieved by collecting the data into three groups. Results of statistical analysis of these three data sets are presented here.

<u>Data set 1</u>

Fertility treatments: Compost and CMP (variety Paragon only) including data from all years and all sites which were treated with Compost and CMP, see Table 15.

Data set 2

Variety and Fertility treatments including data from 6 varieties treated with rhizobial and compost in 2008 and 2009 at site Sheepdrove and Gilchester (Courtyard site is excluded to optimise balance of data). See Table 16.

Data set 3

Variety trial, including data from six varieties from all plots which were classified as untreated, at all sites in all years (data from varieties, Barrie and Monsun were excluded to minimise data imbalance). See Table 17.

Hagberg Falling Number and Specific weight

Results of analysis of wheat samples for specific weight and Hagberg falling number are summarised in Figure 7 and Figure 8.

Figure 7. Effect of variety and site on specific weight

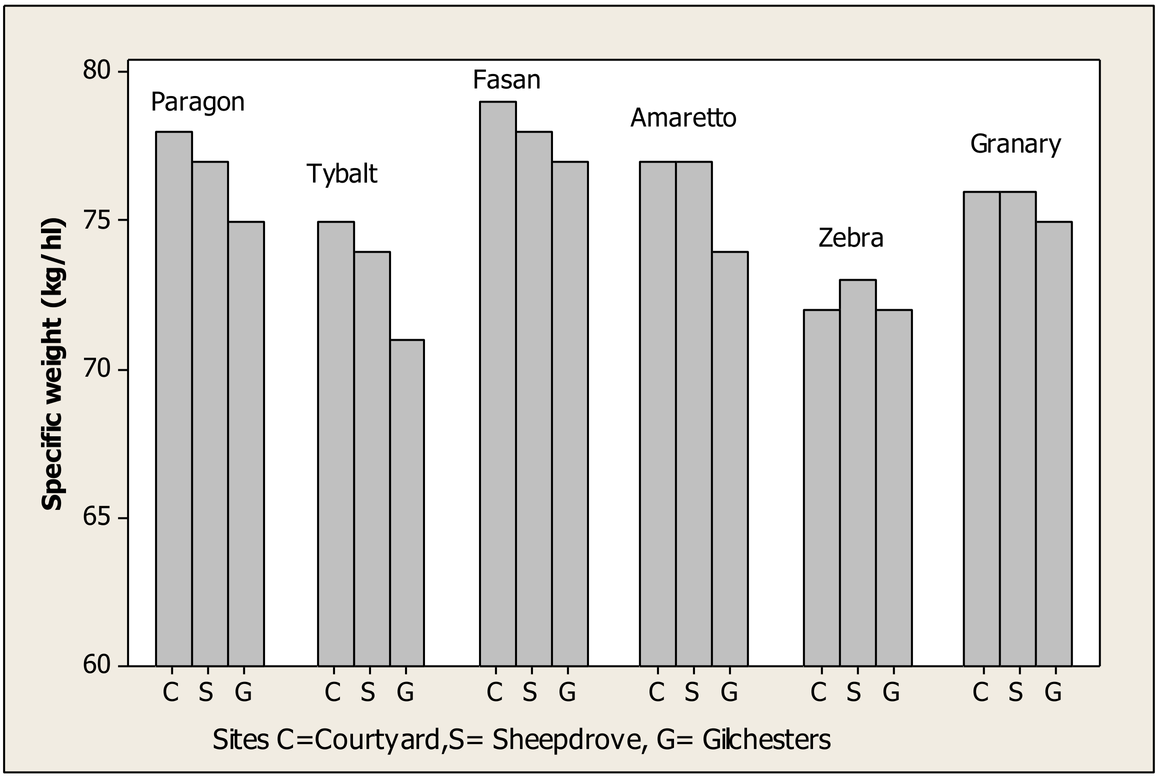


Figure 8. Effect of variety and season on Hagberg falling number

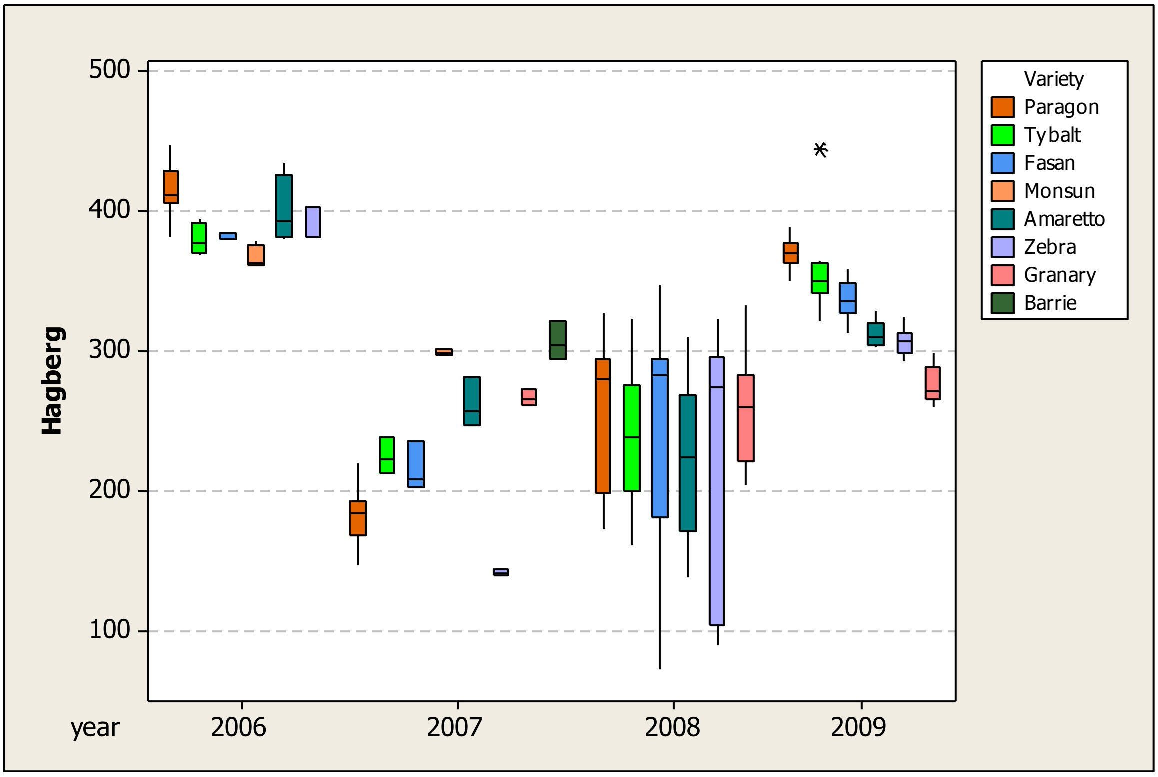


Table 15. Protein content of the wheat variety Paragon from Untreated, compost and Chicken Manure Pellet (CMP) treatments for three sites and over four seasons (2006 to 2009) (Columns: Mean, SD, No of values)

2006				
Site	Fertility Treatment			
	Unt	Comp	CMP	All
Courtyard	11.23	11.03	12.04	11.47
	1.48	0.87	1.06	1.16
	8	16	16	40
Sheepdrove	14.13	14.51	15.41	14.79
	0.43	0.47	0.39	0.68
	8	16	16	40
Gilchester	15.26	15.22	15.58	15.37
	0.59	0.72	0.60	0.65
	8	16	16	40
All	13.54	13.58	14.35	13.88
	1.96	1.97	1.80	1.92
	24	48	48	120

2007				
Site	Fertility Treatment			
	Unt	Comp	CMP	All
Courtyard	12.78	13.04	14.16	13.43
	0.90	0.47	0.95	0.97
	8	16	16	40
Sheepdrove	14.59	13.96	15.31	14.64
	0.73	0.35	0.66	0.82
	7	12	13	32
Gilchester	14.01	13.88	15.28	14.56
	0.76	1.12	1.04	1.20
	6	10	14	30
All	13.73	13.55	14.87	14.15
	1.11	0.79	1.04	1.15
	21	38	43	102

2008				
Site	Fertility Treatment			
	Unt	Comp	CMP	All
Courtyard	10.05		12.52	11.29
	0.38		0.35	1.32
	8	0	8	16
Sheepdrove	12.40	12.72		12.56
	0.45	0.81		0.63
	4	4	0	8
Gilchester	14.72	13.68		14.20
	1.05	1.21		1.19
	4	4	0	8
All	11.80	13.20	12.52	12.33
	2.08	1.09	0.35	1.65
	16	8	8	32

2009				
Site	Fertility Treatment			
	Unit	Comp	CMP	All
Courtyard	9.74	9.77		9.75
	0.04	0.94		0.62
	4	4	0	8
Sheepdrove	10.32	10.05		10.19
	0.32	0.27		0.31
	4	4	0	8
Gilchester	13.69	14.86		14.27
	0.49	0.87		0.90
	3	3	0	6
All	11.02	11.26		11.14
	1.75	2.41		2.06
	11	11	0	22

Table 16. Protein content of wheat, six varieties treated with rhizobial inoculant and compost in 2008 +9 at two sites (Col: Mean, SD, No of values)

Year/site	Treatment	Variety						
		Paragon	Tybalt	Fasan	Amaretto	Zebra	Granary	All
Sheepdrove 2008	Untreated	12.40	13.33	11.68	11.42	13.25	11.89	12.33
		0.45	0.65	0.74	0.58	0.55	0.34	0.91
		4	4	4	4	4	4	24
	Compost	12.72	14.09	12.13	11.93	13.28	12.27	12.74
		0.81	0.56	0.72	0.74	0.37	0.48	0.95
		4	4	4	4	4	4	24
	Rhizo+FYM	13.07	14.01	12.52	12.18	13.56	12.51	12.97
		1.10	1.14	1.61	0.94	0.40	0.62	1.13
		4	4	4	4	4	4	24
	Rhizo	12.46	13.54	11.65	11.40	13.13	11.87	12.34
		0.66	0.57	0.64	0.42	0.33	0.66	0.94
		4	4	4	4	4	4	24
Gilchester 2008	Untreated	14.72	13.49	13.42	12.86	13.34	13.35	13.54
		1.05	0.69	1.73	1.54	0.96	0.69	1.20
		4	4	4	4	3	4	23
	Compost	13.68	13.96	13.53	12.69	14.22	13.78	13.62
		1.21	0.66	2.02	1.11	2.11	1.50	1.46
		4	3	4	4	4	3	22
	Rhizo+FYM	15.16	14.23	13.37	12.71	13.89	13.68	13.85
		1.08	0.42	0.34	0.47	0.88	0.29	1.02
		4	3	3	4	3	3	20
	Rhizo	14.93	13.67	12.64	12.07	13.38	13.21	13.32
		1.67	0.99	0.90	1.39	1.49	1.38	1.49
		4	4	4	4	3	4	23
Sheepdrove 2009	Untreated	10.32	9.66	10.50	9.30	11.62	9.87	10.21
		0.32	0.33	0.17	0.04	0.27	0.18	0.79
		4	4	4	4	4	4	24
	Compost	10.05	9.54	10.51	9.36	11.76	9.96	10.20
		0.27	0.41	0.30	0.24	0.45	0.44	0.87
		4	4	4	4	4	4	24
	Rhizo+FYM	10.07	9.73	10.41	9.40	11.88	9.80	10.21
		0.34	0.22	0.14	0.20	0.41	0.29	0.86
		4	4	4	4	4	4	24
	Rhizo	10.38	9.69	10.49	9.35	11.80	10.11	10.30
		0.36	0.32	0.53	0.32	0.49	0.47	0.88
		4	4	4	4	4	4	24
Gilchester 2009	Untreated	13.69	12.76	12.05	12.86	12.48	13.58	12.90
		0.49	1.51	1.48	0.90	0.96	0.62	1.08
		3	3	3	3	3	3	18
	Compost	14.86	13.86	13.03	13.52	12.12	14.61	13.76
		0.87	2.49	2.43	0.60	1.48	1.49	1.70
		3	3	3	3	2	3	17
	Rhizo+FYM	13.92	12.84	11.82	12.99	12.59	13.18	12.89
		0.93	1.97	1.68	0.51	0.89	0.97	1.24
		3	3	3	3	3	3	18
	Rhizo	13.73	12.86	12.07	12.44	12.11	13.15	12.73
		0.61	1.99	1.47	0.40	1.05	0.78	1.16
		3	3	3	3	3	3	18

Table 17. Protein content of wheat from all untreated plots

(Columns: Mean, SD, No of values)

Year	Site	Variety						
		Paragon	Tybalt	Fasan	Amaretto	Zebra	Granary	All
		11.23	10.36	11.01	10.78	11.45		11.01
	Courtyard	1.48	0.69	0.84	1.11	1.60		1.20
		8	4	4	4	4	0	24
		14.13	12.66	13.78	13.51	15.63		13.97
2006	Sheepdrove	0.43	0.66	0.69	0.97	0.42		1.07
		8	4	4	4	4	0	24
		15.26	14.04	15.05	14.06	14.02		14.61
	Gilchester	0.59	0.38	0.43	0.36	0.57		0.75
		8	4	4	4	4	0	24
		12.78	11.28	11.49	11.22	12.53	12.13	12.03
	Courtyard	0.90	0.22	0.02	0.25	0.17	1.20	0.90
		8	4	4	4	4	4	28
		14.59	15.14	14.35	15.64	14.32	15.10	14.83
2007	Sheepdrove	0.73	1.06	0.40	1.51	0.45	1.18	0.97
		7	4	4	4	4	4	27
		14.01	14.24	12.71	12.27	13.89	12.82	13.36
	Gilchester	0.76	0.78	0.30	0.25		0.88	0.97
		6	4	4	3	1	4	22
		10.05	10.06	9.11	9.29	10.16	9.71	9.73
	Courtyard	0.38	0.42	0.25	0.70	0.35	0.25	0.57
		8	8	8	8	8	8	48
		12.40	13.33	11.68	11.42	13.25	11.89	12.33
2008	Sheepdrove	0.45	0.65	0.74	0.58	0.55	0.34	0.91
		4	4	4	4	4	4	24
		14.72	13.49	13.42	12.86	13.34	13.35	13.54
	Gilchester	1.05	0.69	1.73	1.54	0.96	0.69	1.20
		4	4	4	4	3	4	23
		9.74	9.57	9.23	8.68	10.48	9.79	9.61
	Courtyard	0.04	0.23	0.13	0.08	0.20	0.24	0.60
		4	4	2	4	4	4	22
		10.32	9.66	10.50	9.30	11.62	9.87	10.21
2009	Sheepdrove	0.32	0.33	0.17	0.04	0.27	0.18	0.79
		4	4	4	4	4	4	24
		13.69	12.76	12.05	12.86	12.48	13.58	12.90
	Gilchester	0.49	1.51	1.48	0.90	0.96	0.62	1.08
		3	3	3	3	3	3	18

3.3.4 Discussion: effect of field treatments on protein and baking

Wheat protein content and quality are important parameters which are responsible for the ability of wheat flour to produce a leavened bread. This breadmaking potential is indicated by protein content and influenced by both environmental and genetic factors. The field trials included several factors which would be expected to have an influence on wheat protein content. In the first two years of field trials (2006 and 2007) fertility treatments comprising two types of compost and a CMP product were investigated. These treatments were also included in the trials in 2008 and 2009. Analysis of the effect of these treatments on grain protein content showed that there was no significant effect of the two types of compost on wheat protein content. In addition there was no significant effect of compost application rate. However, the wheat treated with CMP contained a significantly higher protein content compared to wheat from untreated plots.

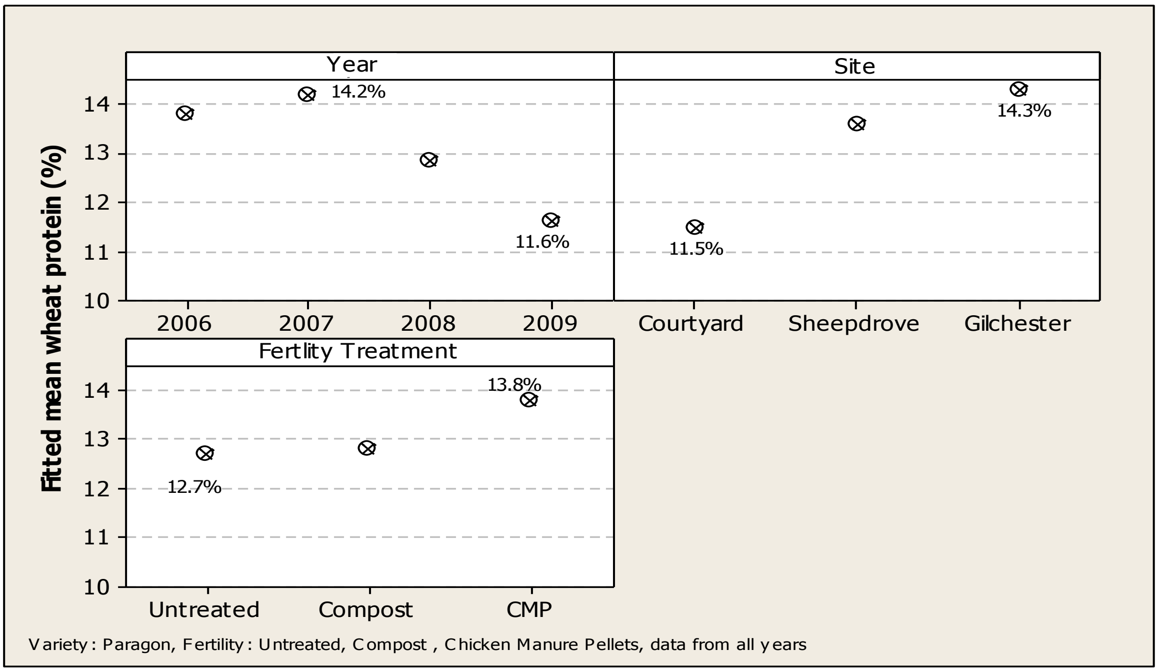
A summary of the main effects of the data in Table 15 is shown in Figure 9 with further detail of the effect of CMP on protein content in Figure 10.

Effect of compost and CMP on wheat protein

Wheat protein content data for all sites and all years for plots of the variety Paragon to which fertility treatments had been applied, was analysed using a General Linear Model. The fitted means from this analysis are shown in Figure 9; the results indicate that there is:

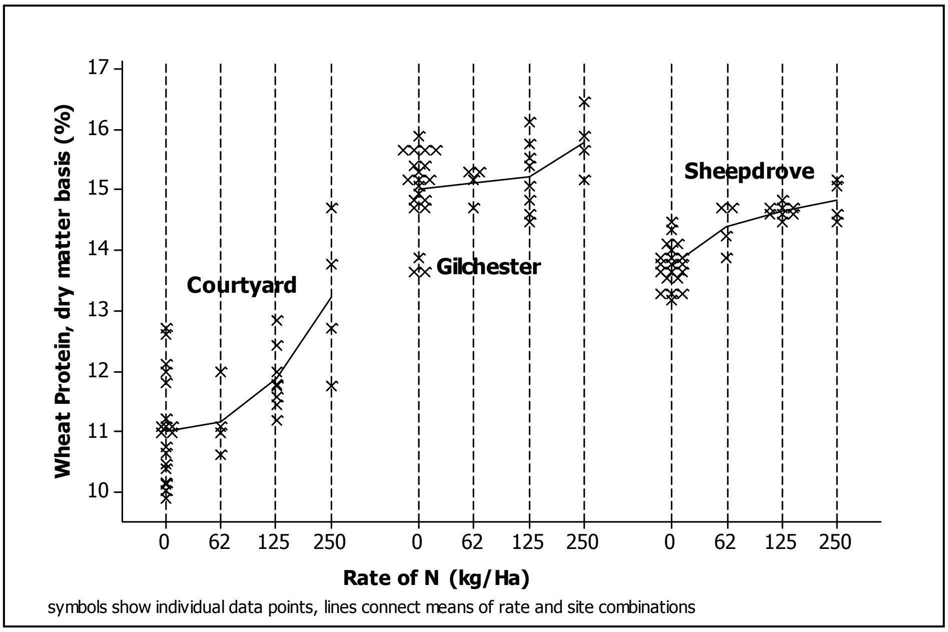
- A significant effect of season; mean differences between years varied from 14.2% (2007) to 11.6% (2009).
- A significant effect of site; mean differences between sites varied from 14.3% (Gilchester) to 11.5% (Courtyard).
- A significant effect of fertility treatment; mean protein content in untreated and compost treated plots was 12.7% and the CMP treated plots was 13.8%.
- Only weak evidence (p=0.02) of a site and treatment interaction, suggesting that the increase in protein content recorded when the CMP treatment is applied would not be seen at a higher fertility site such as Gilchester.

Figure 9. Summary of ANOVA fitted mean wheat protein content by individual factors (Year, Site, Fertility treatment)



ANOVA significant for Year ($p < 0.001$), Site ($p < 0.001$), Fertility treatment ($p < 0.001$)

Figure 10. Effect of Chicken Manure Pellet application rate on wheat protein content at three sites



The application of CMP at rates increasing from 62 to 250kgN/ha does not have a statistically significant effect on protein content, but a trend for an increased protein with higher application rates is seen on the lower fertility Courtyard site in Figure 10.

Effect of compost and CMP on loaf volume

When wheat samples are milled into white flour and baked into bread the measurement of loaf volume gives a good indication of the elasticity and strength of the gluten. Although loaf volume does not indicate overall loaf quality, it is a good indicator of the ability of the wheat to produce a loaf under commercial conditions.

The loaf volume results (data in appendix B) were statistically analysed using a general linear model. The data used were from bread baked using samples of wheat from all sites and all years for plots of the variety Paragon to which fertility treatments had been applied.

The fitted means showing the main effects of the treatments calculated by the GLM indicated that there is:

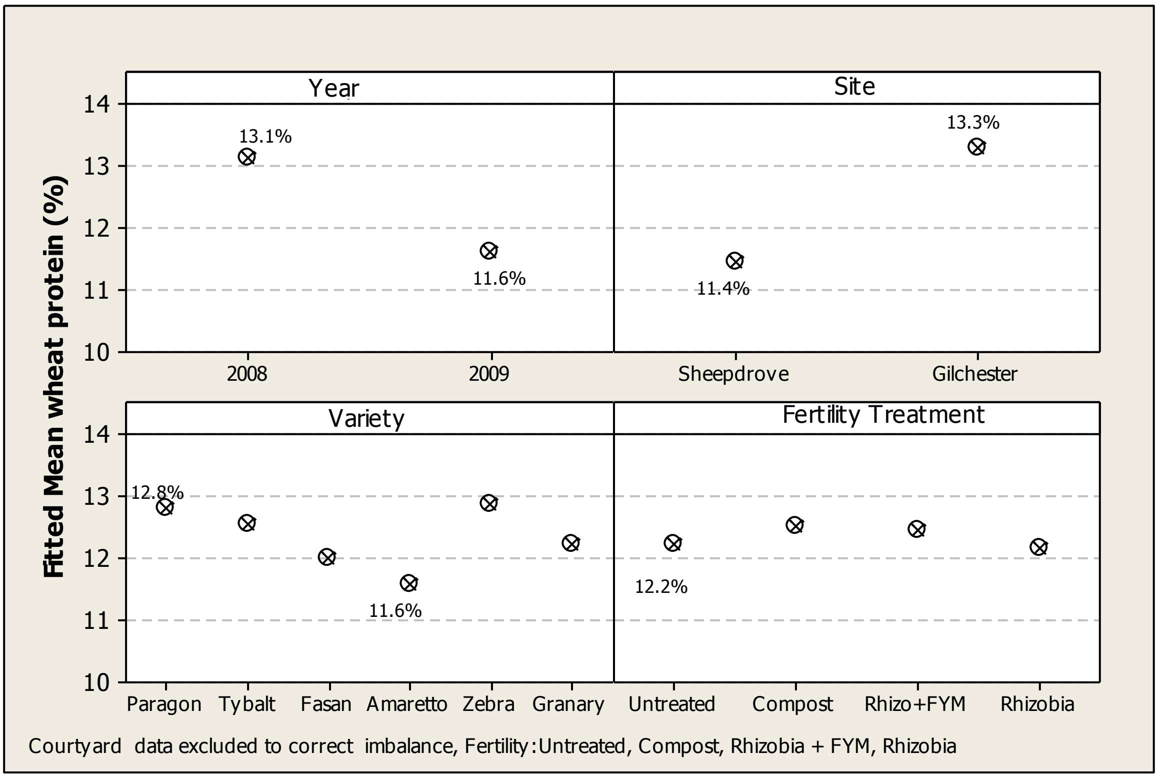
- A significant season effect and that mean differences between years could vary from 3800ml (2006) to 3000ml (2009).
- A significant effect of site; mean differences between sites could vary from 3240ml (Sheepdrove) to 3350ml (Courtyard).
- A significant effect of fertility treatment; mean loaf volume in untreated and compost treated plots would be 3250 ml and in CMP treated plots would be 3340 ml, a difference of 2.8%.
- Only weak evidence (p=0.098) of a site and treatment interaction.

Effect of compost and rhizobial inoculation on wheat protein

The wheat protein content results were statistically analysed using a general linear model (GLM). The data used were from sites Sheepdrove and Gilchester in 2008 and 2009 for 6 varieties from plots given the following treatments: Untreated; Compost; Rhizobia + Compost; Rhizobia.

The fitted means showing the main effects of the treatments calculated by the GLM using the data in Table 15 are shown in Figure 11.

Figure 11. Summary of Anova fitted mean wheat protein content by individual factors (Year, Site, Variety, Fertility Treatment)



The results indicate that there is:

- A significant season effect and that mean differences between years could vary from 13.1% (2008) to 11.6% (2009).
- A significant site effect and that mean differences between sites could vary from 13.3% (Gilchester) to 11.4% (Sheepdrove).
- A significant variety effect and that mean differences between varieties could vary from 12.8% (Paragon and Zebra) to 11.6% (Amaretto).
- Weak evidence for any effect of fertility treatment (p=0.07). The mean differences between treatments would be expected to be between 12.1% and 12.5%.
- No statistically significant evidence that the effect of treatment varies between years, sites or varieties.

Effect of compost and rhizobial inoculation on loaf volume

The loaf volume results were statistically analysed using a general linear model (GLM). The data used were from bread baked using samples of wheat from Sheepdrove and Gilchester sites in 2008 and 2009 for 6 varieties from plots given the following treatments: Untreated; Compost; Rhizobia + Compost; Rhizobia.

The fitted means for the main effects of the treatments were calculated by the GLM. Loaf volume results should be treated with caution as baking performance was influenced by variations in Hagberg Falling Number and hectolitre weight in the raw material.

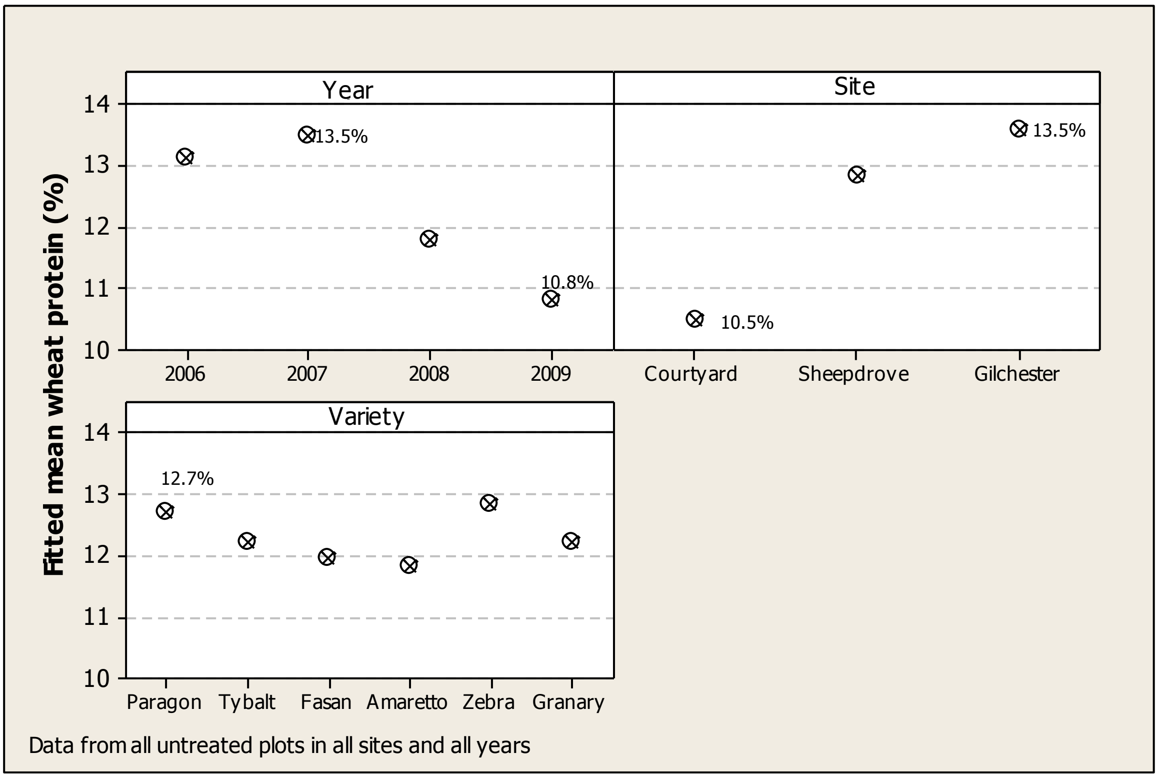
The results indicated that there is:

- A significant season effect and that mean differences between years could vary from 2950 ml (2008) to 3020 ml (2009).
- A significant variety effect and that mean differences between varieties could vary from 3180 ml (Paragon) to 2900 ml (Zebra).
- No evidence of any effect of fertility treatment (p=0.441).
- No statistically significant evidence that the effect of variety varies between years. The effect of year is big, but is different for different varieties. Loaf volume for Amaretto is lower in 2009 than in 2008, loaf volume for Zebra is greater in 2009 than in 2008.

Effect of variety on protein content

Data in Table 17 for wheat protein content for all sites and all years for plots of varieties which were classified as untreated was statistically analysed using a general linear model. The fitted means showing the main effects of the treatments calculated by the GLM are shown in Figure 12.

Figure 12. Summary Anova fitted mean wheat protein content by individual factors (Year, Site, Variety)



The results indicate that there is:

- A significant season effect and that mean differences between years could vary from 13.5% (2007) to 10.8% (2009).
- A significant effect of site and that mean differences between sites could vary from 13.5% (Gilchesters) to 10.5% (Courtyard).
- A significant effect of variety and that the expected protein content of each variety compared to Paragon would be as follows:
    - Tybalt would be between 0 and 1% lower.
    - Fasan would be between 0.25% and 1.25% lower.
    - Amaretto would be between 0.4% and 1.4% lower.
    - Zebra would be between 0.4% lower and 0.6% higher.
    - Granary would be between 0% and 1% lower.
- No significant evidence that the effect of variety varies between years.

Effect of variety on loaf volume

Analysis of the loaf volume data from bread baked using samples of wheat from varieties at all sites and all years for plots which were classified as untreated, indicated that there is:

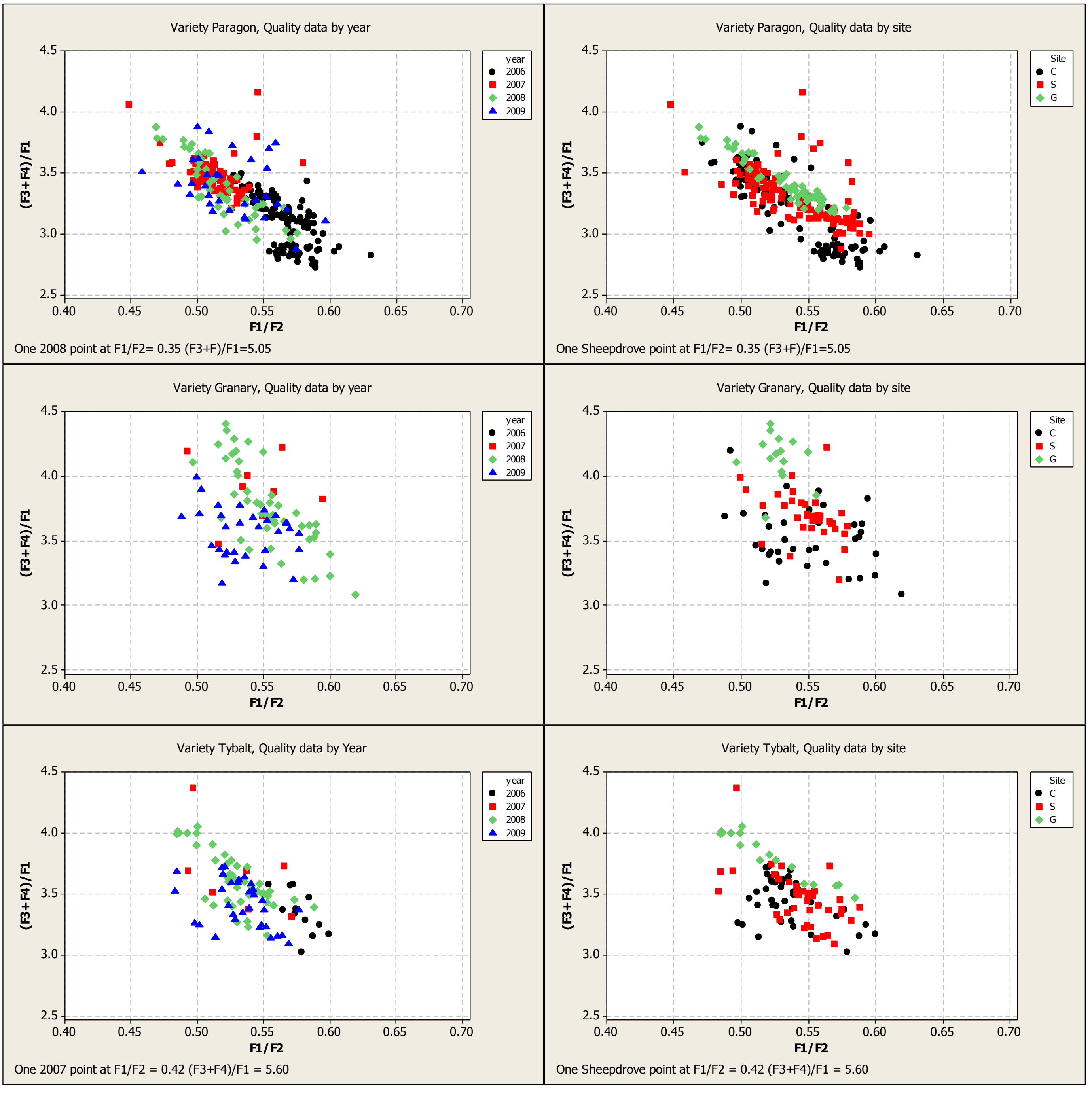
- A significant season effect (>240ml) and that mean differences between years could result in loaf volumes which vary from 3850ml (2006) to 2950ml (2007). This low value for 2007 when protein content was adequate is attributable to low Hagberg values.
- A significant effect of site and that mean differences between sites could vary from 3450ml (Courtyard) to 3090ml (Sheepdrove).
- No significant effect (p=0.82) of variety on loaf volume.

Effect of field treatments on protein quality

Variations in dough strength and baking performance can, to a large extent, be determined by variations in the amount and the quality of gluten proteins in the wheat flour (Godfrey 2008). The main types of gluten proteins, the glutenins and gliadins, make up the polymeric and monomeric fractions, respectively. The monomeric gliadin proteins consist of single polypeptides whose molecular weights fall in the range of 20-70 kDaltons. The polymeric proteins are multiple chain polymers of high molecular weight glutenin subunits (HMW-GS) and low molecular weight glutenin subunits (LMW-GS). This polymeric glutenin complex can range from 100kD to several million Daltons. The size distribution of the glutenin polymeric protein fraction and the monomeric:polymeric protein ratio are believed to control the mixing properties of dough. Both parameters are genetically controlled, but can be modified by environmental conditions (Bhandari 2007).

Size-exclusion high-performance liquid chromatography is commonly used to quantify the absolute and relative amounts of glutenin polymeric protein from the total protein extracted in sodium dodecyl sulphate (SDS) using controlled sonication (Dachkevitch and Autran, 1989; Morel *et al*., 2000; Millar, 2003). A typical size-exclusion profile contains four main peaks (F1-F4) corresponding to the gluten proteins, with an additional peak (F5) corresponding to other wheat proteins, such albumins and globulins. The F1 fraction consists of mainly high molecular mass enriched in HMW-GS; F2 is mainly low molecular mass polymers made up of HMW-GS and LMW-GS, F3 is mainly the larger ω-gliadins, and F4 is mainly the smaller α-, β- and γ-gliadins. The F1/F2 ratio can be related to gluten elasticity and extensibility, and the (F3+F4)/F1 ratio can be related to dough strength. Both ratios may be used as indicators of potential baking strength (Dachkevitch and Autran, 1989; Millar, 2003). Assessment of conventionally grown wheat has suggested that a ratio of (F3+F4)/F1 of about 3-4 may be indicative of good baking potential, while the ratio of F1/F2 should fall within the range of 0.5-0.7, with values below this range indicating excessive extensibility and values greater indicating excessive elasticity. This method was used for assessing the organically-grown samples from the variety and fertility trials. The influence of site and year on the protein quality ratios can be seen in Figure 13. The F1/F2 ratios for Granary and Tybalt were quite similar (0.49-0.62),but were slightly different from those for Paragon (0.45-0.63). Differences between these three varieties was also seen in the (F3+F4)/F1 ratios, whereby the spread of the data for Paragon (2.8-3.9) was lower than for Granary (3.1-4.4) and Tybalt (3.0-4.0). Effect of season was clearly seen for Paragon, whereby the spread of F1/F2 and (F3+F4)/F1 data for 2006 were separated from those for 2007. Although the data was limited , there was some evidence that both these quality-related ratios were different in 2006 and 2007 for Tybalt. There was no evidence of a season effect for the F1/F2 and (F3+F4)/F1 data in the case of the Granary samples. There was some evidence of a site effect between Sheepdrove and Gilcesters with respect to the spread of the F1/F2 and (F3+F4)/F1 values for Paragon, Granary and Tybalt. There was also some evidence for a site effect between Courtyard and Gilcesters with respect to spread of F1/F2 and (F3+F4)/F1 data for Granary and Tybalt.

Figure 13. Effect of site and year on protein quality data (Paragon, Granary, Tybalt)



3.3.5 Milling and baking trials of process variables

In addition to the assessment of baking performance of wheat from individual trial plots, milling and baking trials were also conducted at Campden BRI to investigate the effect of milling and baking variables on loaf quality. The selected variables were:

- extraction rate of white flour;
- particle size of wholemeal flour;
- gluten addition;
- dough work input.

Selected wheat variety samples of sufficient quantity were obtained from the field trials by blending the samples from replicate plots of the same variety. These bulked samples were used to undertake the process trials.

Methods used in study of milling and baking variables

For white flour the mill was set up to produce flour at 72% and 78% extraction rate. For wholemeal flour, wheat was milled as wholemeal flour and bran particles were separated from the endosperm fraction. Bran was ground to two size grades (fine and coarse) and then added back to the flour to produce wholemeal flours with fine and coarse size characteristics. Size grading of the two wholemeal flours gave the following results:

Table 18. Particle size characteristics of fine and coarse flours (%)

Sample ID	710um	500um	200um	<200 um
Fine	1.7	4.9	6.9	85.5
Coarse	12.5	2.9	4.6	78.8

Added protein flours were prepared by adding organic gluten to increase protein content by 2% *(note that organic gluten is 3 times the price of conventional gluten*).

Dough was prepared using a standard recipe; dough mixing was carried out using a computer controlled Morton mixer. Doughs were prepared which had received work inputs of 9, 11 and 13Whr/kg.

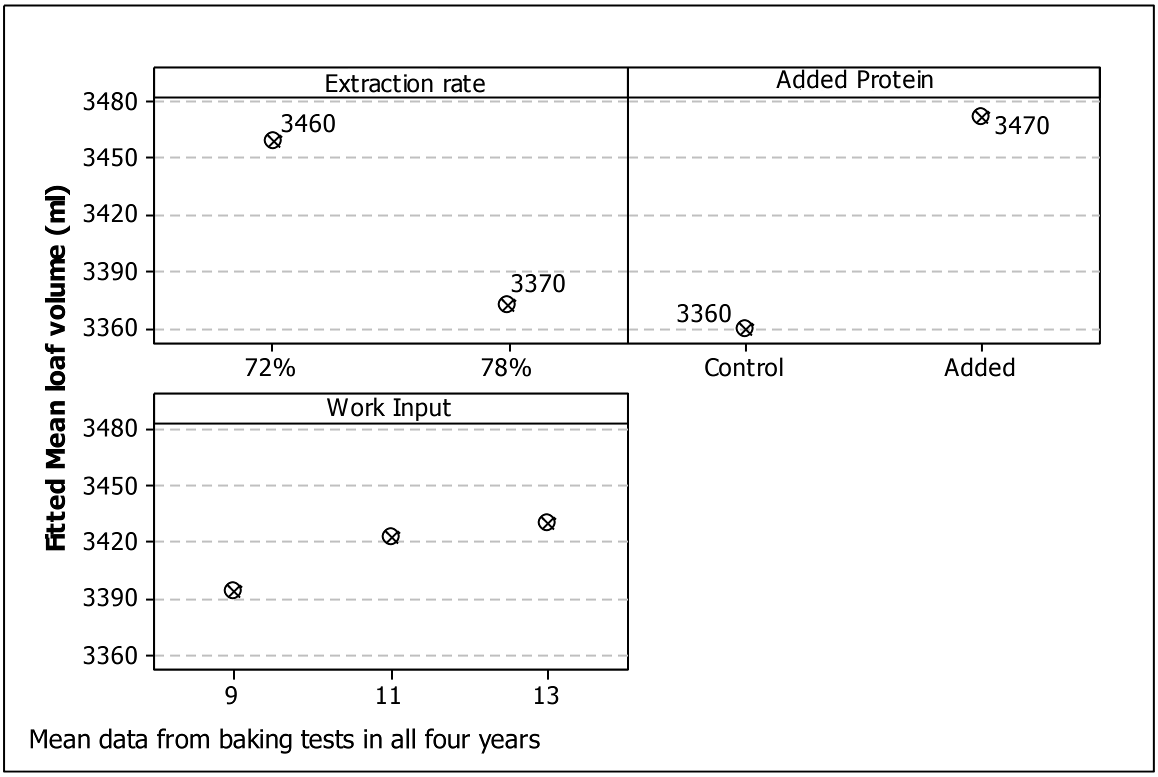
Subsequent baking followed standard procedures. See Section 3.2.1.

Results of milling and baking variables

The effect of process variables on loaf quality were investigated in each year of the project. Extensive studies were completed using wheat from the 2006 harvest. In subsequent years the milling quality of the wheat was more variable and fewer samples were processed.

Trials were conducted using both white and wholemeal flour. The results were statistically analysed using a General Linear Model and the fitted means showing the main effects of the process treatments on leaf volume are shown in Figure 14 (white flour) and Figure 15 (wholemeal flour); Figure 18 gives a summary chart of loaf volume results. Analysis of C-Cell data for cell diameter is displayed in Figure 16 (white flour) and Figure 17 (wholemeal flour).

Figure 14. Summary of fitted mean white loaf volume by processing factors (Extraction Rate, Added Protein, Work input)

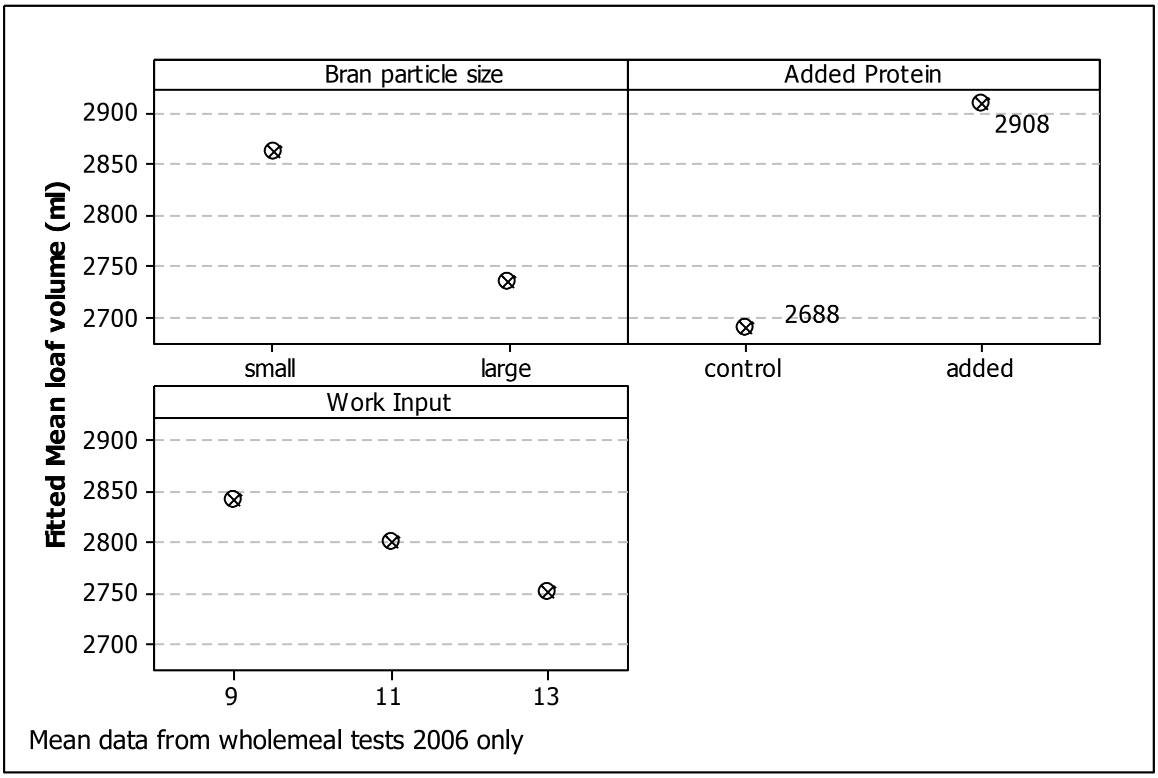


The results indicate that there is:

- A significant effect (p<0.001) of flour extraction rate; white loaf volume could be increased by 8% from 3370ml to 3640ml by changing from 78% to 72% extraction.

- A significant effect (p<0.001) of adding protein; white loaf volume could be increased by 3.3% from 3360ml to 3470ml by adding gluten to the flour.
- No significant effect (p=0.07) of increasing work input when mixing dough.

Figure 15: Summary of Anova fitted mean wholemeal loaf volume by individual factors (Bran particle size, Added protein, Work input)

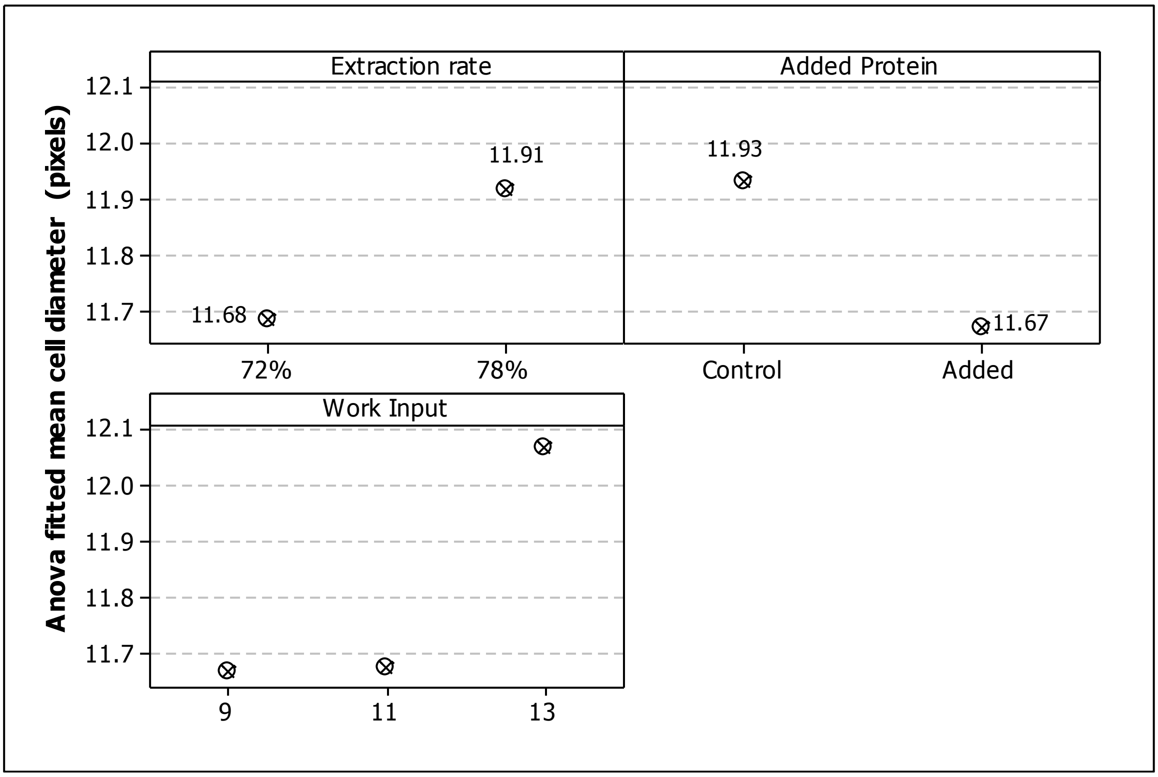


The results indicate that there is:

- A significant effect (p<0.001) of flour particle size; wholemeal loaf volume could be increased by 4.5% from 2735ml to 2860ml by changing from large to small bran particle size.
- A significant effect (p<0.001) of adding protein; wholemeal loaf volume could be increased by 8.2% from 2688ml to 2908ml by adding gluten to increase the flour protein by 2%.
- A significant effect (p<0.001) of work input; wholemeal loaf volume could be increased by 3.3% from 2750ml to 2840ml by changing from work input of 13wh/kg to 9wh/kg when mixing dough.

The results of loaf cell diameter measurements (section 3.2.3) obtained using the C-Cell instrument which recorded the cell structure of the loaf from an image captured using a CCD camera are presented in Figure 16

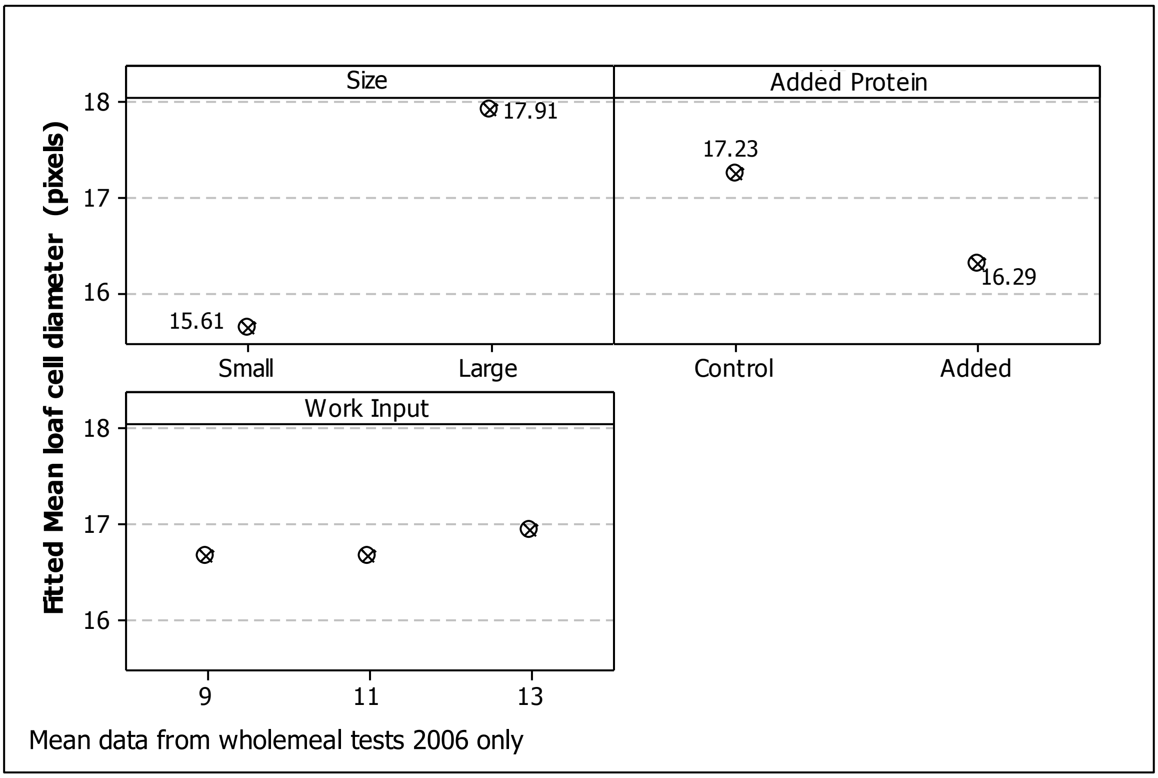
Figure 16. Summary of Anova fitted mean white loaf cell diameter by individual factors (extraction rate, added protein, work input)



The results indicate that there is:

- A non significant effect (p=0.014) of flour extraction rate on white cell diameter.
- A significant effect (p<0.005) of adding protein; white loaf cell diameter could be changed from 11.93 to 11.67 units by adding gluten to the flour, indicating a finer crumb structure which, when allied to the significant increase in loaf volume, was evidence of improved gas retention.
- A significant effect (p<0.001) of increasing work input when mixing; dough cell diameter could be changed from 11.65 to 12.61 units when work rate was increased to 13wh/kg, indicating that a more open structure was a result of longer mixing.

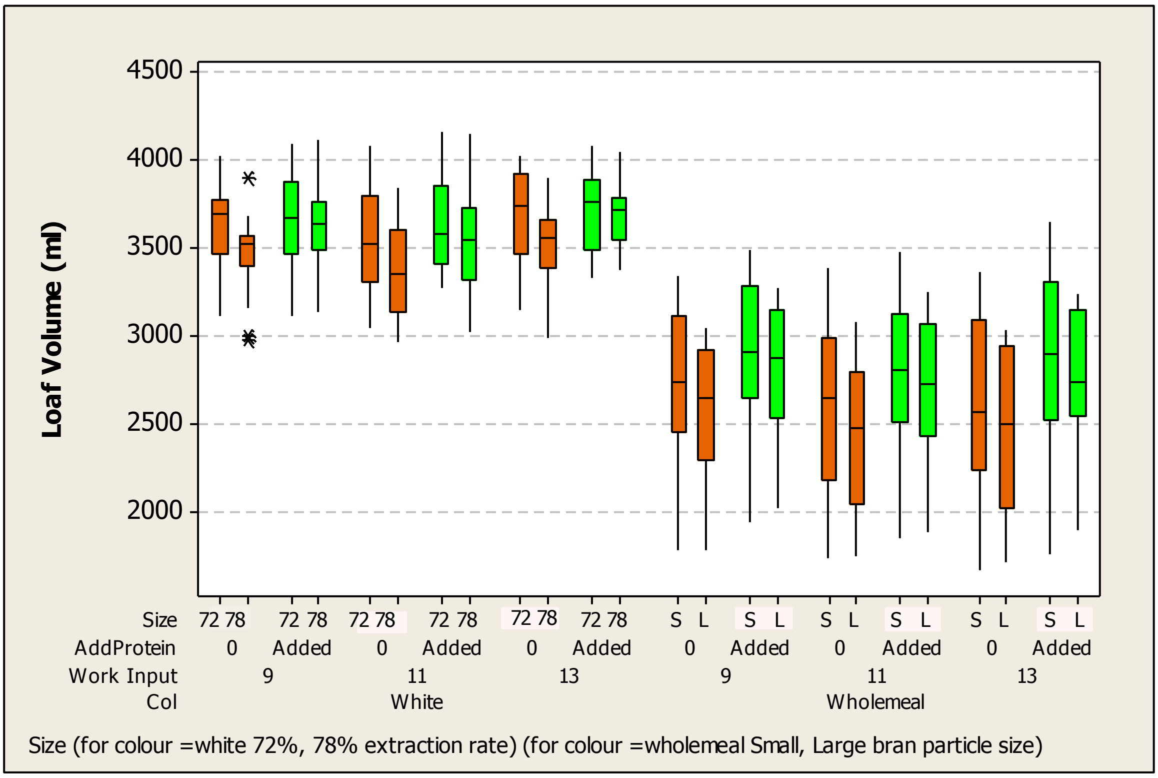
Figure 17. Summary of Anova fitted mean wholemeal loaf cell diameter by individual factors (bran particle size, added protein, work input)



The results indicate that there is:

- A significant effect (p<0.001) of flour particle size; wholemeal cell diameter could be decreased from 17.91 to 15.61 units by changing from large to small bran particle size, indicating a coarser structure with large particles allied to lower volume showing poorer gas retention.
- A significant effect (p<0.001) of adding protein; wholemeal loaf cell diameter could be decreased from 17.23 to 16.29 by adding gluten to the flour, indicating a more open structure as a result of longer mixing.
- A non significant effect (p=0.493) on cell diameter of changing from work input 13wh/kg to 9wh/kg when mixing dough.

Figure 18. Effect of small/large bran particle size (wholemeal), 72/78% extraction rate (white), added protein and 9,11,13 watt hours/kg work input on loaf volume



Discussion of effect of process variables on bread quality

These results indicate that bread quality can be improved by manipulation of the breadmaking process. Evidence is provided that the loaf volume of white bread can be increased by changing the extraction rate of the flour from 78% to 72%. Further increase in loaf volume will result if the flour strength is augmented by the addition of organic gluten.

When baking wholemeal bread, the loaf volume can be increased by adding organic gluten and by reducing the bran particle size. The fine and coarse particle sizes used in this trial (Table 18) indicate an increase in loaf volume with smaller particle size. Trials conducted by industry partners in 2007 using flour with a particle size distribution shown in Table 19 indicated that larger particle size produced larger loaf volume. More work is required to identify the particle size fraction giving a negative impact on loaf volume. Small improvements in loaf volume may be expected by reducing the work input as this would avoid overworking the lower protein dough during the mixing stage.

Changes to work input are simple to introduce and would form part of best practice in bread making; however, operational issues would need to be taken into account to produce a flour with smaller bran particle size. Economic considerations would be predominant when increasing flour protein by adding organic gluten, as this ingredient is significantly more expensive than the conventionally produced equivalent.

Potential clearly exists to optimise mill and bakery process operations in a way which could produce the best performance from UK organic wheat.

3.4 Summary of milling and baking trials by industry partners

3.4.1 Trials carried out in 2006

Warburtons

Variety samples (Paragon, Monsun, Zebra, Fasan) from the 2005 harvest of Experiment 3 were supplied by Newcastle University to Warburtons for test milling and baking as white flour. The wheat was roller milled using a commercial Buhler mill Hagberg falling numbers were Paragon 332, Zebra 293, Monsun 306, Fasan 353. Mean flour proteins corrected for dry matter were Paragon 9.5%, Zebra 8.5%, Monsun 8.8%, Fasan 8.7%. Using a standard recipe (Flour 100%, Salt 1.84%, Yeast 3%, Fat 1%, Conditioner 0.9%) doughs were prepared using a CBP process with a work input of 12wh/kg. The dough was given 60 minutes of proof time and baked at 240°C for 24 minutes.

Paragon samples produced loaves which had good volume and a slightly weak crumb; Zebra had poor dough quality, reasonable volume and very weak crumb; Monsun had poor volume and the worst dough and poor texture; and Fasan had good volume, good texture and the best crumb strength.

W&H Marriage

Variety samples (Paragon, Monsun, Zebra, Fasan) from the 2005 harvest of Experiment 3 were supplied by Newcastle University to W&H Marriage for milling and baking.

Samples were milled into white flour using a Chopin laboratory mill CD1. Samples were test baked on a 30 minute bulk fermentation using a standard recipe of Flour 100%, Salt 1.5%, Fat 2%, Yeast 2%, Fungal alpha amylase 250ppm.

Mean flour proteins were Paragon 9.25%, Zebra 8.3%, Monsun 8.9%, Fasan 8.9%. All varieties produced a flour of good colour and the doughs handled well. Baking results were generally good with the exception of Monsun, which had a relatively poor general performance, with blistering during the intermediate proof and a lack of volume and oven spring. Zebra had a good loaf volume but the crumb structure was fairly open. Fasan, Paragon and Zebra produced good volumes despite low proteins. Evaluation of these 2005 samples indicates that Monsun produced the poorest quality loaf and that Zebra had crumb structure faults when baked by bulk fermentation (Marriage) and CBP (Warburtons). The two varieties which performed best in these tests were Fasan and Paragon.

3.4.2 2006 Harvest trials

W&H Marriage

Variety samples of wheat from the 2006 field trials were milled and baked by W&H Marriage using replicate samples of 6 variety samples supplied from Campden BRI. The wheat was milled by W&H Marriage to wholemeal flour using a Chopin laboratory mill. The dough was prepared using the following recipe: Flour 100%, Yeast 4%, Salt 1.5%, fungal alpha amylase 0.04% and water as required. A planetary mixer was used for 3 minutes at speed 1 and 8 minutes at speed 2. The dough was given a standard 30 minute bulk fermentation following moulding into tins, with a 60 minute proving time. The dough was baked at 230°C for 20-23 minutes. All the samples produced doughs which handled well and had good proof times; none of the wholemeal loaves were found to be outstanding. There was some variation in the performance of the replicate samples but it was observed that more samples with reasonable volumes and crumb structure were produced from the varieties Amaretto and Paragon.

3.4.3 2007 Harvest trials

FWP Matthews, Warburtons, Maple Leaf, Premier Foods

The 2007 harvest was a wet year with low light levels, which had produced wheat samples with generally lower than average protein and Hagberg falling numbers. Work

was undertaken by the project partners in 2007 to investigate the effect of particle size in wholemeal flour on baking performance. A commercial batch of organically grown Paragon was milled by FWP Matthews and supplied for test baking to Warburtons, Maple Leaf and Premier Foods (Rank Hovis Bakery Division).
This commercial sample of Paragon was milled as a wholemeal flour to produce two batches with different particle sizes (fine and coarse). Details of the particle size distribution in each flour is given in Table 19. The data indicate the % of the flour which remains on a sieve of each particle size. The proportion of the flour which is less than 150μm and passed through all the sieves is known as the throughs.

Table 19. Particle size distribution in test flours

Flour type	1.6mm	850μm	250μm	150μm	<150μm
Org wholemeal standard	0.22	1.73	8.39	3.05	86.61
Org wholemeal Trial 1 Fine	0.08	0.54	13.01	4.13	82.24
Org wholemeal Trial 2 Course	2.47	6.13	9.46	2.52	79.42

Test baking at Warburtons using a CBP process concluded that both flours underperformed relative to a commercial flour used as a control in the test and were unsuitable for plant trials in a commercial bakery. The coarse flour produced a loaf with better volume, but both samples had poor internal texture. Some improvement was seen by using lower energy inputs (8.5wh/kg) but the doughs were still weak with poor extensibility.

Baking trials by Premier Foods showed a similar poor bake performance for both flours using a spiral mixer. The loaves had low volumes and crumb strength measurements of 3 and 4 (a good wholemeal loaf would score 8). When the flours were tested using a recipe which included the addition of gluten to increase the protein content from 9.5% to 12%, the result was an improved loaf with a crumb strength score of 6 for the fine flour and 7 for the coarse flour.

The coarse flour was also test baked by Maple Leaf. The standard recipe included the addition of 0.8% of organic gluten by weight; dough was mixed using a twin spiral VMI mixer with slow and fast mixing periods followed by a 60 minute proving time. The coarse flour (using a recipe which included the added gluten) produced an acceptable loaf with slightly smaller volume than the control sample.

It should be noted that the partners agreed to go ahead with these test bakes knowing that baking quality wheat was hard to find in 2007. The organic Paragon used in this trial had low protein and low Hagberg values, and both fine and coarse flours underperformed in all test processes. However, an acceptable loaf was produced in all the tests by using the coarse flour with added gluten to improve protein content.

3.4.4 2008 harvest trials

Breadmatters
As in 2007 the commercial milling and baking trials characterised the performance of organic flour in a low protein season and identified options for optimising loaf quality. Improved final products can be made by adjusting the dough conditioner, fat and gluten components of the recipe. This incurs associated increases in production costs.

Variety samples from the field trials were milled and baked by Breadmatters using a traditional long fermentation sourdough method. Samples of 6 varieties from 2008 field trials were stoneground using a SAMAP composite stone mill into wholemeal flour. The recipe included the test flour (400g), refreshed leaven, prepared using 130g of test flour (300g), water (300ml) and salt (8g). The dough was mixed in a Sammic variable speed planetary mixer, proved for 5 hours then baked as a traditional pain de campagne in a brick oven.

None of the varieties in the 2008 trial performed well; the gluten lacked strength, and Paragon and Zebra were notably dark in colour. Flavour of the samples was good and differences in volume were small. Samples of Granary and Fasan were acceptable, while Tybalt and Amaretto were judged to have produced the best volume and texture.

Matthews, Warburtons, Premier, ADM
A commercial batch of Paragon (protein 12%, Hagberg 370s) was milled by F W P Matthews as wholemeal flour and supplied to Warburtons and Premier for baking evaluation. In 2008 good UK organic milling wheat was again hard to find, with protein levels being generally low.

The Warburtons trial investigated the options for improving the bake performance of a low protein flour.

Dough rheology was improved by doubling the content of palm shortening. Loaf volume was not improved by using an alternative enzyme containing flour improver. In a second trial, dough stability was improved by increasing the gluten content of the flour and by further increasing the content of shortening and by adding higher levels of dough conditioner. Conclusions of this work are that improvements can be made to poorer quality flour. Recommended adjustments are:

- addition of gluten to take flour protein content from 10% to 12%
- increasing dough conditioner levels by 25%
- increasing palm shortening levels by 100%.

The consequence of this is estimated to be an increase of 8% on raw material costs.

The Paragon wholemeal was also test baked by Premier Foods; it produced a lifeless dough with little extensibility. Improvements in loaf volume and crumb strength were obtained by adding 1% fat to the recipe. The most acceptable loaf with good crumb of reasonable strength was produced by adding 1% fat and increasing the flour protein content to 13.6% adding gluten.

Alara
Samples of the six varieties from the field trial were tested for suitability for use in muesli products by Alara Wholefoods. The wheat grains were manufactured into a flake product and assessed for quality. Results indicate that the most suitable variety for muesli products is Fasan, which consistently produced larger grains which resulted in large processed flakes.

3.4.5 2009 harvest trials

Marriage, Premier, ADM, Maple Leaf
Commercial samples of Paragon, Amaretto and Tybalt were produced as roller milled and stone ground wholemeal flours by W&H Marriage. Samples of Tybalt and Amaretto from a different source were produced as roller milled and stone ground flours by ADM Milling.

Premier Foods test baking

Test baking was undertaken by Premier Foods; this comprised two trials, in the first, all the flours were tested using test bakery conditions at their Central Laboratory in Southampton. This was followed by commercial factory trials using the most promising material at a bakery in Surrey. The recipe included 1% added gluten, 1.4% salt, yeast and soft bake for moisture retention. Slow spiral mix conditions were used.

In the test bake, the Tybalt and Amaretto supplied and milled by ADM did not deliver a good baking performance due to low protein content. The samples supplied and milled by W&H Marriage were more suitable for baking and showed Tybalt to have darker crumb colour, and Amaretto to be lighter in colour and to have better crumb strength. Paragon performed best in this test.

In the commercial test all the flours from W&H Marriage were acceptable for commercial production except Amaretto stoneground which did not perform well.

Maple Leaf Bakery test baking

Commercial scale baking trials were undertaken by Maple Leaf Bakery using roller milled Tybalt and Amaretto and Paragon wholemeal flour from W&H Marriage. The recipe included 1.2% gluten, 2.2% salt, organic improver, yeast and vinegar. Mixing conditions were twin spiral fast mix. The flours produced commercially acceptable loaves: Tybalt loaves were darker in colour, and Paragon performed well and was used in production.

Warburton Ltd test baking

Test baking was also performed by Warburtons on these samples. The recipe included 1.6% salt, yeast, paste improver, palm oil, 1% organic gluten and cider vinegar. The mix conditions were high speed pressure vacuum.

Observations were that the stoneground samples had a darker crumb colour, reduced crumb strength and poorer resilience. Paragon was preferred in the roller milled and Amaretto in the stoneground.

Alara Wholefood flake trials

Samples of the six varieties from the field trial were tested for suitability for use in muesli products by Alara Wholefoods. The wheat grains were manufactured into a flake product and assessed for quality. Results indicate that Fasan again produced the most acceptable results. The grain size and level of discoloured grains and the level of admixture are critical factors for this process.

Breadmatters baking trials

Further trials of the test flours were planned by Breadmatters in 2010. Some delays in setting up the baking facilities following a transfer of the business to a new location in Scotland meant that results were not available at the time of publication of the final report. The results of these baking trials using long fermentation times will be circulated to the partners as soon as they are available.

4. CONCLUSIONS

Organic farming systems are planned to maintain soil and crop productivity by selecting management approaches which maintain adequate soil fertility, encourage biodiversity and minimise external inputs. In order to supply the crop with sufficient nitrogen to enable a milling wheat crop to realise its optimum protein content, long term fertility-building strategies are required. In this project, selected strategies were examined to quantify the potential for increasing available nitrogen to spring sown wheat crops on organic farms.

The results indicate that variety choice offers potential for achieving milling grade and that the varieties Paragon, Tybalt, Granary, Fasan and Amaretto are capable of producing adequate protein levels when grown in different regions. However, it should be recognised that seasonal differences can have a large influence on the suitability of UK spring organic wheat for breadmaking.

The use of composted materials based on farm yard manure and green waste can provide a significant ($P<0.001$) increase of up to 0.5t/ha in yield where lower fertility conditions exist, but where adequate background fertility has been maintained by a two year grass clover ley, additional yield benefits from compost applications are unlikely.

The use of supplementary organic fertility inputs based on chicken manure permitted by organic farming standards resulted in a significant ($P<0.001$) yield benefit of up to 0.5t/ha only at sites with lower soil fertility. In addition to this yield effect, wheat protein content was significantly ($P<0.001$) increased by up to 1% in chicken manure treated samples. However, the cost benefit of using this type of supplementary N application is dependent on the input cost of suitable chicken manure based products and an adequate premium for milling grade organic wheat.

The use of microbial inoculants to increase the benefits of nitrogen fixation by preceding clover crops was seen to provide some yield benefits on land which was in conversion to organic production. However, in more extensive trials on organic farm sites in which inoculant treatments preceded spring wheat crops, no increase in crop yield or wheat protein content was observed.

As expected, trial site and season had a significant effect on yield and wheat protein content. Large yield differences were the result of changes in spring and summer weather conditions, with 2006 providing the highest yields compared with 2007 and 2008 when conditions were cool, dull and wet. Yield loss resulting from foliar disease was greatest at the site with lighter soil. Differences in wheat protein content between seasons were up to 2% and between sites up to 2.5%.

The low levels of selenium in UK grown wheat can be effectively augmented from 0.17 to 6.98mg/kg using a targeted soil supplementation technique developed by one of the agronomy partners.

Good baking quality of wheat will only be attained if the grain meets the criteria of adequate protein content (13%), hectolitre weight (76kg/hl) and a Hagberg Falling Number (250s). Fertility management and variety choice can enable protein content targets to be attained but baking quality will not be achieved if weed competition reduces grain size, or wet weather at harvest increases *alpha*-amylase levels in the grain. The results of milling and baking trials showed variety choice and compost treatment did not consistently increase loaf volume compared with the control variety Paragon grown in untreated plots. Chicken manure treatment did increase loaf volume by 3%. Large differences in loaf volume arose from the effect of site (up to 11% difference between sites) and season (up to 30% difference between seasons); these are explained by grain quality variation in hectolitre weight and Hagberg values caused by environmental factors.

The food industry partners evaluated selected milling and baking approaches using test and plant bakery conditions. This showed that protein supplementation and dough recipe modification can result in acceptable quality wholemeal loaves from commercial samples of UK grown organic Paragon, Amaretto and Tybalt. Test baking of wholemeal flour using traditional sourdough techniques produced loaves with good flavour. Evaluation of wheat variety samples for use in muesli products showed Fasan to produce the best flaked product.

5. REFERENCES

Anonymous (1976). Manual of plant growth stage and disease assessment keys. ADAS Plant Pathology Laboratory, Ministry of Agriculture, Fisheries and Foods.

Bhandari, D., Bonet, A. and Anderson, C. (2007). Understanding flour functionality differences between wheat varieties. Campden BRI R&D Report No. 246.

Campden BRI (2010). Guideline No.3. Manual of Methods for Wheat and Flour Testing 4th Edition.

Dachkevitch, T. and Autran, J-C (1989). Prediction of baking quality of bread wheats in breeding programs by size-exclusion high-performance liquid chromatography. Cereal Chemistry, **66:** 448-456.

Defra (2007). Agriculture in the United Kingdom 2006.

Defra (2009). Organic Statistics 2008, United kingdom revision published 16 September.

Defra(2010). Fertiliser recommendations for agricultural and horticultural crops (RB209).

Gelinas, P., Morin, C., Reid, J.F. and Lachance, P.(2009). Wheat cultivars grown under organic agriculture and the bread making performance of stone ground whole wheat flour. International Journal of Food Science and Technology, 44, 525-530.

Godfrey, D. (2008). The impact of nutrition on the development, composition, and breadmaking quality of wheat grain. Dissertation submitted to the University of Bristol for a PhD, December 2008. Chapter 4, 149-166

Gooding, M.J. *et al.* (1993). The challenge of achieving breadmaking quality in organic and low impact wheat in the UK - a review. Aspects of Applied Biology, **36:** 189-198.

HGCA (2008). Organic arable farming – conversion options: Autumn 2008.

HGCA (2009). Nitrogen management in winter wheat guidelines.

HGCA (2010). HGCA Recommended List 2010/11 for cereals and oilseeds.

Hodge, C.A.H., Burton, R.G.O., Corbett, W.M., Evans, R. and Searle, R.S. (1984). Soils and their use in eastern England. Soil Survey of England and Wales Bulletin 13. Lawes Agricultural Trust, Harpenden.

Jarvis, M.G., Allen, R.H., Fordham, S.J., Hazelden, J., Moffat, A.J. and Sturdy, R.G. (1984). Soils and their use in south-east England. Soil Survey of England and Wales Bulletin 15. Lawes Agricultural Trust, Harpenden.

Lampkin, N., Measures, M. and Padel, S. (2008). 2009 Organic Farm Management Handbook. 8th Edition (November 2008).

Millar, S.J. (2003). The development of near infrared (NIR) spectroscopy calibrations for the prediction of wheat and flour quality. HGCA Project Report No. 310.

Morel, M-H., Dehlon, P., Autran, J.C., Leygue, J.P. and Bar-L'Helgouac'h, C. (2000). Effects of temperature, sonication time, and power settings on size distribution and extractability of total wheat flour proteins as determined by size-exclusion high-performance liquid chromatography. Cereal Chemistry, **77:** 685-691.

nabim (2010). nabim Wheat Guide 2010 (In: HGCA Recommended List 2010/11 for cereals and oilseeds, 42-45).

NIAB (2009). Pocket guide to varieties of cereals, oilseeds and pulses: Spring 2010.

Singh, N.K., Donovan, G.R. and MacRitchie, F. (1990). Use of sonication and size-exclusion high-performance liquid chromatography in the study of wheat flour proteins. II. Relative quantity of glutenin as a measure of breadmaking quality. Cereal Chemistry. **67:** 161-170.

Soil Association (2009). Soil Association Standards.

Taylor, B.R. and Cormack, W.F. (2002). Choices of species and varieties, In, *Organic Cereals and Pulses, pp. 9 -28*. Eds. D. Younie, B. Taylor, J.P. Welch, J.M. Wilkinson. Lincoln: Chalcome Publications.

Wilkinson, A., Young, D., Cooper, J.M., Wilcockson, S. and Leifert, C. (2006). Effect of fertility management and variety choice on yield and baking quality of organic spring and winter wheat. Aspects of Applied Biology, **80:** 185-188.

Wilkinson, A., Young, D., Lueck, L., Cooper, J.M., Wilcockson, S. and Leifert, C. (2007). Effect of clover management (*Rhizobium* seed inoculation and greenwaste compost amendments) and variety choice on yield and baking quality of organic spring and winter wheat. In: 3rd International Congress of the European Integrated Project Quality Low Input Food (QLIF), Hohenheim, March 20-23, 2007. Eds Niggli, U., Leifert, C., Alfoldi, T., Lueck, L. and Willer, H. pp 185 – 188.

Zadoks, J.C., Chang, T.T. and Konzak, C.F. (1974). A decimal code for the growth stages of cereals. Weed Research, **14**: 415-421.

6. APPENDIX

A) Micro nutrient supplementation trials by Field Science

Based on a report by Martin Lane, Field Science Ltd.

Introduction

The main purpose of this trial was to address the deficiency of just one of the vital trace elements – selenium. It is already known from using detailed soil and leaf analysis to formulate and apply balancing levels of minerals, that tissue levels of selenium in forage crops can be enhanced. The purpose of this research was to ascertain whether it is possible to replicate the process in milling wheat under organic conditions and improve selenium levels in bread. The aim was to demonstrate that the performance of the plant can be improved and the nutritional content of the bread can also be improved.

In particular the aim was to increase the selenium content of the flour and bread naturally, without supplementation. The reduction in Se content in the UK diet has been linked to an increase in incidence of adult cancers, heart disease and other conditions. Several millers have sought to market the selenium content of their breads but primarily through the use or addition of products of non-UK origin.

Field Science typically analyses soils for 15-20 nutrients. Based on the analysis, a trace element mix is produced and tailored exactly to that analysis. This approach differs from the use of "off the shelf products", which may or may not fit in with imbalances and deficiencies in soil nutrient levels.

The trials

The trial plots were located at Nafferton Farm, Stocksfield, in Northumberland. The sites were managed and monitored by Nafferton Ecological Farming Group.

The 16 trial plots consisted of 4 replicates of untreated control, compost added, trace elements added and compost added with trace elements. The trace element mixes used were tailored according to the soil analysis results such that each treated plot was given a marginally different mix to obtain the optimum balance.

The trials were carried out over two years, 2006 and 2007. Paragon wheat was drilled at 171kg per Ha in both years following a clover crop in the first year.

As well as mineral analysis, yield measurements were taken, chlorophyll levels measured and visual measurement of fungal disease levels taken.

Inputs

For both years 30 tonnes per hectare of compost were applied (giving 175kg per Ha of N) to the compost plots. The trace element mixes were tailored differently for each micronutrient plot and contained cobalt, copper, zinc, molybdenum, boron, iodine, copper and selenium. Each mix was made up to even weight using carrier material and applied at 25kg per hectare.

The micronutrient dressings were prepared by Field Science Limited according to commercially protected formulae. These take account of critical balances between the elements in the mix and in the soil. The compounds used are selected and blended to take account of soil type and the crop.

2006 results

The results of the 2006 trial were influenced by errors in the preliminary soil analysis which resulted in incorrect treatment levels being applied.

2007 results

The crop was not following clover on this occasion. Further soil analysis was taken to set the formulae for the micro nutrient applications. Details are provided in the summary Table A1 and the raw data in Table A2.

i) Mineral nutrient levels

No statistically significant variances were recorded other than in selenium levels.
On this occasion the selenium levels of the grain on the micronutrient plots were boosted to over 20 times and up to 140 times the control levels.

Table A1. Summary results of selenium analysis of wheat from trial plots 2007

Treatment	Wheat Selenium mg/kg
Untreated	0.17
Compost	0.23
Compost + Trace Elements	5.74
Trace Elements	6.98

It should be noted that after the laboratory error in year 1, for trial purposes a deliberate attempt to achieve high selenium levels was made. The levels achieved can be moderated to acceptable nutritional ranges.

ii) Yield

The combination of compost and micronutrients achieved a mean yield of 5.37t per Ha (2.17t per acre). The combination of the two only offered a 0.07 tonne per hectare advantage compared to using one or other in isolation. The treatments showed a 10% yield advantage over control.

It is significant that the addition of micronutrients involves the application of 25kg per hectare of carrier material containing the trace elements compared to 30 tonnes per hectare of compost. The resulting protection of soil structure has to be noted although compost applications remain important to maintain soil organic matter levels.

iii) Fungal disease levels

For the second year no statistically significant variances between the treatments were recorded.

iv) Chlorophyll

Overall there was no statistically significant variance. It is interesting to note that the highest recorded levels of chlorophyll were on micronutrient plots for the earlier reading and for the later reading on the combined compost/micronutrient plots.

Conclusions

The micro-nutrient formula employed can enhance the selenium level of milling wheat to a premium level. (These results have been replicated in separate trials in non organic systems).

i) The yield influence of compost and micronutrients is limited on wheat following clover.
ii) In a second wheat year the addition of micronutrients has a significant yield influence.
iii) The quantity of micro nutrient at 25kg/Ha has an operational advantage compared to bulkier inputs including compost.
iv) The addition of micronutrients achieved no significant advantage in terms of fungal resistance or chlorophyll levels.
v) From parallel experiments conducted by Field Science on conventionally grown milling wheats, it is concluded that selenium enhancement is possible to similar levels in this system, but fertilisers need to be chosen carefully to avoid blocking plant Se uptake.

Recommendations

Consideration should be given to large scale trials taking the crop through to milling in both organic and non-organic conditions. As analysis has shown better nutrient retention in soils with higher OM content, further research should be undertaken to establish the most cost-effective ratio between fertiliser/compost & trace mineral applications.

Consideration should be given to similar trials involving other food crops and other micronutrients, not just selenium. Owing to the industrialised and processed nature of the modern diet, levels of many important trace minerals have fallen sharply.

This technology should be recommended as a valid method for increasing selenium and other minerals currently deficient in the UK human diet. The technology already exists, and has been used as forage treatment for livestock animals for years.

Table A2. Results of selenium analysis 2007

Results of grain mineral analysis 2007 crop: selenium (mg/kg) Nafferton Spring Wheat (analysed 8/11/07)

Plot	Treatment	Se
1	Compost	0.14
2	Untreated	0.08
3	Trace Elements	8.61
4	Compost + Trace Elements	6.75
5	Compost + Trace Elements	4.42
6	Trace Elements	7.05
7	Untreated	0.08
8	Compost	0.05
9	Trace Elements	7.36
10	Compost + Trace Elements	6.70
11	Compost	0.38
12	Untreated	0.27
13	Untreated	0.24
14	Compost	0.35
15	Compost+ Trace Elements	5.08
16	Trace Elements	4.91
	Mean	3.28
	Minimum	0.05
	Maximum	8.61
	standard deviation	3.33
	# of total samples analysed	16
	method detection limits	0.05

Tests completed by UK lab Lancrop.

Results of agronomic assessments 2007

Yield t/ha

Treatment	Block 1	Block 2	Block 3	Block 4	Mean
Compost	6.72	4.76	5.37	4.42	5.32
Control	5.19	5.17	5.15	4.17	4.92
Micronutrients	5.12	5.26	5.70	5.31	5.34
Compost+Micronutrients	5.82	5.32	4.80	5.54	5.37

Moisture Content %

Treatment	Block 1	Block 2	Block 3	Block 4	Mean
Compost	19.30	19.86	20.30	22.65	20.53
Control	19.26	20.27	19.03	21.12	19.92
Micronutrients	21.14	22.19	20.79	18.55	20.67
Compost+Micronutrients	21.03	18.45	20.10	18.66	19.56

1000 seed Wt g

Treatment	Block 1	Block 2	Block 3	Block 4	Mean
Compost	40.95	40.63	39.78	39.43	40.20
Control	40.33	38.92	38.02	39.66	39.23
Micronutrients	41.30	41.5	39.87	40.91	40.90
Compost+Micronutrients	40.94	41.4	40.80	40.68	40.96

Chlorophyll 09-July

Treatment	Block 1	Block 2	Block 3	Block 4	Mean
Compost	41.00	43.20	40.50	39.20	40.98
Control	34.50	40.40	43.80	40.50	39.80
Micronutrients	44.30	38.90	43.40	43.50	42.53
Compost+Micronutrients	37.90	45.40	41.50	41.10	41.48

Chlorophyll 18-July

Treatment	Block 1	Block 2	Block 3	Block 4	Mean
Compost	40.70	41.70	41.30	38.50	40.55
Control	41.00	44.00	40.60	39.00	41.15
Micronutrients	40.50	43.90	42.10	37.90	41.10
Compost+Micronutrients	44.70	44.50	40.40	40.30	42.48

Note: Compost Applied 175 kgN/ha (140 units per acre)

B) Loaf volume results

Table B1, Loaf volume results (ml)from wheat variety Paragon in Untreated, compost and Chicken Manure Pellet (CMP) treatments for three sites and over four seasons (2006 to 2009) (Columns: Mean, SD, No of values)

Year	Site	Treatment			
		Unt	Comp	CMP	All
2006	S	3710	3666	3862	3753
		92	133	72	136
		6	12	12	30
2007	C	3131	3152	3069	3115
		60	68	73	77
		6	12	12	30
2008	C	3330		3444	3387
		269		178	226
		6	0	6	12
	S	3216	3299		3258
		100	10		78
		3	3	0	6
2009	S	2775	3075		2925
		346	77		278
		3	3	0	6

Table B2, Loaf volume results (ml)for six varieties of wheat treated with rhizobial inoculant and compost in 2008 +9 at two sites (Col: Mean, SD, No of values)

Year/ Site	Treatment	Variety						
		Paragon	Tybalt	Fasan	Amaretto	Zebra	Granary	All
2008 S	Untreated	3216	2783	3074	3146	2644	2787	2942
		100	155	113	135	126	12	240
		3	3	3	3	3	3	18
	Compost	3299	2844	3042	3216	2567	2876	2974
		10	69	115	219	238	38	280
		3	3	3	3	3	3	18
	Rhizo+FYM	3310	2799	2936	3204	2579	2842	2945
		121	97	160	101	269	83	285
		3	3	3	3	3	3	18
	Rhizo	3176	2753	3058	3259	2675	2834	2959
		117	42	48	80	279	33	250
		3	3	3	3	3	3	18
2009 S	Untreated	2775	3016	3076	2737	3217	2973	2966
		346	50	176	80	128	46	225
		3	3	3	3	3	3	18
	Compost	3075	3058	2866	2719	3189	3055	2994
		77	111	157	68	154	62	186
		3	3	3	3	3	3	18
	Rhizo+FYM	3122	3096	3004	2827	3235	3020	3051
		185	66	280	240	186	114	207
		3	3	3	3	3	3	18
	Rhizo	3439	3007	3083	2777	3138	3013	3076
		551	131	168	164	243	151	309
		3	3	3	3	3	3	18

Table B3 Loaf volume results (ml) for wheat from all untreated plots (Columns: Mean, SD, No of values)

Year	Site	Variety						
		Paragon	Tybalt	Fasan	Amaretto	Zebra	Granary	All
2006	S	3710	3632	3568	3624	3876		3686
		92	83	268	85	45		152
		6	3	3	3	3	0	18
2007	C	3131	3142	3208	3225	2959	3155	3136
		60	28	52	31	77	55	95
		6	3	3	3	3	3	21
2008	C	3330	3326	3271	3317	3313	3225	3297
		269	130	194	208	206	129	185
		6	6	6	6	6	6	36
	S	3216	2783	3074	3146	2644	2787	2942
		100	155	113	135	126	12	240
		3	3	3	3	3	3	18
2009	S	2775	3016	3076	2737	3217	2973	2966
		346	50	176	80	128	46	225
		3	3	3	3	3	3	18

C) Partner contact list

LINK Project Better Organic Bread (LK0960)

Richard Stanley Lead Participant	Campden BRI	Campden BRI, Chipping Campden Gloucestershire GL55 6LD Tel 01386 842004
Carlo Leifert Steven Wilcockson Academic Partner	University of Newcastle upon Tyne	Nafferton Ecological Farming Group, Nafferton Farm, Stocksfield, Northumberland, NE43 7XD Tel 01661 830222
Paul Matthews	FWP Matthews	Station road, Shipton Under Wychwood, Chipping Norton, Oxfordshire OX7 6BH Tel 01993 830342
George Marriage	W&H Marriage and Sons Ltd	Chelmer Mills, New Street, Chelmsford, Essex, CM1 1PN Tel 01245 354455

David Heathcote	ADM Milling	ADM Milling Ltd, Technical Centre, Hosegoods Mill, Old Dock, Avonmouth, Bristol, BS11 9DL, Tel 0117 912 3390
Shaun Taylor Colin Johnson	Rank Hovis Bakery Division Premier Foods	Premier Foods Group Ltd, Solent Flour Mills, Western Dock, Southampton, Hants, SO15 1BS Tel +44 0238 0902011
Brian Clarke	Maple Leaf Bakery UK Ltd	Maple Leaf Bakery UK Ltd, 38 Raleigh Street, Walsall, West Midlands, WS2 8RB, Tel 07711 989061
Bob Beard Stuart Jones	Warburtons	Warburtons Ltd, Hereford House, Hereford St, Bolton, Greater Manchester, BL1 8JB Tel 01204 531004
Alex Smith	Alara Wholefoods	Alara Wholefoods Ltd, 110-112 Camley Street, London NW1 0PF Tel 0207 387 9303
Andrew Whitley	BreadMatters	Macbiehill Farmhouse, Lamancha, West Linton, Peeblesshire, EH46 7AZ, Scotland Tel: 01968 660449
Simon Hook	HGCA-AHDB	HGCA-AHDB, Stoneleigh Park, Warwickshire, CV8 2TL Tel 0247 6478748
Peter Kindersley	Sheepdrove Organic Farm	Warren Farm, Lambourn Berkshire, RG17 7UU Tel 01488 674700
Peter Melchett	Courtyard Farm	Courtyard farm Ltd, Ringstead, Hunstanton Norfolk, PE36 5LQ Tel 01485 525251
Andrew Wilkinson	Gilchesters Organics	Gilchesters, Hawkwell, Stamfordham, NE18 0QL Tel 01661-886119
Charlie Langton	Field Science Ltd	C/o Cyberacres Ltd, Podsbank Allendale, Hexham, Northumberland, NE47 9EF Tel 0845 121071
Nigel Gossett	Norton Organic Grain Ltd	Norton Organic Grain Ltd, Ash Street, Boxford, Sudbury , Suffolk CO10 5DZ Tel 01787 210899
Peter Street	Sustainable Arable LINK	Defra, Room 601, Cromwell House, Dean Stanley Street, London SW1 3JP Tel 0207 2381515

D) Meetings held with project partners

Date	Venue	Host
11th Oct 2005	Campden BRI	Richard Stanley
17th Jan 2006	Sheepdrove Farm Lambourn	Peter Kindersley
24th May 2006	Nafferton Ecological Farming Group Corbridge	Carlo Leifert
14th Nov 2006	Sheepdrove Farm Lambourn	Peter Kindersley
14th May 2007	Courtyard Farm Hunstanton	Peter Melchett
14th Nov 2007	ADM Flour Mill Knottingley	David Heathcote
10th Mar 2008	Campden BRI	Richard Stanley
15th May 2008	Maple Leaf Bakery Park Royal, London	Brian Clarke
12th Nov 2008	University of Newcastle	Carlo Leifert
20th May 2009	FWP Matthews Flour Mill Chipping Norton	Paul Matthews
10th Dec 2009	W&H Marriage Flour Mill Chelmsford	George Marriage
25th May 2010	Nafferton Ecological Farming Group Corbridge	Carlo Leifert

E) Technology Transfer activities

1 Project summary presented at HGCA review meeting December 2006.

2 Results of Trial 3 presented at QLIF conference by Carlo Leifert in Germany March 2007.

3 Project presented to meeting of farmers and millers organised by FWP Matthews at Barrington Estate on 11th July 2007.

4 Results presented at Organic Arable open day at Sheepdrove 17th June 2008.

5 Trials results presented to organic arable meeting at Sheepdrove June 2008.

6 Attendance at Contemplating Conversion event, Shrewsbury June 2008.

7 Results presented to HGCA variety meeting 10th December 2008.

8 Presentation to Campden BRI Cereals Milling and Baking panel May 2009.

9 Project presented at Campden Day June 2009.

10 Project demonstrated at Cereals 2009 event. June 2009.

11 Project presented at Organic Cereals event July 2009.

12 Presentation to HGCA monitoring meeting December 2009.

13 Poster displayed at Campden BRI Day June 2010.

14 Attendance at Cereals 2010 June 2010.

15 Attendance at Organic Cereals event July 2010.