HGCA

## PROJECT REPORT No. 320

# BARLEY QUALITY AND GRAIN SIZE HOMOGENEITY FOR MALTING:

## VOLUME I: AGRONOMIC EFFECTS ON VARIETIES

## VOLUME II: ASSESSMENT AND CONTROL

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# BARLEY QUALITY AND GRAIN SIZE HOMOGENEITY FOR MALTING:

## VOLUME I: AGRONOMIC EFFECTS ON VARIETIES

By

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Volume I is the final report of a 34-month project that started in July 2001. The research was funded by a grant of £149,345 from HGCA (project no. 2306).

## VOLUME II: ASSESSMENT AND CONTROL

By

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Volume II is the final report of a 36-month project that started in July 2001. The research was funded by a grant of £128,000 from HGCA (project no. 2294).

# Joint abstract covering Project Report No. 120, Volumes I and II

Homogeneity, a measure of grain uniformity, is important for malting and brewing performance and is of increasing interest to maltsters who have to produce a homogeneous malt. The aim of this project was to investigate how barley and malt homogeneity are affected and could be improved by, agronomic management and malting process.

The work was conducted at two sites over three years.

**Field trials (Volume I of Project Report No. 120)**

The influences of barley variety, nitrogen application, seed rate, fungicide treatment and sowing date on barley properties were examined by ADAS.

**Malting trials (Volume II of Project Report No. 120)**

The grain produced in the field trials was passed to Brewing Research International for malting. The influence of the malting process (both commercial and laboratory) on malt homogeneity was then examined.

Reducing plant density significantly increased grain size and, possibly, grain size distribution. Grain size has a large influence on the homogeneity of a sample of barley. Seed rate may therefore be a practical way of agronomically influencing homogeneity. Grain nitrogen also increased at reduced plant densities. This effect was greater than that of variety and should be taken into consideration to achieve malting specification.

Fertiliser nitrogen rate and fungicide programme affected grain size by altering crop canopy size and duration and also influenced homogeneity. Nitrogen rate effects on grain nitrogen and thus endosperm structure are a major influence on homogeneity. There is a need to balance use of these agronomic treatments for homogeneity whilst aiming to optimise yield.

The main factors influencing the homogeneity of the malt were damage to grain, endosperm structure of the grain and the corn size distribution. Commercial malting plants did not have a major effect of malt homogeneity.

The main factor influencing the homogeneity of malt was the quality of the barley and the way it was treated in the field. The three key results found when malting grain obtained from the field trials were:

- a significant influence of the seed rate on the corn size distribution (mentioned above),
- a significant influence of nitrogen application on the endosperm structure of the grain (by LTm),
- a significant influence of variety on endosperm structure, corn size distribution and on homogeneity.

Treatments in the commercial malting plant had much less influence than did agronomic factors. This suggests that there are opportunities to grow malting barley under agronomic management to increase homogeneity. However, as such management regimes may not necessarily optimise output for the grower, premiums would have to be set to encourage their adoption.

## Contents

## Abstract

Barley homogeneity, a measure of grain lot uniformity, is important for malting and brewing performance and is of increasing interest to maltsters who have to produce a homogeneous malt sample. The aim of this project was to investigate how barley homogeneity was affected and could be improved by, agronomic management.

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Four field experiments were set-up at three sites in three years (2000, 2001 and 2002).

Experiment 1: four varieties at five seed rates in 2000-02.
Experiment 2: three nitrogen and three fungicide treatments with one variety at two seed rates in 2000-01.
Experiment 3: thirteen varieties at two sites in 2002.
Experiment 4: seven varieties at two sowing dates in 2002.

Spring barley compensates for reduced plant population similarly to winter wheat. Increases in tiller number, ear number per plant and grain number were all recorded at reduced plant densities. However, full compensation to maintain yield at low plant densities was not achieved. Hence, economic optimum seed rates for spring barley cannot be reduced as much as is possible with wheat.

Reducing plant density significantly increased grain size and, possibly, grain size distribution. Grain size has a large influence on the homogeneity of a sample of barley. Seed rate may therefore be a practical way of agronomically influencing homogeneity. Grain nitrogen also increased at reduced plant densities. This effect was greater than that of variety and should be taken into consideration to achieve malting specification.

Fertiliser nitrogen rate and fungicide programme affected grain size by altering crop canopy size and duration and also influenced homogeneity. Nitrogen rate effects on grain nitrogen and thus endosperm structure are a major influence on homogeneity. There is a need to balance use of these agronomic treatments for homogeneity whilst aiming to optimise yield.

Results suggest that there are opportunities to grow malting barley under agronomic management to increase homogeneity. However, as such management regimes may not necessarily optimise output for the grower, premiums would have to be set to encourage their adoption.

## Summary

### Introduction

Barley homogeneity is a measure of the uniformity of grains in a sample of barley. A number of grain properties are thought to influence homogeneity. Grain size, texture (mealiness and steeliness) and germinability (rate and evenness of germination) are considered to be most important. The homogeneity of barley is important for malting and brewing performance and thus is of increasing interest to processors. Poor homogeneity is often masked as analyses are carried out on milled samples of large numbers of grains. This variation between grains can lead to processing difficulties and a less uniform malt than is desirable for optimal brewing performance.

The aim of this project was to investigate the agronomic manipulation of key crop factors, such as tiller number and ear size that were most likely to influence homogeneity and therefore could be employed by growers to increase the homogeneity of their malting barley. A suite of field experiments that provided treatments with a 'stretch' in environmental and management regimes were investigated at three sites over three years.

### Aims and Objectives

Main aim:

1. To optimise barley homogeneity through variety-specific agronomic manipulation.

Specific Objectives:

1. To determine the major agronomic factors affecting homogeneity of barley samples through effects on tiller number, crop canopy, ear size and individual grain weight.
2. To develop understanding of the genetic influence of current and future varieties on tillering ability, source:sink relationships and variation in grain quality parameters.
3. To apply this understanding for manipulating crop performance and growth in the management of future varietal types.
4. To provide malting barley grain of known provenance for homogeneity evaluation by BRi.

### Methods

In each of three years, fully randomised and replicated field trials were set up at three sites. A site at ADAS Bridgets, Martyr Worthy, Winchester, Hampshire was used in 2000 and 2001 harvest years. ADAS Terrington, Terrington St.Clement, King's Lynn, Norfolk was used in 2002. A west of England site at White House Farm, Sellack, Ross-on-Wye was used in 2000 and at ADAS Rosemaund, Preston Wynne, Hereford in 2001 and 2002. A site at plant breeders New Farm Crops, Market Stainton, Lincolnshire was used in all three years.

At all sites in all years plots were drilled with an 'Oyjord type' tractor-mounted seed drill. Plot dimensions were 2m wide by 24m long at the ADAS sites and 1.5m wide by 10m long at

Syngenta seeds. Other than the experimental treatments described crops were grown using standard rates of agrochemicals and fertilisers with an aim to maintain undisturbed and healthy crop growth.

Experiment 1: Variety x Seed rate

Four varieties (Optic, Chariot, Cellar and Tavern), which represented the leading commercially available varieties at the time, were chosen. These varieties were sown at five seed rates (50, 100, 200, 400 and 800 seeds $m^{-2}$) in a two-way factorial design of variety and seed rate replicated three times.

Experiment 2: Seedrate x nitrogen/fungicide

A single variety Optic was sown at two seed rates 100 and 400 seeds $m^{-2}$ at three sites in 2000 (Ross-on-Wye, Bridgets and NFC) and 2001 (Rosemaund, Bridgets and NFC). Nitrogen treatments with rates of prilled ammonium nitrate of 50, 100 and 150 kg/ha were applied. Three fungicide treatment programmes were used:

1. GS30/31 Amistar Pro 2.0 l/ha plus Unix 0.67 kg/ha
2. GS30/31 Opus 1.0 l/ha plus Corbel 0.5 l/ha
3. GS30/31 Amistar Pro 2.0 l/ha plus Unix 0.67 kg/ha and GS45-59 Amistar Pro 2.0 l/ha

The experimental design was a fully randomised three-way factorial replicated three times.

Experiment 3: Variety typing

At two sites (Rosemaund and NFC) in 2002 thirteen varieties were sown at a standard seed rate (400 seeds $m^{-2}$). The varieties evaluated were Optic, Chariot, Cellar, Tavern, Chalice, County, Pewter, Static, Colston, Cocktail, Vortex, Novello and Sebastien. The varieties were fully randomised in each block and replicated three times.

Experiment 4: Sowing date x Variety

At a single site (Terrington) in 2002 seven varieties were sown at a standard seed rate (400 seeds m-2) on two sowing dates: a normal sowing on 18 February 2002 and a late sowing of 10 April 2002. The seven varieties evaluated were Optic, Cellar, Tavern, Chalice, County, Pewter and Static. The experimental design was a split plot plus factorial with sowing date as main plots and variety as fully randomised sub-plots.

**Measurements**

At the ADAS sites crop establishment was assessed pre-tillering with the number of plants counted in 10m x 1m row lengths per plot. Weekly measurements of light interception with ceptometers (Sunfleck meters) allowed canopy development to be monitored through the growing season. Crop growth assessed as both dry matter and green area index measurements were taken when 50% of all the main shoots reached mid-anthesis (GS65). An assessment of the components of yield was made on samples taken immediately pre-harvest. Grain yield was measured using a plot combine from a harvest area of 10m by 2m. Grain was analysed for moisture content and specific weight using a GAC 2000 grain analysis computer (Dickey-John corporation) and thousand-grain weight measured using a numigral grain counter. Additional image analysis assessments of grain size distribution were done on a sub-set of samples (see Appendix 5 for full methodology).

At NFC crop establishment was assessed pre-tillering with the number of plants counted in 10m x 1m row lengths per plot. Grain yield was measured using a plot combine from a harvest area of 10m by 1.5m. Grain was analysed for moisture content, specific weight, sieving fractions and grain nitrogen %.

## Key results and conclusions

### Plant population

The number of plants established from a given seed rate varied between sites and years, plant densities ranged from 30 to 721 plants m$^{-2}$ from the seed rates used of 50 to 800 seeds m$^{-2}$. Plant populations were lowest on a silty clay loam over chalk soil at Bridgets, Hampshire in 2000 and 2001 and highest in all three years on a loamy clay soil at NFC, Lincolnshire. Plant establishment declined with increasing seed rate with on average a 3.4% decline for every 100 seeds/m$^2$ increase in seed rate. This concurred with findings in wheat (Spink et al, 2000) although on average the rate of decline was less in spring barley. However, there was a greater variation in the magnitude of the effect than in wheat; establishment ranged from a high of 100% at 50 seeds to a low of 43% at 800 seeds. This may indicate that a spring-drilled barley crop's establishment may be more influenced by soil type, seedbed conditions and prevailing weather conditions post drilling than a winter-drilled cereal.

### Plant compensation for reduced plant densities

Tiller production primarily through extension of the duration of tillering has been shown to be a key mechanism by which plants compensate for reduced plant densities. Fertile shoot counts assessed from a destructive growth analysis sample at mid-anthesis showed that a 3.5 fold difference in plant density had been reduced to a 1.5 fold difference in shoot number by increased tiller production. Fertile shoot numbers of 439 and 684 per m$^2$ had been produced from 76 and 264 plants per m$^2$ respectively. As well as greater tiller production at reduced plant densities the size of the shoots in both dry matter and green area terms was increased. Green area and dry matter per shoot were increased on average by 24 and 32% respectively.

Variety effects showed that Tavern had a greater tiller capacity than the other three varieties, which produced similar numbers of tillers.

This compensation was maintained through to harvest with the 1.5 fold difference further reduced to a 1.3 fold difference in final ear numbers indicating a small increase in tiller survival. At the extremes of plant density (470 to 43 plants $m^{-2}$) an 11-fold difference in established plant number had been reduced to 2-fold difference in final ear number. Varietal differences in ear numbers confirmed what was observed in shoot numbers earlier in the season with the varieties ranked Tavern > Cellar > Chariot > Optic.

Ear number per plant calculated from final ear number and established plant population showed that on average 10 ears per plant were produced from low plant densities compared to 1.8 at the highest. In wheat up to 20 ears per plant were produced from reduced plant densities. The smaller response in spring barley may be symptomatic of the shorter time period available for tiller production in a spring-drilled crop.

Significant increases in grain number per ear as seed rate was reduced were seen in three site seasons. In 2000, 20% more grains per ear were produced as seed rate was reduced from 400 to 100 seeds and in 2001 an increase of 30% from 800 to 100 seeds. The increases, where they occurred, were significantly less than that seen in wheat where increase up to 70% have been recorded. This is because 2-row barleys have a determinate number of spikelets per floret (1) so the only mechanism for increasing ear size is to increase the numbers of spikelets. Wheat, however, has a determinate spikelet number but has the flexibility to increase the floret number per spikelet and therefore a greater capacity to increase grain number per ear. All of the varieties commonly grown for malting are 2-row barleys.

<u>Yield response to reduced plant densities</u>

Average yields ranged from 3.8 to 7.56 t/ha at Rosemaund in 2001 and NFC in 2000 respectively, showing considerable variation between sites and seasons. An initial rapid increase in yield as seed rates increased was recorded which then slowed once 200 seeds $m^{-2}$ (153 plants $m^{-2}$) was reached, but in general continued to increase up to the highest seed rates. In a number of site seasons Chariot in particular demonstrated the need for high seed rates for optimum yield. In the majority of site seasons for the other varieties no significant increase in yield was seen over and above 200 seeds $m^{-2}$. Using the linear plus exponential curve fits and a seed cost to grain price ratio of 3:1, economic optimum seed rates were estimated. Optima ranged from 136 to 364 seeds $m^{-2}$ or 81 to 328 plants $m^{-2}$. The wide variation between sites, seasons and varieties suggests that there is a greater risk in reducing seed rates in spring barley. A significant proportion of the variation is accounted for by establishment suggesting that soil conditions, seed bed quality and weather conditions immediately post-drilling are also critical.

Effects of reduced plant densities on grain quality

Significant increases in grain size in response to reduced plant population were recorded in all sites and seasons except Terrington in 2002. Grain size increased on average 11.5 % when plant population was reduced from 470 to 43 plants m$^{-2}$. In absolute terms this resulted in thousand-grain weight increases from 4 to 9 g (figure 1.0). This is almost double that seen in wheat, where average increases over the range of 16 to 340 plants m$^{-2}$ were 3.2g.

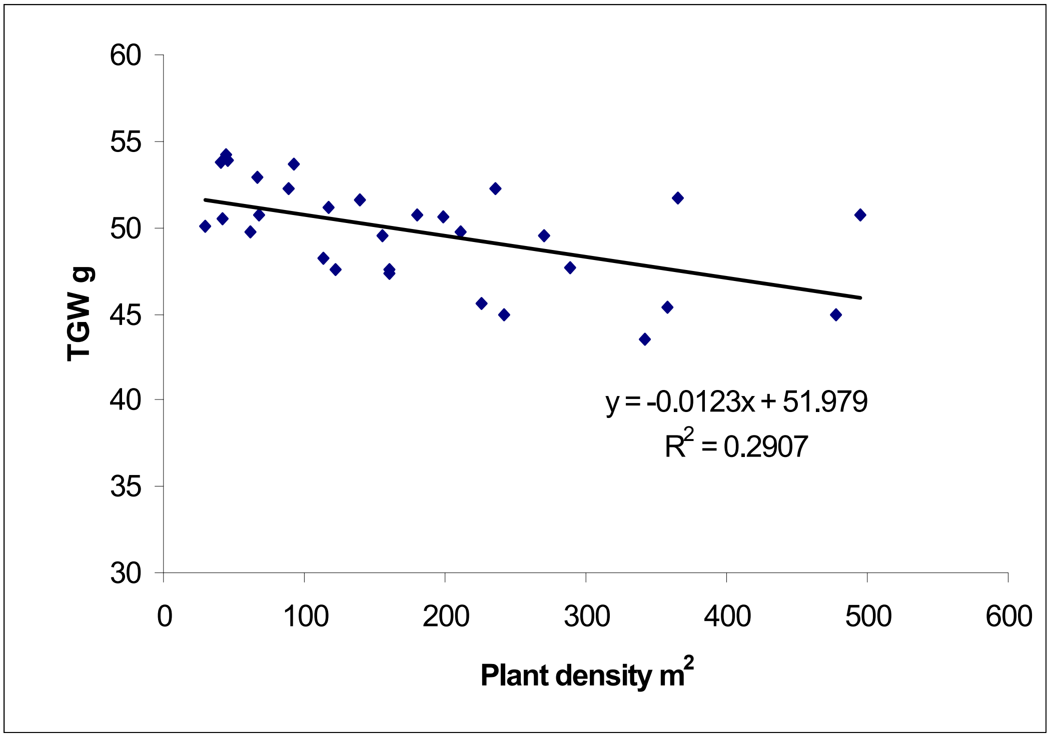


Figure 1.0. Regression analysis to indicate the relationship between thousand grain weight (g) and plant density (plants m$^2$) in spring barley from five site seasons meaned across four varieties.

This compensatory mechanism for reduced plant density may be the most important in terms of influencing homogeneity for two reasons: firstly because of the magnitude of the increases seen and secondly because of the importance of grain size in malting performance.

In five site seasons, the highest grain nitrogen contents were consistently produced from the lowest seed rates with 50 seed m$^{-2}$ on average 0.27%N higher than 800 seeds m$^{-2}$. This seed rate effect was double that seen between varieties where the lowest was Tavern and the highest was Chariot at 1.54 and 1.68% respectively (figure 1.1).

Grain nitrogen is of critical importance to ensure malting specifications are met and to increase saleability into a particular malting market. Malting barley growers select varieties and manage the nitrogen and fungicide inputs carefully to ensure crops meet malting specification and attract a premium. These results suggest that seed rate, and hence plant population, should also be taken into consideration, as its effects are considerable.

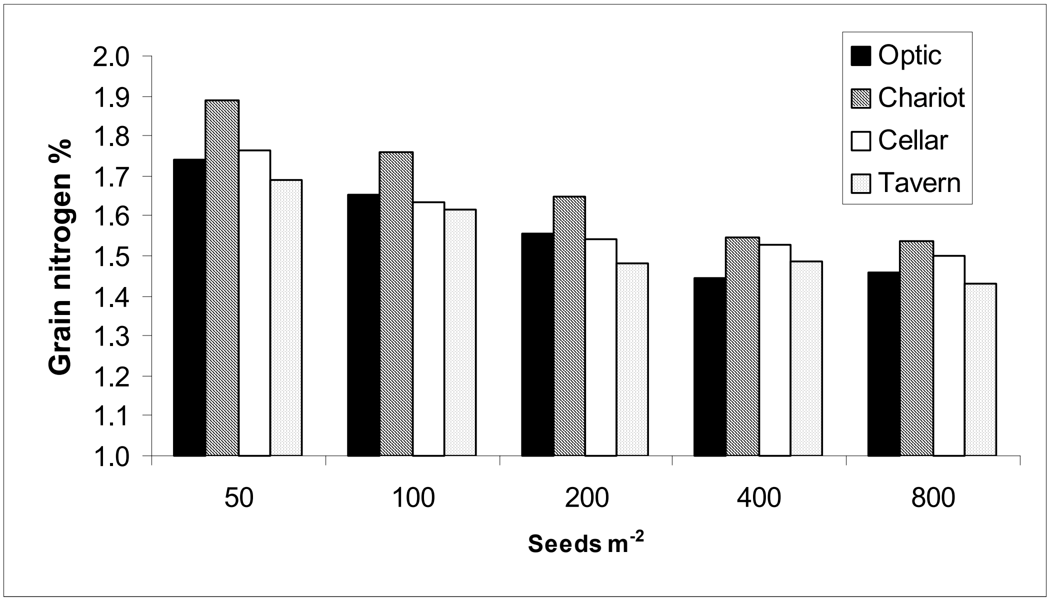


Figure 1.1. Grain nitrogen content (%) from four varieties across a range of seed rates mean of five site seasons.

## Effects of nitrogen and fungicide

Nitrogen and fungicide effects on canopy size were seen from data collected from two sites Rosemaund and Bridgets in 2000 and 2001 on the variety Optic. Increased fertiliser nitrogen rate were seen resulted in significant increases in both leaf and total green area index (GAI) and dry matter. On average, GAI was increased by 30 and 55 % from the 100 and 150 kg/ha N treatments compared to the 50 kg/ha. Dry matter was increased by 17.8 and 20.6% from the same two treatments. Strobilurin fungicide programmes increased GAI at mid-anthesis. On average, compared to the triazole program, GAI was 9% larger at mid-anthesis from a single application of strobilurin and 7.5% larger from a two-spray application.

These increases in crop size resulted in significant yield responses in all years to nitrogen. As fertiliser nitrogen rate increased yield increased, for every 1 kg/ha of applied nitrogen there was an increase of 15 kg of grain. Using a strobilurin fungicide programme increased yield in all years. On average, there was a 3% yield benefit in using a strobilurin compared to triazole in a single spray programme and 7% in using two sprays of a strobilurin. There was an indication that this response to strobilurin was improved at higher nitrogen rates especially at the more traditional light soil spring barley sites such as Bridgets in Hampshire on a loam soil overlaying chalk (figure 1.4).

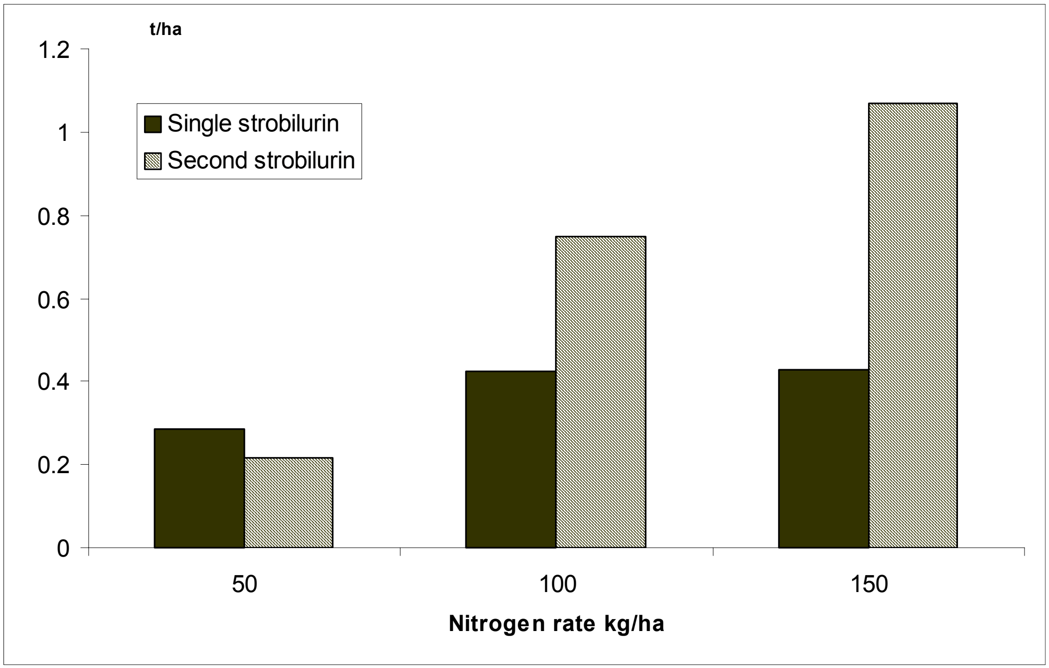


Figure 1.4. Yield responses in Optic to strobilurin fungicide programmes at three nitrogen rates average of Bridgets in 2000 and 2001.

The importance of grain size in malting performance discussed in the malting section of this report indicates that any manipulation through agronomy is of significance. Both nitrogen and fungicide significantly affect thousand-grain weight (tgw) (figure 1.4). On average, increases compared to the lowest N rate were 2.1 and 2.4% from the 100 and 150 kg/ha nitrogen treatments. Using a strobilurin fungicide increased tgw in three years out of four. Using a strobilurin instead of a triazole in a single spray programme increased tgw by 2% and in a two-spray programme by 3.8% on average. Although the effects are less than that seen with seed rate it demonstrates that careful consideration of a range of inputs will be needed if the grower is going to grow malting barley for maximum homogeneity.

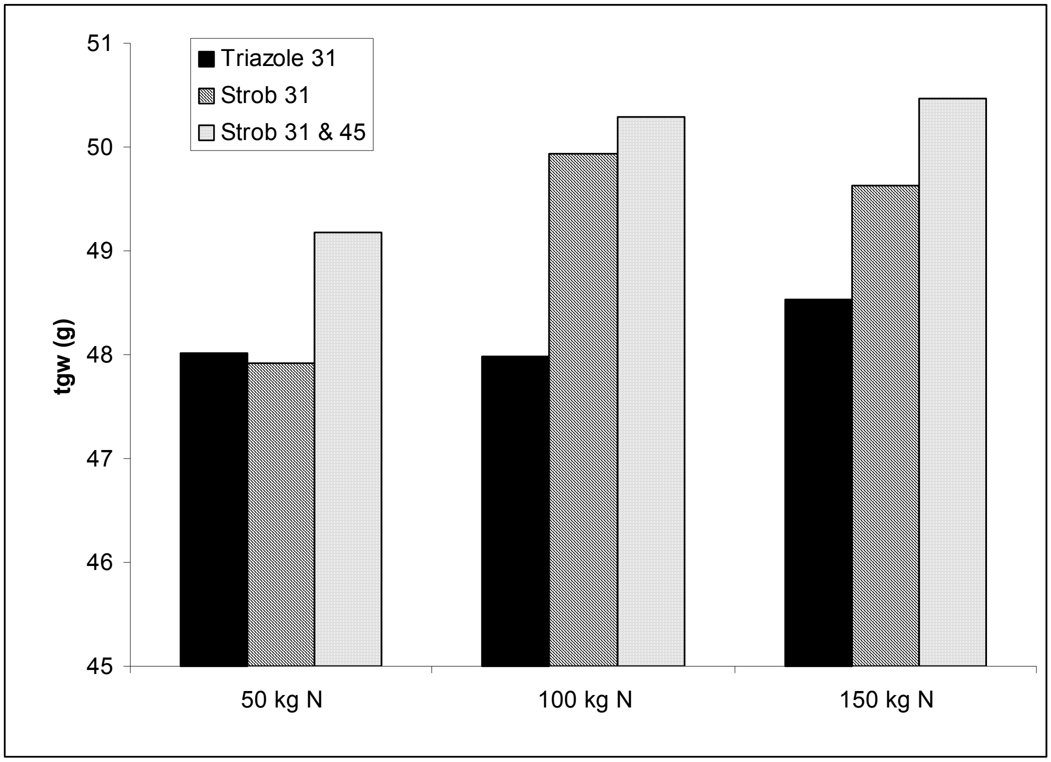


Figure 1.4. Thousand grain weight (g) in Optic from three fungicide programmes at three nitrogen rates average of four site years (Rosemaund, Bridgets 2000 and 2001)

Meeting the correct grain nitrogen specification is of critical importance to growers in order for them to achieve a saleable product at a malting premium. The changes in the maltsters requirements to higher grain nitrogen specifications in recent years means that the risk of over shooting on grain nitrogen has lessened. This allows growers a greater opportunity to maximise yield by increasing nitrogen rates. On average from the four site seasons of data collected in this study for every 50kg/ha increase in fertiliser nitrogen a 0.075% increase in grain nitrogen is seen. So the increases in yield with nitrogen rate would have to be balanced with risk of missing the 1.6-1.8% grain nitrogen target. This would suggest that nitrogen inputs of around 120-130 kg/ha would maximise yield without a high risk of producing grain higher than 1.8%. However, it has been seen earlier that plant population has a significant effect on grain nitrogen and this, along with soil type and soil mineral nitrogen reserves, would have to also be taken into consideration. There was no significant evidence of yield dilution effects of strobilurins on grain nitrogen (figure 1.5). The effect of nitrogen on endosperm structure and thus homogeneity is discussed further in the malting section of this report.

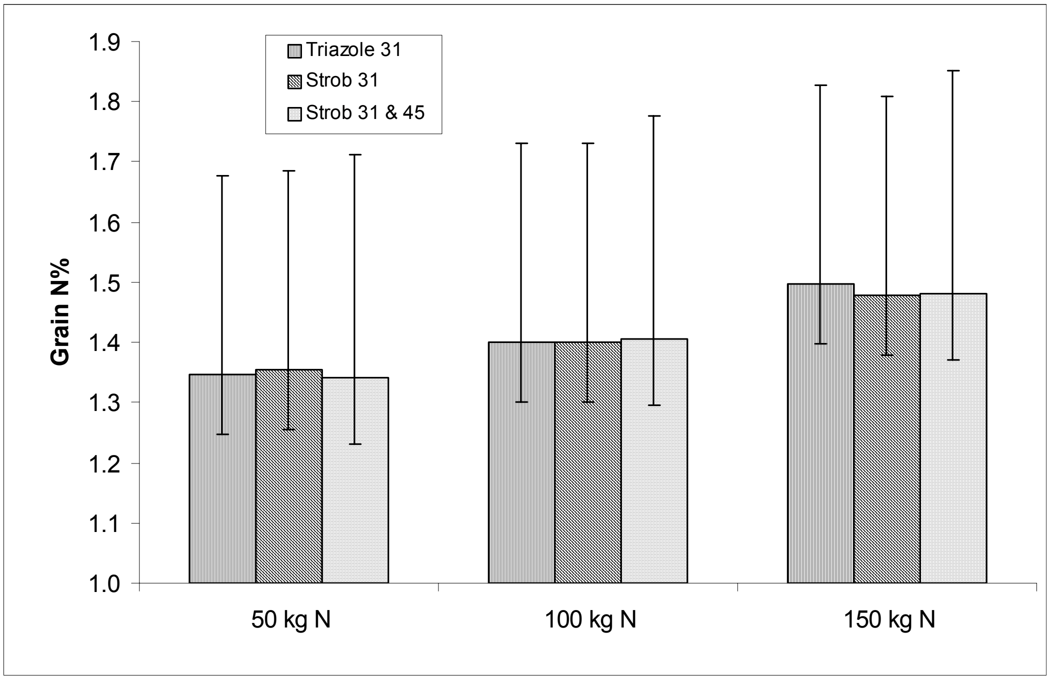


Figure 1.5. Grain nitrogen (%) from three fungicide programmes at three nitrogen rates average of four site years (Rosemaund, Bridgets 2000 and 2001)

Effects of sowing date

From the limited amount of data collected in this study there was an indication of significant interaction between sowing date and variety in terms of crop growth. The significant differences in crop growth seen did not result in significant interactions in terms of grain yield. Further research would be needed across a wider range of sowing dates in order to investigate these growth differences further and to assess the affect on ultimate grain yield and quality.

Image analysis

Results from this analysis technique concurred with those found by more traditional assessment methods such as thousand-grain weight. Increased grain area, perimeter, width and length were seen as seed rate was reduced. Frequency distribution graphs of grain area and width suggested that reducing seed rate had an adverse effect on grain size distribution, with a less homogeneous sample produced at reduced seed rates. With further validation against malt homogeneity and digital technology development of the technique, it may then be able to be used as a rapid analysis method at the grain intake stage.

## Implications

A main aim of this project was to identify whether agronomic factors can be used to manipulate and optimise the homogeneity of barley grain. Results show that seed rate can be used to manipulate grain size and possibly grain size distribution. This has been identified as a key influence barley homogeneity. Seed rate also has a large effect on grain nitrogen, which is also important in achieving homogeneous malt. Thus seed rate offers the grower one relatively easy agronomic way of manipulating homogeneity and possibly saleability. Nitrogen and choice of fungicide programme also have effects on grain size although to a lesser extent than seed rate. These inputs also have larger beneficial effects on yield than seed rate. Hence use of these inputs would have to be balanced with the effects of other agronomic and quality factors such as yield optimisation and grain nitrogen. The conclusion of the project forming Part II of this report on malt homogeneity, that how the crop is grown has a much larger effect on homogeneity than malting processes offers the grower further encouragement to grow for homogeneity. However, growing methods to produce the most homogeneous malt may not always correspond to the highest output to the grower, so premiums would have to be offered to encourage adoption by growers.

Further validation of the interaction of seed rate and fungicide programme in current and new varieties would enable growers to ‘grow for homogeneity’ with greater confidence. It would then be possible to set some graduated quality criteria for homogeneity, which would attract a varying premium to incentivise growers to achieve a more homogeneous sample.

## Technical detail

### Introduction

The importance of further research into quality requirements relating to Barley homogeneity was identified at the HGCA Malting Barley Workshop (Dr D Baxter, 29/30 June 1998). Barley homogeneity is defined as the uniformity between grains in a sample of barley. It can refer to numerous grain properties but those considered of most importance for malting are grain size, texture (mealiness and steeliness) and germinability (rate and evenness of germination). Homogeneity is an important parameter for malting and brewing performance and is becoming of increasing interest amongst processors, as evidenced by a number of recent publications in this area (Axcell, 1999; Home et al., 1999; Palmer, 1999).

Poor homogeneity is frequently overlooked because barley and malt analyses are carried out on a milled sample from a large number of individual grains. Poor homogeneity masked in this way can lead to processing difficulties for which the cause cannot be easily identified. Variation between grains in a sample of barley is further exacerbated during the malting process due to differences in grain hydration and rate of germination, thus leading to different rates of modification. Malting factors such as uneven steep aeration and differential kiln drying rates contribute further variation with the resultant malt being considerably less uniform than is desirable for optimal brewing performance. Rapid malting programmes such as are found in many modern malting plants means that greater emphasis must be placed on the homogeneity of barley if a uniform sample of malt is to be produced.

The agronomic manipulation of the key crop factors, such as tiller number and ear size (grain number/ear), thought most likely to have the most significant affect on homogeneity was the main focus of the project. The hypotheses of how agronomic manipulation can affect these factors are summarised in Table 1.

Table 1. Hypotheses on the effects of agronomic variables on tiller numbers and ear size

| Factor | Effects on tillering | Effects on ear size |
|---|---|---|
| Variety type | Varieties differ in economy of tillering due to genetic makeup | Grains/ear and individual grain weight strongly influenced by genetic factors |
| Seedrate | High seedrates lead to higher ear numbers m² and greater intra plant competition | High seedrates can result in less grains/ear on average and lower individual seed weight<br>Relationships not linear |
| Sowing date | Early sowing date encourages additional tillers since the tiller production phase is prolonged | Early sowing resulting in more fertile tillers which can reduce grains/ear |
| Nitrogen/ fungicides | Greater plant available N maximises tillering. More N can increase survival of later tillers but usually small. Fungicides, by prolonging photosynthetic tissue increase tiller survival and duration of grain filling. | Fungicides can enhance grain fill, enhancing grain size and perhaps texture, mealiness:steeliness. |

These hypotheses were investigated in a suite of field experiments at three sites over three years. The field experiments were designed to ‘stretch’ environmental and management regimes to provide a wide range of UK produced barley samples. The project therefore had the main aim:

To optimise barley homogeneity through variety specific agronomic manipulation. Optimising the balance between source and sink relationships in malting barley will maximise yield of saleable, quality grain. An incorrect balance may lead to loss of potential yield as shrivelled or smaller grains or poor homogeneity in malting performance. Work was carried out in parallel with a study at Brewing Research International in which aspects of the malting process of importance for malt homogeneity were examined (see Volume II of Project Report No. 320).

Specific objectives were set to achieve the main aim:

To determine the major agronomic factors affecting homogeneity of barley samples through effects on tiller number, crop canopy, ear size and individual grain weight.

To develop understanding of the genetic influence of current and future varieties on tillering ability, source:sink relationships and variation in grain quality parameters.

To apply this understanding for manipulating crop performance and growth in the management of future varietal types.

To provide malting barley grain of known provenance for homogeneity evaluation by BRi.

# Appendix 1

## Variety x Seed rate Interaction experiments

### Materials & Methods

In each of three years, fully randomised and replicated field trials were set up at three sites. A site at ADAS Bridgets, Martyr Worthy, Winchester, Hampshire was used in 2000 and 2001 harvest years and was replaced by ADAS Terrington, Terrington St.Clement, King's Lynn, Norfolk in 2002. A west of England site at White House Farm, Sellack, Ross-on-Wye was used in 2000 and at ADAS Rosemaund, Preston Wynne, Hereford in 2001 and 2002. A site at plant breeders New Farm Crops (NFC, now part of Syngenta seeds) Market Stainton, Lincolnshire was used in all three years.

The design was a two way factorial of variety and seedrate replicated three times. Four varieties were chosen (Optic, Chariot, Cellar and Tavern) which represented the leading commercially available varieties and a genetic variation in key traits. These varieties were sown at five seedrates (50, 100, 200, 400 and 800 seeds m$^{-2}$), which was expected to give a stretch in both plant population and tiller number. Plot size was 2m wide by 24m long at the ADAS sites and 1.5m wide by 10m long at Syngenta seeds. An Oyjord tractor mounted seed drill was used for drilling at all sites. All plots received standard rates of agrochemicals and fertilisers with an aim to maintain undisturbed and healthy crop growth.

Crop establishment was assessed pre-tillering with the number of plants counted in 10 x 1m row lengths per plot. Weekly measurements of light interception with ceptometers (Sunfleck meters) allowed canopy development to be monitored through the growing season. Crop growth was measured as both dry matter and green area index when 50% of all the main shoots reached mid-anthesis (GS65). An assessment of the components of yield was made on samples taken immediately pre-harvest and their relationship with combine grain yield and quality investigated.

## Results and Discussion

### Plant Establishment

Plant densities ranged from 30-721 plants m$^{-2}$ from the seed rates used 50 to 800 seeds m$^{-2}$ (Table 1.1). Establishment rates were higher at lower seed rates than at high seed rates this concurred with recent findings in wheat (Spink et al, 2000). Plant populations were low at the Bridgets site in 2001 and were highest in all three years at the NFC site in Lincolnshire.

Table 1.1. Plant establishment meaned across varieties and 3 sites

| Seed rate Seeds m$^{-2}$ | Established plant population m$^{-2}$ | | | | Plant establishment % |
|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | Mean | Mean |
| 50 | 47.37 | 37.20 | 42.83 | 43.17 | 86.34 |
| 100 | 87.60 | 76.95 | 81.62 | 82.85 | 82.85 |
| 200 | 161.37 | 147.45 | 145.95 | 152.99 | 76.49 |
| 400 | 300.63 | 303.70 | 278.15 | 295.09 | 73.77 |
| 800 | 481.77 | 426.45 | 495.70 | 469.94 | 58.74 |

The varieties differed in their establishment with Optic consistently being the poorest to establish with a mean establishment across the seed rates over the seven site seasons of 70.98% compared with Chariot 75.74, Cellar 76.26 and Tavern 76.50.

Establishment declined with increasing seed rate, averaged over all sites and years there was a decline of 3.4% establishment for every 100 seeds/m$^2$ that seed rate was increased. There was however significant variation in the magnitude of this effect, for example in the first year: at Rosemaund establishment declined from 92% at 50 seeds to 59% at 800 seeds, at Bridgets comparable figures at the same seed rates were 84% down to 43% and at New Farm Crops 100% down to 78%, the reason for this variation is however not understood. Autotoxicity is thought to be due to germinating seeds exuding chemicals which inhibit the germination of their neighbours (Molisch,1937 and Putman,1985) the efficacy of these chemicals may be influenced by soil type and or prevailing meterological conditions. For example, in wet weather these exudates may be diluted, or leached down into the soil away from the germinating seed.

### Canopy Production

Plant compensatory mechanisms for reduced plant populations in winter wheat crops have been the focus of much research recently. The increased tillering capacity and duration of tillering have been identified as key. It was thought that the shorter growing season and faster development rates of spring barley may limit the crops ability to compensate in the same way.

However evidence of compensation for reduced plant population was seen in the fertile shoot counts taken with the growth analysis sample at GS 65 from a reduced and normal plant density. Where a 3.5 fold reduction in plant density (264 to 76 plants m$^{-2}$) was reduced to a 1.5 fold reduction in shoot number by increased tiller production (Table 1.2). There were significant differences in tillering between the varieties, Tavern, was consistently the most profuse of the four with the others having a similar tillering capacity. This response was consistent across the seed rates with a significant interaction in only one site year, at Bridgets in 2000, at this site Chariot produced few tillers at a low seed rate but was one of the best tillered at a higher seed rate.

Table 1.2 Average Canopy growth data from GS 65 growth analysis at two seed rates from two sites (Rosemaund and Bridgets) in all three years.

| Variety | Plant Density | Fertile shoots (m$^2$) | Green area index | Dry matter (t/ha) | Green area per shoot (cm$^2$) | Dry matter per shoot (g/m$^2$) |
|---|---|---|---|---|---|---|
| Optic | 72 | 446.32 | 2.88 | 5.88 | 64.62 | 1.35 |
| Chariot | 76 | 387.25 | 2.53 | 6.13 | 63.53 | 1.57 |
| Cellar | 82 | 422.60 | 2.63 | 6.51 | 62.28 | 1.56 |
| Tavern | 70 | 500.09 | 2.74 | 6.46 | 54.32 | 1.30 |
| **Mean** | **76** | **439.12** | **2.69** | **6.24** | **60.49** | **1.43** |
| | | | | | | |
| Optic | 242 | 608.57 | 3.37 | 6.70 | 54.24 | 1.11 |
| Chariot | 265 | 702.49 | 3.44 | 7.88 | 47.68 | 1.14 |
| Cellar | 274 | 637.45 | 3.35 | 7.19 | 50.02 | 1.12 |
| Tavern | 275 | 786.31 | 3.65 | 7.57 | 44.79 | 0.97 |
| **Mean** | **264** | **683.55** | **3.45** | **7.34** | **48.80** | **1.08** |
| | | | | | | |
| **Overall mean** | | **561.24** | **3.08** | **6.79** | **53.69** | **1.22** |

Canopy sizes and to a lesser extent dry matter production were lower than those that are produced by winter cereals and were particularly low in the first two years as a consequence of dry periods in the spring during canopy formation. In the three years 2000, 2001, 2002, green area indices ranged from 1.51 to 3.37, 1.28 to 4.03 and 3.79 to 6.87 respectively. At lower plant densities green area per shoot was on average 24% higher to that at a higher density. This is consistent with the findings in wheat where an average increase of 22% was seen. In dry matter terms shoots of lower density plants are larger as well. On average across the varieties shoots from plants grown at low density had 32% more dry matter than those at a higher density. Therefore the compensation for reduced plant densities was not only in increased tillering but also in the size of the tillers.

The small canopies in spring barley maybe a factor limiting yield potential and have possible quality implications and therefore worthy of further research. The quality implications will be discussed further later in this report.

An indication of the timing of this compensation during the growing season and therefore it's impact on resource capture and yield formation can be gained from weekly light interception readings. These indicate that by GS 45, the compensation and the effect of seed rate on the plant's ability to intercept photosynthetically active radiation (PAR) in the all of the seed rates apart from the lowest were negligible, an example from one site season can be seen in Figure 1.

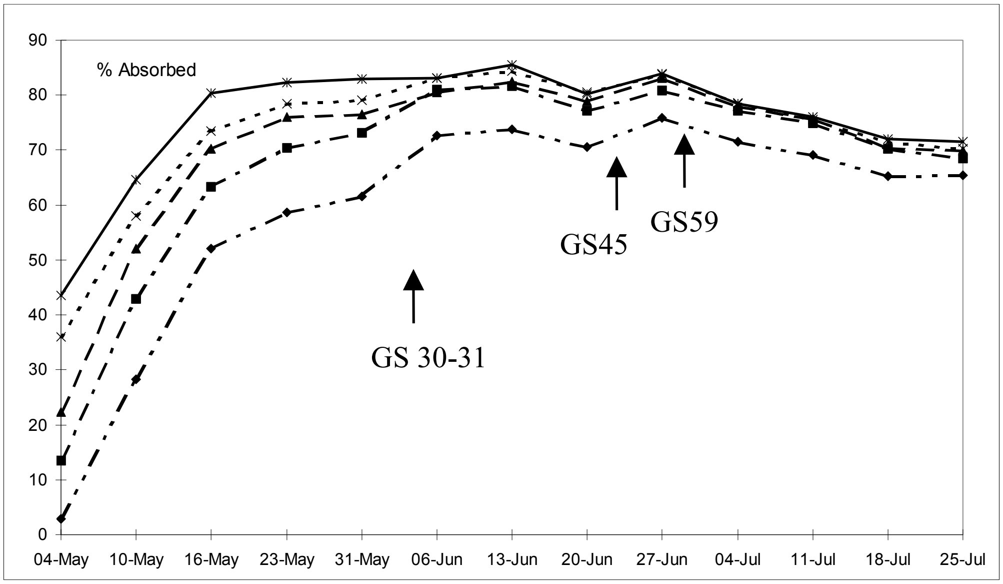


Figure 1.0 PAR absorbed by the spring barley crop at Rosemaund 2000 at 50 (◆—••—◆), 100 (■—•—■), 200 (▲— —▲), 400 (×--×), 800 seeds (✳—✳).

## Fertile ear numbers

By harvest, the 3.5 fold difference in plant density from seed rates 100 and 400 seeds had been further reduced from a 1.5 fold difference seen at GS 65 to a 1.3 fold difference in final ear numbers. This was due to a slightly improved tiller survival at the lower plant densities. At the extremes of plant density (470 to 43 plants m$^{-2}$) an 11 fold difference in established plant number had been reduced to 2 fold difference in final ear number.

Varietal differences in ear numbers confirmed what was observed in shoot numbers earlier in the season with the varieties ranked Tavern > Cellar > Chariot > Optic. Tavern, Cellar, Chariot and Optic produced 662, 625, 600 and 598 ears/m$^2$ respectively averaged over all the seed rates in seven site seasons. There was a significant interaction of variety and seed rate in the first year only at both Rosemaund and Bridgets. At Bridgets, Tavern produced fewer ears than the other varieties at reduced plant densities whereas at high densities it was the converse. At Rosemaund, Optic was one of the varieties that produced the most ears at reduced plant densities but at high densities produced the least.

**Ear numbers per plant**

Using the final ear number and the established plant population to calculate fertile ear numbers per plant, on average 10 ears per plant were produced at the lowest plant density compared to 1.8 at the highest. This compensation for low plant densities is about half that seen in wheat where 20 ears per plant were produced at low plant densities. This is most likely to be due to the shorter period of time after crop emergence of a spring drilled crop compared to a winter crop that is available for the plant to produce tillers.

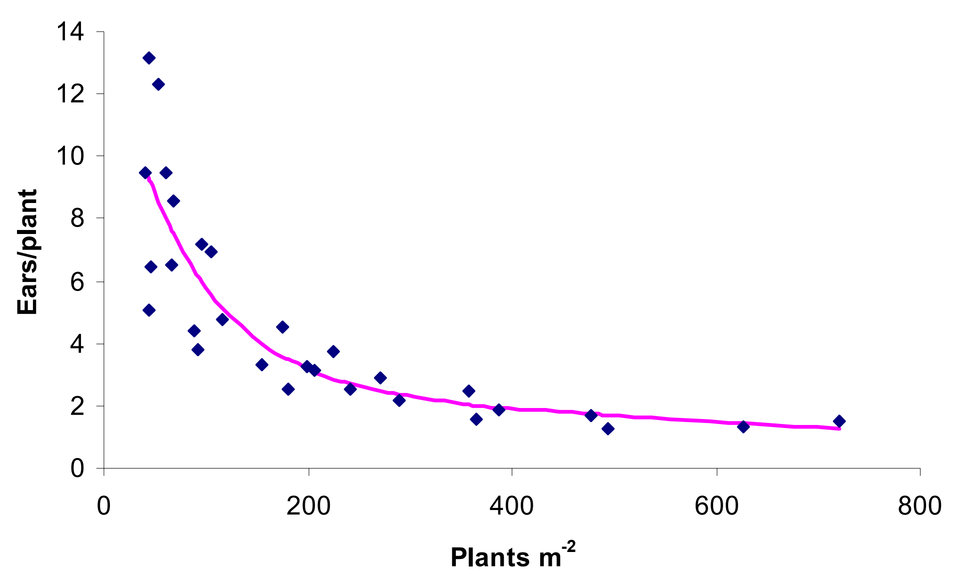


Figure 1.2. The effect of plant density of ear number per plant meaned across the varieties from seven site seasons, variance accounted for 71.8%. Curve fitted 2.51 + 11.89 * 0.98778$^x$ + -0.00173x.

The ranking of the varieties differs when you look at them in terms of ear numbers per plant compared to tiller number (Figure 1.3) although due to Tavern's high tillering capacity it still has significantly more ears per plant. This ranking remained constant across the changes in plant densities so no interaction of variety and seed rate was observed.

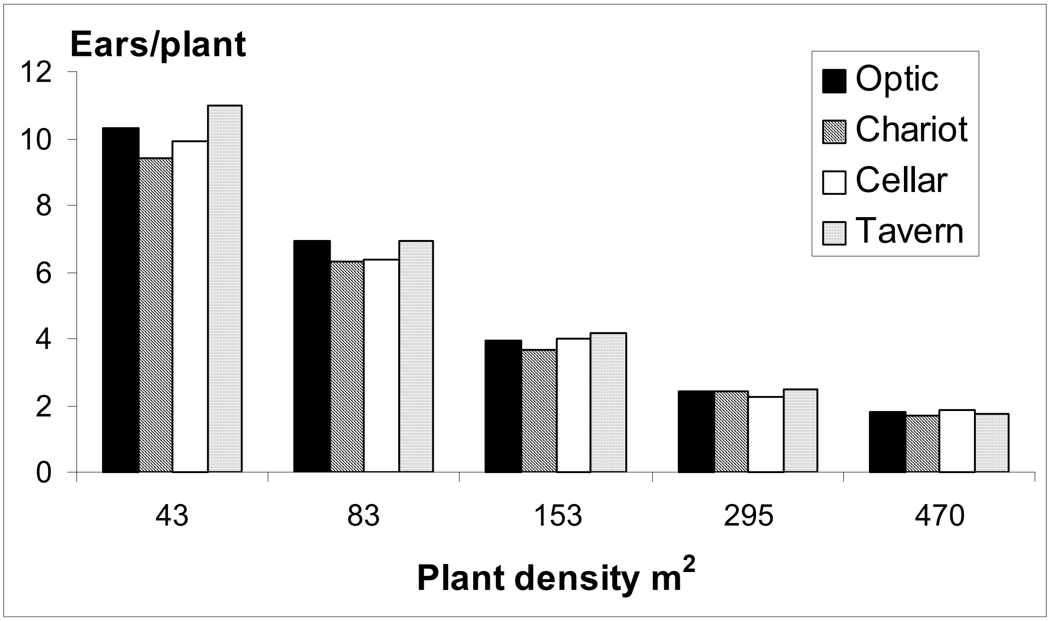


Figure 1.3 Varietal differences in ear numbers per plant calculated from final ear numbers and established plant population across a range of plant densities average across seven site seasons.

**Grain number per ear**

As with wheat there was a significant increase in grain number per ear as seed rate was reduced at both Rosemaund and Bridgets in the first year resulting in an increase in grain number of about 20% as seed rate was reduced from 400 to 100 seeds/m$^2$. In the second year there was again a significant increase in grain number with 100 seeds producing about 30% more grain per ear than 800 seeds per m$^2$ (Figure 1.4). However this effect was not seen, at either Bridgets in the second year or either site in the third year. Even where increases in grain number per ear were observed they were relatively small in comparison to those found in wheat where increases of up to 70% have been recorded (Spink et al, 2000). This is perhaps unsurprising as these 2-row barleys have a determinate number of spikelets per floret and any increase in ear size must be due to increased spikelet number, whereas wheat although determinate in terms of spikelet number has significant flexibility in floret number per spikelet, with up to 10 possible but rarely more than 3-4 viable.

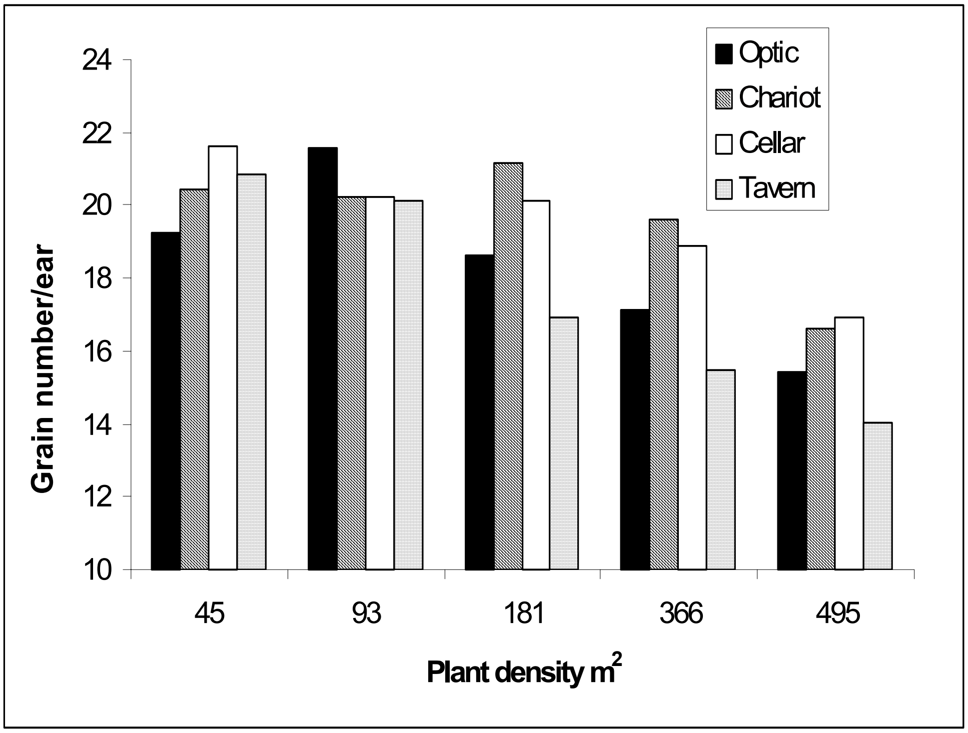


Figure 1.4. Grain number per ear across the range of plant densities for all varieties from ADAS Rosemaund in Year 2 (2001). SED for seed rate means is 1.31 (*P* = 0.003), Variety and Seed rate x Variety not significant.

**Grain size**

Grain size increased with decreasing seed rate in all sites and seasons except Terrington in year 3, where average thousand grain weight (TGW) decreased by 3g from 800 seeds to 50 seeds. Grain size increase over the same seed rate range over the other sites and years averaged 6g, but ranged from 4g at Bridgets in the second year to 9g at Rosemaund in the first year (Table 1.3). This 11.5 % increase in grain size at reduced plant population was significantly greater than the 6 % seen in wheat, where average TGW increased by 3.2 g from 640 to 20 seeds per m$^2$ (Spink et al, 2000). The importance and significance in terms of homogeneity and malting performance of the changes in TGW at different plant populations will be discussed later in this report but this does suggest that the grower can use seed rate in spring malting barley to manipulate the physical grain size of his crop.

There are significant differences in TGW between the varieties in all sites and seasons, in most cases this is due to Chariot having significantly smaller grain than the other three varieties (Table 1.4). In all years except Rosemaund in the first year and Bridgets in the second year there is no interaction between Variety and seed rate therefore the ranking in grain size terms of Cellar > Tavern > Optic > Chariot remained relatively constant across the seedrates.

Table 1.3. Thousand grain weight (g, 15% moisture) at a range of seed rates ($m^{-2}$) at two sites in each of three years, 2000, 2001 and 2002 meaned across four varieties.

| Seed rate | Year 1 (2000) | | Year 2 (2001) | | Year 3 (2002) | |
|---|---|---|---|---|---|---|
| Seeds $m^{-2}$ | Rosemaund | Bridgets | Rosemaund | Bridgets | Rosemaund | Terrington |
| 50 | 53.9 | 50.54 | 54.17 | 50.1 | 53.83 | 33.19 |
| 100 | 52.3 | 50.74 | 53.72 | 49.7 | 52.93 | 35.71 |
| 200 | 49.5 | 47.58 | 50.75 | 48.2 | 51.14 | 37.36 |
| 400 | 47.7 | 45.55 | 51.74 | 45 | 50.65 | 37.33 |
| 800 | 44.9 | 43.57 | 50.77 | 45.4 | 49.53 | 36.88 |
| **Mean** | **49.7** | **47.6** | **52.23** | **47.4** | **51.62** | **36.09** |
| **Seedrate SED** | **0.602** | **0.907** | **1.827** | **0.653** | **0.691** | **1.359** |
| **p value** | **<0.001** | **<0.001** | **NS** | **<0.001** | **<0.001** | **0.005** |

Table 1.4. Thousand grain weight (g, 15% moisture) of Optic, Chariot, Cellar, and Tavern at two sites in each of three years, 2000, 2001 and 2002 meaned across five seed rates ($m^{-2}$).

| Seed rate | Year 1 (2000) | | Year 2 (2001) | | Year 3 (2002) | |
|---|---|---|---|---|---|---|
| Seeds $m^{-2}$ | Rosemaund | Bridgets | Rosemaund | Bridgets | Rosemaund | Terrington |
| Optic | 51.22 | 48.26 | 55.14 | 47.90 | 49.80 | 35.69 |
| Chariot | 46.18 | 44.77 | 47.57 | 43.92 | 46.38 | 30.33 |
| Cellar | 51.72 | 49.63 | 54.60 | 49.06 | 56.22 | 39.26 |
| Tavern | 49.56 | 47.73 | 51.60 | 48.68 | 54.07 | 39.10 |
| **Mean** | **49.67** | **47.60** | **52.23** | **47.39** | **51.62** | **36.09** |
| **Variety SED** | **0.539** | **0.811** | **1.634** | **0.584** | **0.618** | **1.216** |
| **p value** | **<0.001** | **<0.001** | **<0.001** | **<0.001** | **<0.001** | **<0.001** |

As well as average grain size the distribution of grain size may be important in determining homogeneity. An image analysis method was therefore developed whereby a number of grains were scanned and the projected area measured. The results reflected the increased grain size at lower seed rates but indicated larger variation in grain size as indicated by the higher standard deviation at lower seed rate (figures 1.6 and 1.7). This suggests that although lower seed rates have more large grains because of the larger variation in size this may lead to a less homogeneous sample.

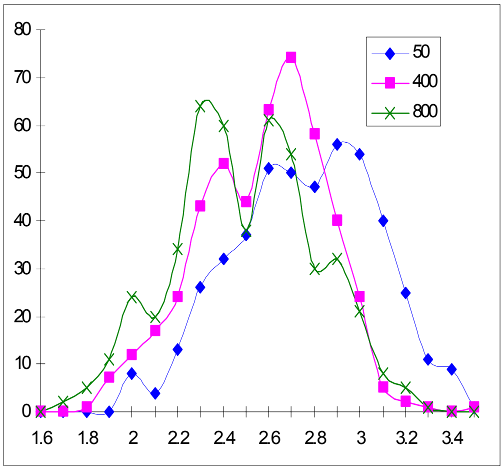


Figure 1.6. Frequency distribution graphs for grain area mm$^{-2}$ for 50, 400 and 800 seeds from Rosemaund in year 1.
Standard deviations 50 = 0.312, 400 = 0.278
800 = 0.313.

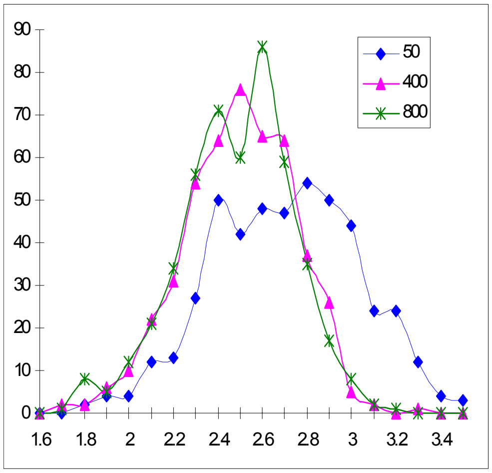


Figure 1.7. Frequency distribution graphs for grain area mm$^{-2}$ for 50, 400 and 800 seeds from Bridgets in year 1.
Standard deviations 50 = 0.331, 400 = 0.248
800 = 0.252.

## Yield

Seed rate and variety main effects were significant at all sites in all years (Table 1.5). Considerable variation in grain yield was seen between sites and seasons with average yields ranging from 3.8 t/ha at Rosemaund in 2001 to 7.56 t/ha at New Farm Crops in 2000.

Variety main effects showed Tavern and Cellar having similar average yields of 5.78 and 5.72 t/ha respectively, Optic 5.4 and Chariot consistently the poorest yielding at 4.79.

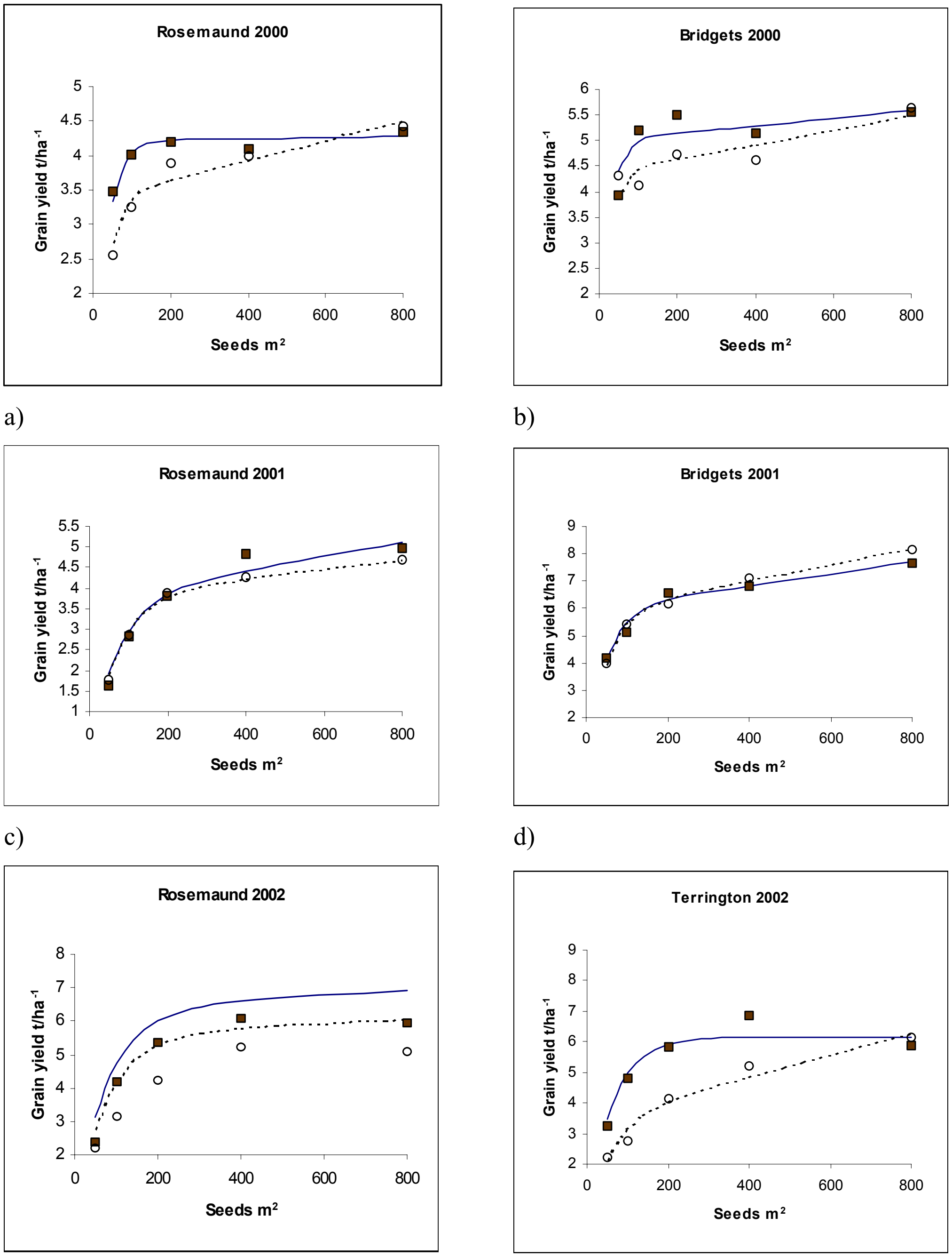
As seed rate and thus plant population is increased from 50 seeds m$^{-2}$ or 43 plants m$^{-2}$ yield increased rapidly once 200 seeds m$^{-2}$ or 153 plants m$^{-2}$ is reached the yield increases lessen but tend to continue to increase up to 800 seeds m$^{-2}$ or 470 plants m$^{-2}$. This response curve to seed rate is in general consistent with that seen in wheat at low populations but in wheat once at plant population of 150 plants m$^{-2}$ is achieved there is no further significant increase in yield.

Table 1.5. Significance (F pr) of the seed rate, variety and seed rate * variety interaction.

| | **Rosemaund** | | | **Bridgets** | | **Terrington** | **New Farm Crops** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2000** | **2001** | **2002** | **2000** | **2001** | **2002** | **2000** | **2001** | **2002** |
| Seed rate | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NA |
| Variety | 0.002 | <0.001 | <0.001 | 0.003 | <0.001 | <0.001 | <0.001 | <0.001 | NA |
| Interaction | 0.113 | 0.049 | 0.406 | 0.157 | 0.635 | 0.467 | 0.051 | 0.040 | NA |

However there are significant interactions between seed rate and variety in a number of site seasons (Table 1.5). In 2000 at Rosemaund (P=0.049), Chariot appeared to need higher seed rates with yield increasing up to 800 seeds m$^{-2}$ when there is little increase seen in the other three varieties over 400 seeds m$^{-2}$. At NFC in 2001 (P = 0.04) Chariot appeared to be loosing yield more rapidly at low seed rates than the other varieties. This effect is repeated at NFC in 2000 (p = 0.051). In 2002 at Terrington (P=0.044) Chariot's yield continued to increase at 800 seeds m$^{-2}$ whereas the other varieties decline from 400 to 800, it also seemed to loose yield more rapidly at low seed rates. There were, no significant interactions at other sites. This differentiation in Chariots yield response to seed rate compared to the other varieties, where similar trends were seen (regression analyses of yield and seed rate in figure 1.8 demonstrate this with a comparison of Chariot and Optic as an example of the other varieties). May be related to its small seed size, which limited the varieties ability to compensate at reduced populations, and thus it produces an optimum yield from high seed and ear numbers.

Economic optimum seed rates were established from the linear plus exponential curve fitting, these took into account the cost of seed, a nominal price of £240/t was used and the price of malting barley, £80/t was used giving a ratio of 3:1. The resulting optima reflected the site and seasonal variation in yield mentioned earlier (Table1.6). In 2000 the optima for all varieties except Chariot were 140 seeds m$^{-2}$ with Chariot higher at 207 seeds m$^{-2}$. In 2001 at Rosemaund optima were generally much higher with Chariot, Tavern and Cellar with optimums of 364, 287 and 297 seeds m$^{-2}$ respectively and Optic not reaching an optimum. which was the case for all of the varieties at Bridgets in the same year. At Rosemaund in 2002 they were reasonably consistent for all varieties ranging from 331 for Chariot to 360 for Cellar. At Terrington in the same year optimum seed rates were 242, 252 and 261 for Tavern, Optic and Cellar respectively with Chariot not achieving an optimum. The variability in the optimum seed rates achieved indicates the greater susceptibility of a spring crop to soil and seed bed conditions at planting and weather conditions post drilling particularly in early spring. The site variations in optima suggest that at lighter soil sites more typical of traditional spring malting barley growing areas (such as Bridgets) there maybe a greater opportunity to reduce seed rates.



a)

b)

c)

d)

e)

f)

Figure 1.8. a-f. Relationship between seed rate seeds m$^{-2}$ and grain yield t/ha at two sites in three years. Curve fitted linear plus exponential Y = a + b(r)$^{x}$ +cx. Variety Optic (■ fitted curve solid line) Chariot (0 fitted curve dashed line).

Table 1.6. Relationship between yield and seed rates, and the coefficients a, b, c and r in the linear plus exponential equation $Y = a + b(r)^x + cx$. % var refers to % of variance accounted; SE to standard error; opt rate to optimum seed rate and opt plants to optimum plant population.

| Year | Site | Variety | a=-b | c | r | % var | opt rate | SE opt rate | opt plants |
|---|---|---|---|---|---|---|---|---|---|
| 2000 | Rosemaund | Optic | 4.20 | 0.0001 | 0.9688 | 35.4 | 144 | 18 | 115 |
| | | Chariot | 3.36 | 0.00143 | 0.9688 | 35.4 | 230 | >opt | 183 |
| | Bridgets | Optic | 4.99 | 0.00073 | 0.9597 | 39.9 | 136 | 24 | 81 |
| | | Chariot | 4.36 | 0.00143 | 0.9597 | 39.9 | 184 | >opt | 110 |
| 2001 | Rosemaund | Optic | 3.74 | 0.00173 | 0.9866 | 79.8 | >max | - | - |
| | | Chariot | 3.81 | 0.00112 | 0.9866 | 79.8 | 364 | 115 | 328 |
| | Bridgets | Optic | 5.98 | 0.00214 | 0.9789 | 88.4 | >max | 235 | - |
| | | Chariot | 5.79 | 0.00301 | 0.9789 | 88.4 | >max | - | - |
| 2002 | Rosemaund | Optic | 6.32 | 0.00075 | 0.9867 | 78.7 | 352 | 77 | 176 |
| | | Chariot | 5.57 | 0.00061 | 0.9867 | 78.7 | 331 | 64 | 166 |
| | Terrington | Optic | 6.16 | -0.00001 | 0.9834 | 85.8 | 252 | 25 | 189 |
| | | Chariot | 3.45 | 0.00356 | 0.9834 | 85.8 | >max | >max | - |

### Grain quality

#### Specific weight

The effect of seed rate on specific weight was generally small and inconsistent. There were, however, significant effects in all but two sites, the lowest seed rate was never the best on average 2.4 % lower. The highest specific weights were achieved from 800 seeds m$^{-2}$ in five of the nine site seasons, but in the other four years it was as poor as the lowest seed rate. The intermediate seed rates of 100-400 seeds m$^{-2}$ were however consistently good and comparable to each other, 400 seeds m$^{-2}$ having the overall highest specific weight. Varietal effects were significant in all years bar one, however the effects were inconsistent across site seasons and suggested no real varietal trends. The ranking of the varieties averaged across all years was Tavern > Optic > Cellar > Chariot.

#### Grain moisture

The moisture content of grain at harvest is always of concern to growers due to storage and drying costs but the effect of moisture content on malting processes due to differential water uptake may not have been considered. The perceived higher risk of increased moisture contents from crops grown at reduced plant populations due to greater tiller hierarchy and therefore an increased risk of immature tillers has also concerned growers. In these experiments moisture content was significantly higher in low compared to high seed rates at all sites. The effect was greatest at the 50 seeds m$^{-2}$, and sometimes the 100 seeds m$^{-2}$ seed rate, there was rarely however a significant difference between the 200 and 800 seed rates.

There were perhaps unsurprisingly significant variety differences in grain moisture, this is to be expected if varieties with different maturity dates are harvested on the same date following identical sowing dates. There was however more surprisingly a significant variety * seed rate interaction at Bridgets in years 1 & 2, NFC in year 2 and Rosemaund and Terrington in year 3. This interaction appeared to be due to a tendency for Optic to suffer from particularly high moisture contents at low seed rates.

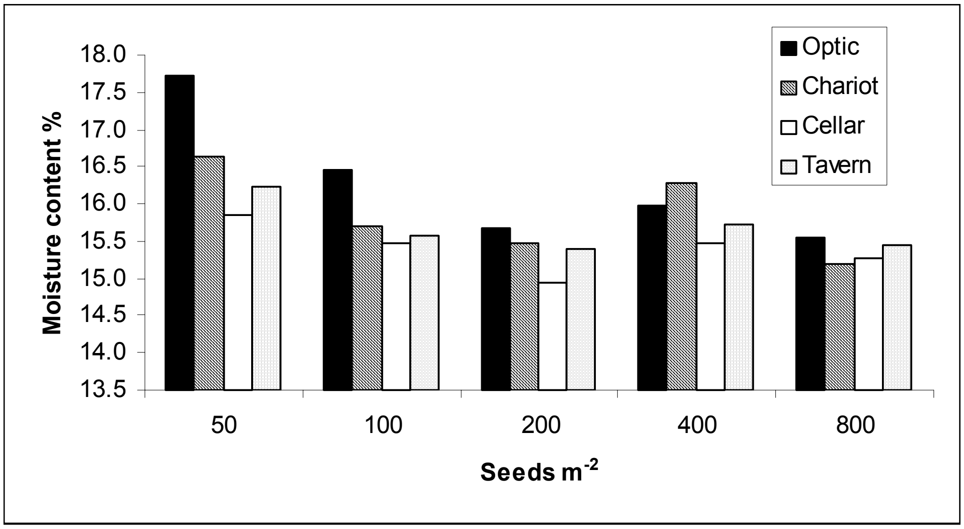


Figure 1.9 Moisture content of harvested grain from four varieties across a range of seed rates mean of seven site seasons.

**Grain nitrogen**

Grain nitrogen was measured on replicated samples at the Bridgets site in years 1 & 2 and on treatment-bulked samples at the NFC site in all three years. In all years the lowest seed rates produced higher grain nitrogen than high seed rates. The 50 seeds m$^{-2}$ treatment produced grain 0.27%N higher on average than the 800 seeds m$^{-2}$ treatment, which produced grain nitrogen of on average 1.48%. Where it was possible to statistically analyse (the Bridgets site) seed rate was significant in both years (P=< 0.001).

The varietal effects seen are that Chariot produces high grain nitrogen of on average 1.68 compared to 1.57, 1.59, for Optic and Cellar respectively, Tavern tended to produce the lowest grain nitrogens particularly in years 2 and 3 producing on average 1.54 % (Figure 2.0).

The significant and consistent effect of seed rate on grain nitrogen is of particular interest due to the importance of which malting market the grain is targeted. The effect of seed rate is double that which is seen between varieties. It emphasises that choice of seed rate and thus plant population should be considered as important as variety choice or nitrogen management when the grower plans his market for his spring malting barley.

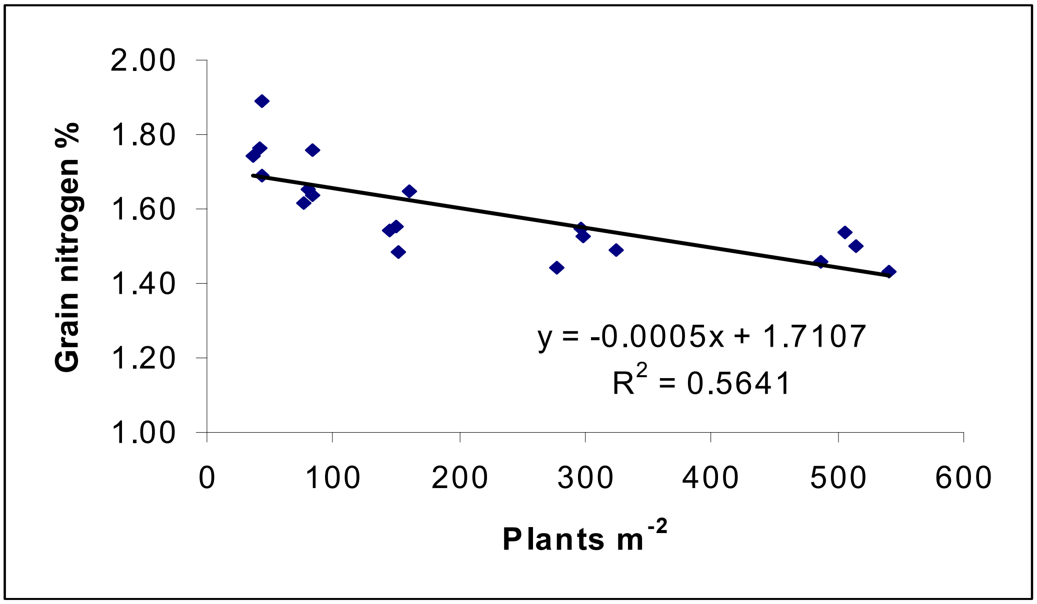


Figure 2.0. Relationship between plants $m^2$ and grain nitrogen %.

## Appendix 2

## Seedrate x nitrogen/fungicide interaction

### Materials & Methods

Fully randomised and replicated field trials were set up at three sites in two years. A site at ADAS Bridgets, Martyr Worthy, Winchester, Hampshire was used in 2000 and 2001 harvest years. A west of England site at White House Farm, Sellack, Ross-on-Wye was used in 2000 and at ADAS Rosemaund, Preston Wynne, Hereford in 2001. A site at plant breeders New Farm Crops (NFC, now part of Syngenta seeds) Market Stainton, Lincolnshire was used in both years.

The experimental design was a three way factorial replicated three times, there were two seed rates, three nitrogen rates and three fungicide applications on a single variety, Optic. Two seed rates (100 and 400 seeds $m^{-2}$) were selected as examples of a reduced and a normal seed rates. At NFC 200 seeds $m^{-2}$ was used as the reduced rate. Nitrogen treatments with rates of prilled ammonium nitrate of 50, 100 and 150 kg/ha were applied. Three fungicide treatment programmes were used and applied using a hand held knapsack sprayer:

1. GS30/31 Amistar Pro 2.0 l/ha plus Unix 0.67 kg/ha
2. GS30/31 Opus 1.0 l/ha plus Corbel 0.5 l/ha
3. GS30/31 Amistar Pro 2.0 l/ha plus Unix 0.67 kg/ha and GS45-59 Amistar Pro 2.0 l/ha

Plots were drilled with an ‘Oyjord type’ tractor mounted seed drill and plot dimensions were 2m wide by 24m long at the ADAS sites and 1.5m wide by 10m long at Syngenta seeds.

At the ADAS sites soil samples were taken to a depth of 90 cm to establish residual soil mineral nitrogen supply in the spring. Crop establishment was assessed pre-tillering with the number of plants counted in 10 x 1m row lengths per plot. Weekly measurements of light interception with ceptometers (Sunfleck meters) allowed canopy development to be monitored through the growing season. Crop growth as both dry matter and green area index measurements were taken when 50% of all the main shoots reached mid-anthesis (GS65) from the normal seed rates only. An assessment of the components of yield was made on samples taken immediately pre-harvest. Grain yield was measured using a plot combine from a harvest area of 10m by 2m. Grain was analysed for moisture content and specific weight using a GAC 2000 grain analysis computer (Dickey-John corporation) and thousand grain weight measured using a numigral grain counter.

At NFC crop establishment was assessed pre-tillering with the number of plants counted in 10 x 1m row lengths per plot. Grain yield was measured using a plot combine from a harvest area of 10m by 1.5m. Grain was analysed for moisture content, specific weight, sieving fractions and grain nitrogen %.

## Results and Discussion

### Plant establishment

Plant counts assessed before nitrogen or fungicide treatments were applied concurred with findings of the seed rate x variety interaction experiments with higher establishment at reduced seed rates (Table 2.1.). On average 80.4% and 72.7% of plants were established from 100 and 400 seeds $m^{-2}$. Establishment was consistent across the years in both seed rates although higher establishment was achieved at Rosemaund in 2001.

Table 2.1. Plant establishment of Optic spring barley at 2 sites, White House farm (Wh) in 2000, ADAS Rosemaund (Rm) in 2001 and ADAS Bridgets (Br) in 2000 and 2001.

| Seed rate Seeds $m^{-2}$ | Established plant population $m^{-2}$ | | | | Plant establishment % | | | |
|---|---|---|---|---|---|---|---|---|
| | 2000 | | 2001 | | 2000 | | 2001 | |
| | Wh | Br | Rm | Br | Rm | Br | Rm | Br |
| 100 | 76.8 | 77.5 | 88.4 | 79.0 | 76.8 | 77.5 | 88.4 | 79.0 |
| 400 | 259.3 | 256.7 | 387.7 | 260.0 | 64.8 | 64.2 | 96.9 | 65.0 |

### Crop growth

The effects of nitrogen nutrition on canopy formation and size and fungicide programmes particularly strobilurins on canopy duration were quantified by growth analysis of the high seed rates at mid-anthesis. There were no significant interactions between nitrogen and fungicide however there were significant main effects particularly nitrogen. Increases in fertile shoot numbers with nitrogen were significant at Bridgets in both 2000 (*p*= <0.001) and 2001 (*p*= 0.031), they were not significant in the west in either year however the trend was similar. On average, shoot numbers were increased 9.5% with the first 50 kg of nitrogen applied over and above 50 kg/ha and 5.7% for the second (table 2.2). As nitrogen was increased canopy size increased consistently across all site years. Increased rates of nitrogen significantly increased (*p*= <0.001) both leaf and overall green area index at all sites except Rosemaund in 2001. When 100 kg/ha of nitrogen was applied leaf and overall green area index were increased compared with the 50 kg/ha by 0.46 and 0.7 respectively. At 150 kg/ha there were increases of 0.85 and 1.26 in leaf and overall green area index respectively. Significant increases in canopy size in terms of dry matter were also seen in all years except Rosemaund in 2001. On average leaf dry matter was increased by 0.18 and 0.27 t/ha when 100 and 150 kg/ha of nitrogen was applied, respectively. Total dry matter increased by 1.07

and 1.24 t/ha respectively from the same two treatments. These increases in crop dry matter biomass with increasing nitrogen nutrition were still significant when assessed at a growth analysis taken immediately pre-harvest. Both straw and grain dry matter were significantly increased in all site years, illustrated by the total crop dry matter presented in table 2.3. On average, compared to the lowest nitrogen treatment crop dry matter was increased by 27 % and 39.5% with the addition of an extra 50 and 100 kg/ha respectively. This diminishing response in canopy size and crop dry matter to nitrogen application is typical of response curves seen in other crops (Sylvester-Bradley et al, 1984, DT Stokes et al, 1998).

The effects of the fungicide treatments were less consistent than that seen for nitrogen emphasising the seasonal effects on disease pressure and fungicide response. Shoot numbers were not significantly affected by fungicide application. However there was a trend for the two spray application of a strobilurin to have more shoots due to the relatively late timing of the second spray this is most likely, to have been due to improved tiller survival. The expected effect of the strobilurin treatments on prolonging the duration of canopy greenness through improved retention of green leaf area index was only statistically significant at Bridgets in 2000. At this site both strobilurin treatments had significantly (*p*= <0.001) higher leaf and overall green area index than the triazole treatment. A single spray of strobilurin produced a 36% larger green area index than the single spray triazole treatment and a two spray strobilurin 23% more than a single spray of either a strobilurin or a triazole. The response at this site was reflected at other sites and in the overall trend averaged across the four site seasons. On average compared to the triazole program, green area index was 9% larger at mid-anthesis from a single application of strobilrurin and 7.5% larger from a two spray application (table 2.2). This indicated strobilurin sprays did have an effect on the canopy, although it was not always significant and that an early season strobilurin spray was the most important for canopy retention.

Leaf dry matter data was consistent with the green area index data; again with Bridgets in 2000 the only site with statistically significant (*p*= 0.001) differences between the strobilurin and triazole fungicide treatments. A single spray of strobilurin produced a 50% higher leaf dry matter than the single spray triazole treatment and a two spray strobilurin 35%. On average compared to the triazole program, leaf dry matter was 14% higher at mid-anthesis from a single application of strobilurin and 10% larger from a two spray application. By the time of harvest, crop dry matter increases due to fungicide program were still evident. A two-spray strobilurin program significantly increased crop dry matter at both White House (*p*= 0.009) and Bridgets (*p*= 0.035) in 2000 (table 2.3). On average over the four site seasons, a two-spray strobilurin program increased dry matter by 8.5% compared with a single triazole spray.

The data from the growth analysis indicated effects of strobilurins on canopy size, the resultant effect on yield and quality will be discussed later in this report.

Table 2.2 Average Canopy growth data of Optic spring barley from GS 65 growth analysis at 400 seeds/m$^2$ from two sites (Rosemaund and Bridgets) in two years (2000, 2001).

| Nitrogen | Fungicide | Fertile shoots (m$^2$) | Leaf area index | Green area index | Leaf dry matter (t/ha) | Crop dry matter (t/ha) |
|---|---|---|---|---|---|---|
| 50 kg N | Strob 31 | 570 | 1.22 | 2.32 | 0.41 | 5.81 |
| | Triazole 31 | 579 | 0.94 | 2.08 | 0.36 | 5.88 |
| | Strob 31 & 45 | 647 | 1.24 | 2.43 | 0.41 | 6.34 |
| **Mean** | | **599** | **1.14** | **2.28** | **0.39** | **6.01** |
| 100 kg N | Strob 31 | 660 | 1.74 | 3.20 | 0.62 | 7.01 |
| | Triazole 31 | 689 | 1.54 | 2.92 | 0.53 | 7.32 |
| | Strob 31 & 45 | 622 | 1.53 | 2.81 | 0.55 | 6.91 |
| **Mean** | | **656** | **1.60** | **2.98** | **0.57** | **7.08** |
| 150 kg N | Strob 31 | 673 | 2.07 | 3.56 | 0.67 | 7.21 |
| | Triazole 31 | 678 | 1.78 | 3.33 | 0.61 | 7.10 |
| | Strob 31 & 45 | 720 | 2.12 | 3.72 | 0.68 | 7.52 |
| **Mean** | | **690** | **1.99** | **3.54** | **0.66** | **7.25** |
| | | | | | | |
| Strob 31 Mean | | 634 | 1.68 | 3.03 | 0.57 | 6.65 |
| Triazole 31 Mean | | 648 | 1.42 | 2.78 | 0.50 | 6.77 |
| Strob 31 & 45 Mean | | 663 | 1.63 | 2.99 | 0.55 | 6.92 |

Table 2.3 Crop dry matter t/ha of Optic spring barley from pre-harvest growth analysis at 400 seeds/m$^2$ from two sites, White House and Bridgets in 2000, Rosemaund and Bridgets in 2001.

| | | 2000 | | 2001 | | |
|---|---|---|---|---|---|---|
| Nitrogen | Fungicide | White House | Bridgets | Rosemaund | Bridgets | Average |
| 50 kg N | Strob 31 | 10.39 | 7.64 | 5.23 | 12.25 | 8.88 |
| | Triazole 31 | 8.56 | 7.46 | 6.22 | 11.17 | 8.35 |
| | Strob 31 & 45 | 10.91 | 7.81 | 6.31 | 11.81 | 9.21 |
| **Mean** | | **9.95** | **7.64** | **5.92** | **11.74** | **8.81** |
| 100 kg N | Strob 31 | 10.41 | 9.29 | 7.71 | 15.58 | 10.75 |
| | Triazole 31 | 11.42 | 9.51 | 8.85 | 15.2 | 11.25 |
| | Strob 31 & 45 | 11.76 | 9.79 | 6.85 | 17.86 | 11.57 |
| **Mean** | | **11.19** | **9.53** | **7.81** | **16.21** | **11.19** |
| 150 kg N | Strob 31 | 11.3 | 10.48 | 8.67 | 17.34 | 11.95 |
| | Triazole 31 | 11.86 | 9.79 | 8.07 | 17.36 | 11.77 |
| | Strob 31 & 45 | 13.56 | 12.2 | 9.58 | 11.77 | 11.78 |
| **Mean** | | **12.08** | **10.8** | **8.78** | **17.49** | **12.29** |
| Strob 31 Mean | | 10.7 | 9.13 | 7.21 | 15.06 | 10.53 |
| Triazole 31 Mean | | 10.61 | 8.92 | 7.71 | 14.58 | 10.46 |
| Strob 31 & 45 Mean | | 12.08 | 9.93 | 7.58 | 15.81 | 11.35 |
| | Grand Mean | 11.13 | 9.33 | 7.5 | 15.15 | |
| | cv% | 8.8 | 8.4 | 22.2 | 17.3 | |
| | Nitrogen p value | <0.001 | <0.001 | 0.007 | <0.001 | |
| | SED | 0.462 | 0.37 | 0.786 | 1.233 | |
| | Fungicide p value | 0.009 | 0.035 | 0.802 | 0.608 | |
| | SED | 0.462 | 0.37 | 0.786 | 1.233 | |
| | Nitrogen x Fungicide p value | 0.122 | 0.162 | 0.469 | 0.888 | |
| | SED | 0.801 | 0.641 | 1.361 | 2.135 | |

| | | | | | |
|---|---|---|---|---|---|
| | df | 16 | 16 | 16 | 16 |

**Yield components**

The components of yield may be considered to be the relationship between three crop components, ears per $m^{-2}$, grains per $ear^{-1}$ and grain size. Agronomic treatments that influence one or more of these components usually results in a response in grain yield. The increases in shoot numbers seen at an earlier stage in the season were sustained through to harvest ear numbers. Although this was only significant at Bridgets in 2000 the overall trend was for ear numbers to increase with increasing rates of nitrogen (table 2.4). On average, the 50, 100 and 150 kg/ha nitrogen treatments maintained 687, 790 and 765 ears respectively until harvest. Fungicide effects on tiller survival were not detected at mid-anthesis but there was an indication by harvest that strobilurin sprays had increased tiller survival. At White house in 2000 there was a significant increase in final ear numbers with a two spray application of strobilurin. Similar trends were seen at the Bridgets site in both years. This resulted in on average across the four site seasons, a 10% increase in ear numbers from two sprays of strobilurin compared to a single triazole.

Table 2.4 Ear numbers per $m^{-2}$ of Optic spring barley from pre-harvest growth analysis at 400 seeds/$m^2$ from White House and Bridgets in 2000, Rosemaund and Bridgets in 2001.

| | | 2000 | | 2001 | | |
|---|---|---|---|---|---|---|
| Nitrogen | Fungicide | White House | Bridgets | Rosemaund | Bridgets | Average |
| 50 kg N | Strob 31 | 695 | 612 | 591 | 1007 | 726 |
| | Triazole 31 | 591 | 617 | 558 | 735 | 625 |
| | Strob 31 & 45 | 729 | 566 | 494 | 857 | 662 |
| **Mean** | | **672** | **598** | **609** | **867** | **687** |
| 100 kg N | Strob 31 | 683 | 594 | 604 | 959 | 710 |
| | Triazole 31 | 711 | 706 | 718 | 965 | 775 |
| | Strob 31 & 45 | 753 | 747 | 590 | 1423 | 878 |
| **Mean** | | **716** | **682** | **646** | **1116** | **790** |
| 150 kg N | Strob 31 | 687 | 724 | 631 | 967 | 752 |
| | Triazole 31 | 725 | 697 | 663 | 950 | 759 |
| | Strob 31 & 45 | 805 | 830 | 692 | 1016 | 836 |
| **Mean** | | **739** | **750** | **592** | **978** | **765** |

| | | | | | |
|---|---|---|---|---|---|
| Strob 31 Mean | 688 | 643 | 609 | 978 | 730 |
| Triazole 31 Mean | 676 | 673 | 646 | 883 | 720 |
| Strob 31 & 45 Mean | 762 | 714 | 592 | 1099 | 792 |
| Grand Mean | 709 | 677 | 616 | 987 | |
| cv% | 9.6 | 9.8 | 12.3 | 31.1 | |
| Nitrogen p value | 0.137 | <0.001 | 0.191 | 0.255 | |
| SED | 32.1 | 31.3 | 62.8 | 144.6 | |
| Fungicide p value | 0.033 | 0.105 | 0.682 | 0.351 | |
| SED | 32.1 | 31.3 | 62.8 | 144.6 | |
| Nitrogen x Fungicide p value | 0.381 | 0.063 | 0.733 | 0.493 | |
| SED | 55.6 | 54.3 | 108.8 | 250.4 | |
| df | 16 | 16 | 16 | 16 | |

Nitrogen treatments increased grain number per ear in three out of the four years (table 2.5) although it was only significant at Rosemaund in 2001 (*p*=0.036). At Rosemaund in 2001, grain number per ear was increased by 6.5% and 21.4% by the 100 and 150 kg/ha nitrogen treatments respectively when compared to the 50 kg/ha rate. The overall trend was for the 100 and 150 kg/ha nitrogen treatments to increase grain number per ear by 3.8 and 9.5% respectively.

Fungicide programmes had no significant affect on grain number per ear.

Table 2.5 Grain number per ear of Optic spring barley from pre-harvest growth analysis at 400 seeds/m$^2$ White House and Bridgets in 2000, Rosemaund and Bridgets in 2001.

| | | 2000 | | 2001 | | |
|---|---|---|---|---|---|---|
| Nitrogen | Fungicide | White House | Bridgets | Rosemaund | Bridgets | Average |
| 50 kg N | Strob 31 | 19.6 | 19.6 | 12.9 | 15.6 | 16.9 |
| | Triazole 31 | 19.9 | 19.0 | 15.5 | 19.0 | 18.4 |
| | Strob 31 & 45 | 19.9 | 21.0 | 17.8 | 16.9 | 18.9 |
| **Mean** | | **19.8** | **19.9** | **15.4** | **17.2** | **18.1** |
| 100 kg N | Strob 31 | 19.7 | 21.3 | 16.9 | 19.0 | 19.2 |
| | Triazole 31 | 20.9 | 20.1 | 17.1 | 19.8 | 19.5 |
| | Strob 31 & 45 | 19.7 | 18.6 | 15.2 | 16.6 | 17.5 |
| **Mean** | | **20.1** | **20.0** | **16.4** | **18.5** | **18.8** |
| 150 kg N | Strob 31 | 20.9 | 20.4 | 19.0 | 18.6 | 19.7 |
| | Triazole 31 | 21.5 | 19.2 | 17.2 | 20.1 | 19.5 |
| | Strob 31 & 45 | 21.4 | 19.6 | 19.9 | 19.8 | 20.2 |
| **Mean** | | **21.3** | **19.7** | **18.7** | **19.5** | **19.8** |
| Strob 31 Mean | | 20.1 | 20.4 | 16.3 | 17.7 | 18.6 |
| Triazole 31 Mean | | 20.8 | 19.4 | 16.6 | 19.7 | 19.1 |
| Strob 31 & 45 Mean | | 20.3 | 19.7 | 17.6 | 17.8 | 18.9 |
| | Grand Mean | 20.4 | 19.9 | 16.8 | 18.4 | |
| | cv% | 6.6 | 6.4 | 15 | 12.9 | |
| | Nitrogen p value | 0.084 | 0.887 | 0.036 | 0.151 | |

| | | | | |
|---|---|---|---|---|
| SED | 0.637 | 0.599 | 1.19 | 1.122 |
| Fungicide p value | 0.56 | 0.251 | 0.516 | 0.177 |
| SED | 0.637 | 0.599 | 1.19 | 1.122 |
| Nitrogen x Fungicide p value | 0.938 | 0.102 | 0.185 | 0.581 |
| SED | 1.103 | 1.037 | 2.061 | 1.943 |
| df | 16 | 16 | 16 | 16 |

Significant effects of nitrogen on grain size were seen at Bridgets in 2001 ($p$=0.001). Thousand grain weight (tgw) increased by 3.2% and 6.2% with the 100 and 150 kg/ha nitrogen treatments respectively when compared to the 50 kg/ha rate (table 2.6). At other sites the trend was smaller or there was no significant difference between nitrogen treatments. Fungicide effects were significant at both sites in 2000 (table 2.6), at both sites tgw was higher when a strobilurin fungicide was used. A two spray program had the greatest effect with increases of 5% at White house and 9% at Bridgets compared to the triazole treatment.

Table 2.6 Thousand grain weight (g) of Optic spring barley from pre-harvest growth analysis at 400 seeds/m$^2$ White House and Bridgets in 2000, Rosemaund and Bridgets in 2001.

| | | 2000 | | 2001 | | |
|---|---|---|---|---|---|---|
| Nitrogen | Fungicide | White House | Bridgets | Rosemaund | Bridgets | Average |
| 50 kg N | Strob 31 | 49.0 | 41.1 | 50.2 | 52.4 | 48.2 |
| | Triazole 31 | 46.3 | 41.0 | 50.5 | 52.1 | 47.5 |
| | Strob 31 & 45 | 48.7 | 44.3 | 51.6 | 53.9 | 49.6 |
| **Mean** | | **48.0** | **42.1** | **50.8** | **52.8** | **48.4** |
| 100 kg N | Strob 31 | 48.7 | 44.2 | 51.7 | 55.5 | 50.0 |
| | Triazole 31 | 47.1 | 40.4 | 53.2 | 52.8 | 48.4 |
| | Strob 31 & 45 | 49.6 | 44.1 | 51.4 | 55.1 | 50.1 |
| **Mean** | | **48.5** | **42.8** | **52.1** | **54.5** | **49.5** |
| 150 kg N | Strob 31 | 48.1 | 42.6 | 53.6 | 56.7 | 50.3 |
| | Triazole 31 | 46.8 | 40.9 | 51.0 | 56.1 | 48.7 |
| | Strob 31 & 45 | 48.9 | 45.1 | 51.7 | 55.6 | 50.3 |
| **Mean** | | **48.0** | **42.6** | **52.1** | **56.1** | **49.7** |
| Strob 31 Mean | | 48.6 | 42.7 | 51.9 | 54.8 | 49.5 |
| Triazole 31 Mean | | 46.7 | 40.8 | 51.6 | 53.7 | 48.2 |
| Strob 31 & 45 Mean | | 49.1 | 44.5 | 51.6 | 54.8 | 50.0 |
| | Grand Mean | 48.1 | 42.6 | 51.7 | 54.5 | |
| | cv% | 3.3 | 2.7 | 3.6 | 2.9 | |
| | Nitrogen p value | 0.756 | 0.318 | 0.255 | 0.001 | |
| | SED | 0.747 | 0.536 | 0.882 | 0.732 | |

|  |  |  |  |  |
|---|---|---|---|---|
| Fungicide p value | 0.016 | <0.001 | 0.932 | 0.224 |
| SED | 0.747 | 0.536 | 0.882 | 0.732 |
| Nitrogen x Fungicide p value | 0.931 | 0.081 | 0.274 | 0.361 |
| SED | 1.293 | 0.928 | 1.527 | 0.732 |
| df | 16 | 16 | 16 | 16 |

The grain size differences seen in the hand-harvested samples were reinforced when tgw was assessed on samples taken from the combine. In these samples in most years the main effects were significant this may be due to the hand threshed samples losing less of the smaller grains hence figures are lower than from the combine samples. As a result there is more variation and less significance detected compared to the combine samples. Increasing fertiliser nitrogen rate increased tgw significantly at White house in 2000 (*p*=<0.001), Rosemaund (*p*=0.009) and Bridgets (*p*=0.002) in 2001 (figure 2.1). On average, increases compared to the lowest N treatment were 2.1 and 2.4% from the 100 and 150 kg/ha N respectively. Seed rate effects were significant in all years (*p*=<0.001) with tgw higher at lower seed rates. Increases ranged from 2.2 g at Rosemaund in 2001 to 5.1g at Bridgets in 2000 (figure 2.2). On average there was an increase in tgw of 8% as seed rate was reduced from 400 to 100 seeds $m^{-2}$, the difference seen was very consistent with that seen in the variety x seed rate interaction trials. Fungicide effects were significant in three out of the four years, White house, Bridgets in 2000 (*p*=<0.001) and Bridgets in 2001 (*p*=0.009), Rosemaund in 2001 was not significant but the trend was the same. The effects seen were consistent with that seen in the hand-harvested samples with significantly higher tgw when a strobilurin fungicide was used compared to a triazole (figure 2.3). A two spray strobilurin programme produced the largest grain with on average a 3.8% increase over a triazole. Grain size has been identified in section 2 of this report as one of the most influential factors in homogeneity. So agronomic treatments that effect grain size offer the grower a way of manipulating homogeneity.

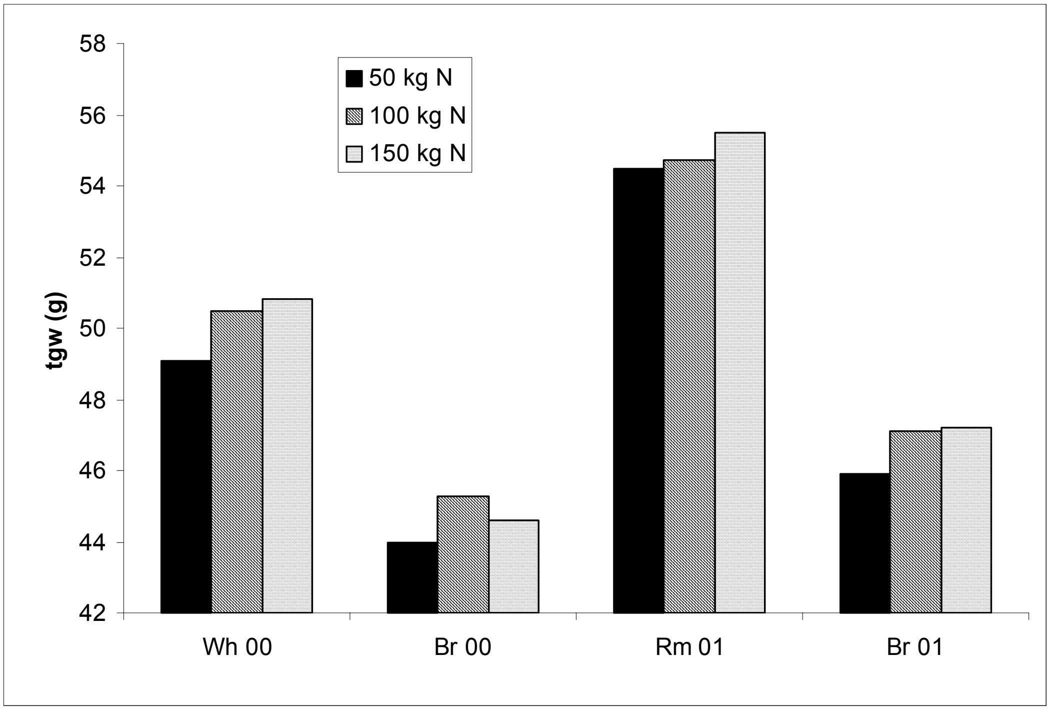


Figure 2.1. Thousand grain weight (g) in Optic spring barley at three nitrogen rates (50, 100 and 150 kg/ha N) from four site seasons.

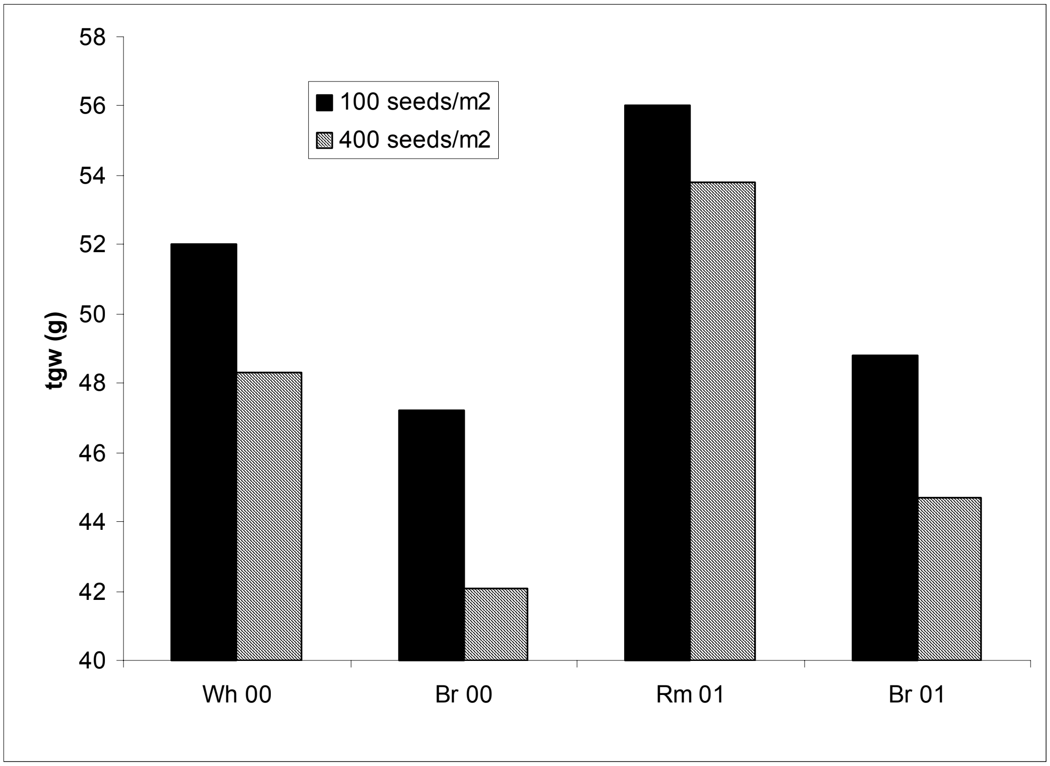


Figure 2.2. Thousand grain weight (g) in Optic spring barley at two seed rates (100 and 400 seeds m$^{-2}$) from four site seasons.

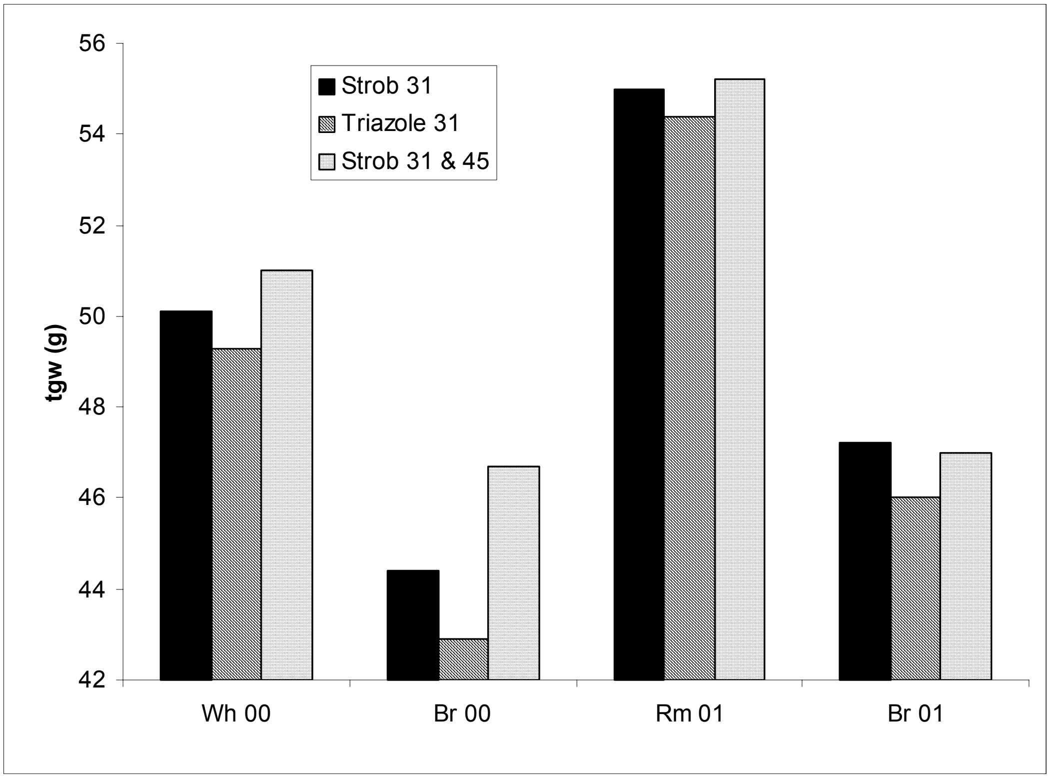


Figure 2.2. Thousand grain weight (g) in Optic spring barley from three fungicide programmes from four site seasons.

**Yield responses**

Grain yield was significantly increased with increasing nitrogen rate in all six site years (table 2.7). Responses to the 100 kg/ha rate of nitrogen compared to the lowest nitrogen treatment ranged from 1.54 t/ha from Bridgets in 2000 to 0.26 at NFC in 2001. Responses to 150 kg/ha ranged from 1.56 t/ha at NFC in 2000 and 0.58 t/ha from the same site in 2001. On average, responses were 0.86 t/ha and 0.87 t/ha to each increment of 50 kg N/ha. This concurred with findings throughout the season of the nitrogen treatments producing larger canopies which therefore had more assimilates to maintain and increase crop yield components which in turn leads to an increase in yield.

Fungicide main effects on grain yield were significant in three site years, Rosemaund and Bridgets in 2000 and Bridgets in 2001 (table 2.8). A significant interaction was seen between fungicide and nitrogen treatments at Bridgets in 2000 and close to significant at the same site in 2001. At Bridgets in 2001 there was very little yield response to a second strobilurin at 50 or 100 kg/ha of nitrogen but there was at 150 kg/ha whereas the response to single strobilurin decreased from 0.23 to 0.03 t/ha as nitrogen was increased. At Bridgets in 2000, the response to either strobilurin program was significantly better at the higher nitrogen rates than the response at the low nitrogen rate (figure 2.4). There was an indication of this trend in other years, which can be illustrated by the mean yield response across the six site years presented in figure 2.5. This suggests that yield responses to strobilurins are greater at higher nitrogen rates when crop canopies are larger. However the effects of fungicide program on grain quality and therefore eventual malting market must be taken into consideration, this will be discussed further in the malting section of this report.

As seed rate was increased from 100 to 400 seeds$^{-2}$ grain yields increased significantly at four out of the six sites (table 2.8). The increases seen ranged from 0.2 t/ha at White house in 2000 to 1.13 t/ha at Rosemaund in 2001. On average over the six site seasons the difference between 100 and 400 seeds was 0.45 t/ha. This represents an 8% yield benefit in using the higher seed rate for a 300% increase in seed cost. The economic implications of changes in seed rate are discussed further in Appendix 1 of this report. In general there was no interaction of seed rate with any other treatment, however the effect of seed rate on physical grain quality again is something the grower must take into consideration when growing a crop of spring malting barley.

Table 2.7 Combine grain yield (t/ha) of Optic spring barley at harvest from White House and Bridgets in 2000, Rosemaund and Bridgets in 2001.

| | | | 2000 | | | 2001 | | |
|---|---|---|---|---|---|---|---|---|
| Nitrogen treatment | Fungicide treatment | Seedrate | Wh | Bridgets | NFC | Rosemaund | Bridgets | NFC |
| 50 kg N | Strob 31 | 100 | 4.88 | 4.88 | 5.38 | 2.61 | 7.14 | 5.31 |
| | | 400 | 5.13 | 5.13 | 5.18 | 3.56 | 8.21 | 5.21 |
| | Triazole 31 | 100 | 4.89 | 4.89 | 5.57 | 2.5 | 7.48 | 5.24 |
| | | 400 | 4.44 | 4.44 | 5.77 | 3.53 | 7.41 | 5.2 |
| | Strob 31 & 45 | 100 | 4.85 | 4.85 | 5.28 | 2.56 | 7.13 | 5.33 |
| | | 400 | 5.31 | 5.31 | 5.66 | 5.57 | 7.92 | 5.08 |
| | Mean | | **4.92** | **4.92** | **5.48** | **3.06** | **7.55** | **5.3** |
| 100 kg N | Strob 31 | 100 | 6.51 | 6.51 | 5.66 | 3.41 | 8.54 | 5.55 |
| | | 400 | 6.44 | 6.44 | 5.78 | 3.87 | 9.69 | 5.57 |
| | Triazole 31 | 100 | 5.89 | 5.89 | 5.32 | 2.72 | 8.44 | 5.49 |
| | | 400 | 5.71 | 5.71 | 6.55 | 4.2 | 9.44 | 5.41 |
| | Strob 31 & 45 | 100 | 7.21 | 7.21 | 5.51 | 3.39 | 8.75 | 5.62 |
| | | 400 | 6.98 | 6.98 | 6.71 | 4.58 | 9.53 | 5.67 |
| | Mean | | **6.46** | **6.46** | **5.92** | **3.69** | **9.07** | **5.56** |
| 150 kg N | Strob 31 | 100 | 6.83 | 6.83 | 6.77 | 3.72 | 9.18 | 5.81 |
| | | 400 | 7.20 | 7.2 | 7.09 | 5.05 | 10.56 | 5.84 |
| | Triazole 31 | 100 | 6.38 | 6.38 | 6.79 | 3.19 | 9.24 | 5.8 |
| | | 400 | 6.00 | 6 | 7.13 | 4.93 | 10.45 | 5.9 |
| | Strob 31 & 45 | 100 | 7.69 | 7.69 | 6.99 | 3.89 | 9.84 | 6.03 |
| | | 400 | 7.68 | 7.68 | 7.49 | 4.97 | 11.13 | 6.18 |
| | Mean | | **6.97** | **6.97** | **7.04** | **4.29** | **10.07** | **5.88** |
| | Strob 31 Mean | | 6.17 | 6.17 | 5.98 | 3.7 | 8.89 | 5.56 |
| | Triazole 31 Mean | | 5.55 | 5.55 | 6.19 | 3.51 | 8.74 | 5.51 |
| | Strob 31 & 45 Mean | | 6.62 | 6.62 | 6.27 | 3.83 | 9.05 | 5.67 |
| | 100 seeds/m$^2$ | | 6.13 | 6.13 | 5.92 | 3.12 | 8.42 | 5.59 |
| | 400 seeds/m$^2$ | | 6.10 | 6.1 | 6.37 | 4.25 | 9.37 | 5.6 |
| | Grand Mean | | 6.11 | 6.11 | 6.15 | 3.68 | 8.89 | 5.58 |
| | | cv% | 6.8 | 6.8 | 9.6 | 16.4 | 3.6 | 5.8 |
| | | Nitrogen p value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| | | SED | 0.139 | 0.139 | 0.197 | 0.202 | 0.107 | 0.108 |
| | | Fungicide p value | <0.001 | <0.001 | 0.314 | 0.303 | 0.03 | 0.374 |
| | | SED | 0.138 | 0.138 | 0.197 | 0.202 | 0.107 | 0.108 |
| | | Seedrate p value | 0.819 | 0.819 | 0.008 | <0.001 | <0.001 | 0.749 |
| | | SED | 0.113 | 0.113 | 0.161 | 0.165 | 0.088 | 0.088 |
| | | Nitrogen.Fungicide p value | 0.038 | 0.038 | 0.87 | 0.871 | 0.06 | 0.959 |

| | | | | | | |
|---|---|---|---|---|---|---|
| SED | 0.240 | 0.24 | 0.197 | 0.349 | 0.186 | 0.187 |
| Nitrogen.Seedrate p value | 0.674 | 0.674 | 0.193 | 0.871 | 0.01 | 0.123 |
| SED | 0.196 | 0.196 | 0.278 | 0.285 | 0.152 | 0.153 |
| Fungicide.Seedrate p value | 0.162 | 0.162 | 0.259 | 0.458 | 0.09 | 0.991 |
| SED | 0.196 | 0.196 | 0.278 | 0.285 | 0.152 | 0.153 |
| Nitro.Fung.Seed p value | 0.628 | 0.628 | 0.824 | 0.809 | 0.208 | 0.648 |
| SED | 0.340 | 0.34 | 0.482 | 0.494 | 0.263 | 0.265 |
| df | 34 | 34 | 34 | 34 | 32 | 34 |

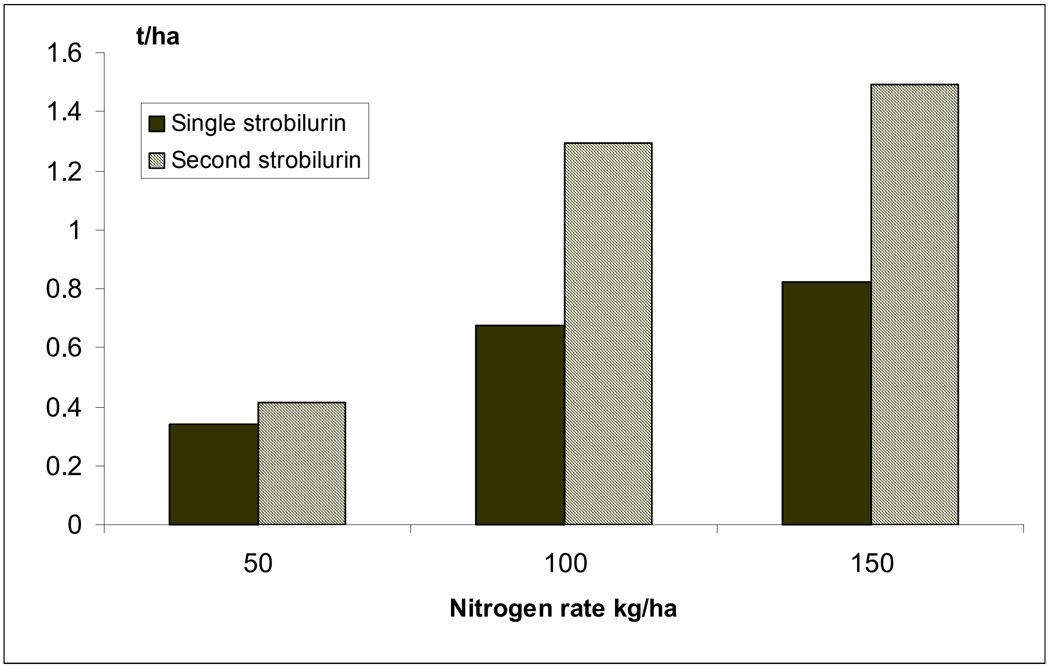


Figure 2.4. Yield response in Optic spring barley to strobilurin fungicide programmes at three nitrogen rates from Bridgets in 2000.

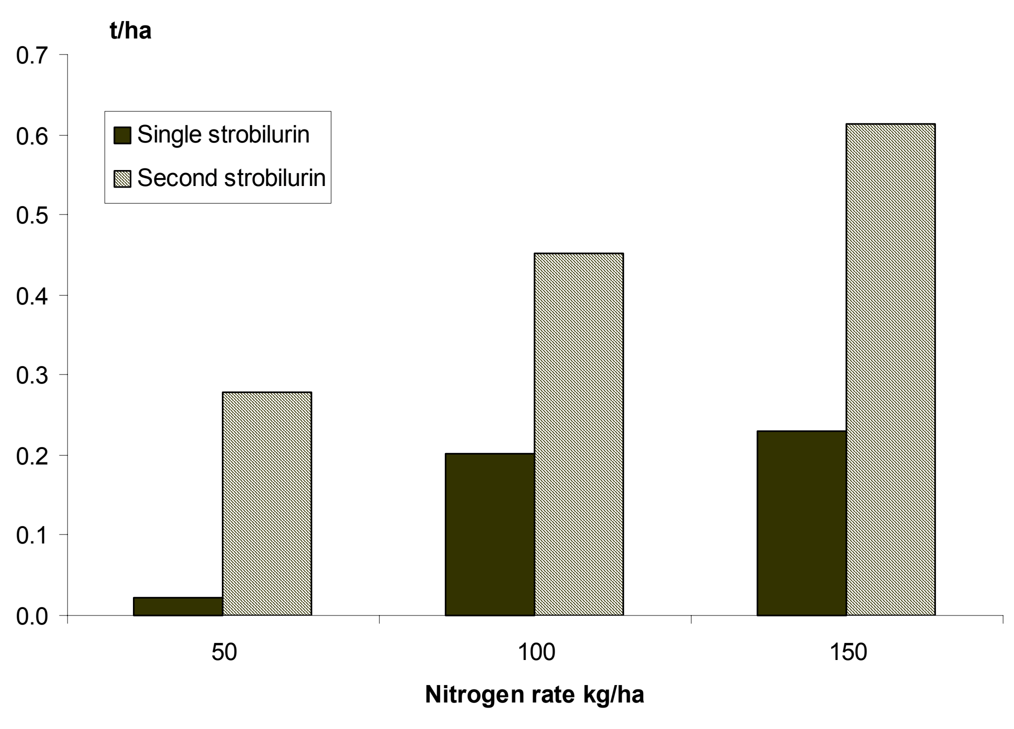


Figure 2.5. Average yield responses in Optic spring barley to strobilurin fungicide programmes at three nitrogen rates from six site years.

**Grain quality**

**Specific weight**

Specific weight differences were generally small with no significant interactions between the treatments. Nitrogen had the most significant effect, specific weight increased significantly as nitrogen rate increased in all six site seasons. Increases from nil to 2.3 kg/hl were seen from l00 kg N/ha and 0.6 to 2.7 from 150 kg/ha compared to the 50 kg N/ha treatment. On average across all site seasons, responses were 1.3% and 2% from 100 and 150 kg/ha respectively compared to the 50 kg/ha nitrogen treatment. Fungicide main effects were significant (*p*= <0.001) at all three sites in 2000 but no differences were seen at either site in 2001. Where significant differences were seen, both strobilurin fungicides programmes increased specific weight but the most significant were seen from a two-spray programme. Increases of 2.6, 3.7 and 0.7% compared to the single triazole program were seen at White house, Bridgets and NFC respectively in 2000. Seed rate main effects were significant at Bridgets and NFC in 2000 and Rosemaund in 2001 however they were inconsistent and overall there was little difference between the seed rates. Although specific weight is used as a quality specification in the purchase of grain it is of little use as an indicator of malting quality or homogeneity for brewing performance. Quality measurements for homogeneity that are better at predicting brewing performance have been identified in section 2 of this report which may be more useful than specific weight.

Table 2.8 Specific weight (kg/hl) of Optic spring barley at harvest from White House and Bridgets in 2000, Rosemaund and Bridgets in 2001.

| | | | 2000 | | | 2001 | |
|---|---|---|---|---|---|---|---|
| Nitrogen treatment | Fungicide treatment | Seedrate | Wh | Bridgets | NFC | Rosemaund | Bridgets |
| 50 kg N | Strob 31 | 100 | 68 | 69.6 | 65.6 | 68.9 | 69.9 |
| | | 400 | 67.3 | 69.4 | 65.3 | 68.9 | 69.9 |
| | Triazole 31 | 100 | 68.3 | 70.1 | 65.6 | 69 | 70 |
| | | 400 | 67.3 | 68.7 | 65.4 | 69.6 | 69.6 |
| | Strob 31 & 45 | 100 | 68.7 | 70.9 | 66.1 | 68.8 | 70 |
| | | 400 | 68.7 | 70.5 | 65.9 | 69.6 | 70.4 |
| | Mean | | 68.1 | 69.9 | 65.7 | 69.2 | 69.9 |
| 100 kg N | Strob 31 | 100 | 69.5 | 72.8 | 65.7 | 69.6 | 70.4 |
| | | 400 | 68.9 | 71.9 | 65.5 | 69.9 | 70.6 |
| | Triazole 31 | 100 | 68.6 | 71.6 | 65.9 | 69.6 | 70.3 |
| | | 400 | 68.3 | 70.9 | 65.3 | 70 | 70.9 |
| | Strob 31 & 45 | 100 | 69.7 | 73.4 | 66.6 | 69.6 | 70.3 |
| | | 400 | 70.1 | 72.5 | 66.4 | 70.2 | 70.6 |
| | Mean | | 69.2 | 72.2 | 65.7 | 69.8 | 70.5 |
| 150 kg N | Strob 31 | 100 | 69.7 | 72.3 | 66 | 70.2 | 70.5 |
| | | 400 | 70.2 | 72.9 | 65.5 | 70.5 | 71.3 |
| | Triazole 31 | 100 | 69.5 | 72.3 | 66.3 | 69.7 | 70.7 |
| | | 400 | 69.3 | 70.6 | 65.6 | 70.3 | 70.4 |
| | Strob 31 & 45 | 100 | 70.7 | 73.8 | 66.5 | 70.4 | 70.1 |
| | | 400 | 70.7 | 73.4 | 66.7 | 70.5 | 71.1 |
| | Mean | | 70 | 72.6 | 66.3 | 70.3 | 70.7 |
| | Strob 31 Mean | | 69 | 71.5 | 65.6 | 69.7 | 70.4 |
| | Triazole 31 Mean | | 68.5 | 70.7 | 65.7 | 69.7 | 70.3 |
| | Strob 31 & 45 Mean | | 69.8 | 72.5 | 66.3 | 69.9 | 70.4 |
| | 100 seeds/m$^2$ | | 69.2 | 71.9 | 66 | 69.5 | 70.2 |
| | 400 seeds/m$^2$ | | 69 | 71.2 | 65.7 | 69.9 | 70.5 |
| | Grand Mean | | 69.1 | 71.6 | 65.9 | 69.7 | 70.4 |
| | | cv% | 0.8 | 0.9 | 0.7 | 0.7 | 0.9 |
| | | Nitrogen p value | <0.001 | <0.001 | 0.058 | <0.001 | 0.003 |
| | | SED | 0.192 | 0.211 | 0.161 | 0.153 | 0.217 |
| | | Fungicide p value | <0.001 | <0.001 | <0.001 | 0.415 | 0.884 |
| | | SED | 0.192 | 0.211 | 0.161 | 0.153 | 0.217 |
| | | Seedrate p value | 0.152 | <0.001 | 0.024 | 0.003 | 0.092 |
| | | SED | 0.157 | 0.172 | 0.132 | 0.125 | 0.178 |
| | | Nitrogen.Fungicide p value | 0.427 | 0.186 | 0.87 | 0.383 | 0.76 |
| | | SED | 0.332 | 0.365 | 0.279 | 0.265 | 0.377 |

| | | | | | |
|---|---|---|---|---|---|
| Nitrogen.Seedrate p value | 0.19 | 0.745 | 0.918 | 0.938 | 0.668 |
| SED | 0.271 | 0.298 | 0.228 | 0.216 | 0.307 |
| Fungicide.Seedrate p value | 0.303 | 0.041 | 0.546 | 0.645 | 0.317 |
| SED | 0.271 | 0.298 | 0.228 | 0.216 | 0.307 |
| Nitro.Fung.Seed p value | 0.563 | 0.251 | 0.813 | 0.645 | 0.528 |
| SED | 0.47 | 0.516 | 0.395 | 0.375 | 0.532 |
| df | 34 | 34 | 34 | 34 | 32 |

**Grain nitrogen**

Grain nitrogen % was assessed at two sites (Bridgets and NFC) in each of two years, at Bridgets replicate samples were analysed at NFC composite treatment samples were analysed. At Bridgets where statistical analyses were possible, increasing nitrogen rate significantly (*p*=<0.001) increased grain nitrogen in 2000 but not however in 2001, similar increases with nitrogen rate were seen at the NFC site. This resulted on average with a 10% increase in grain nitrogen from 150 kg/ha compared to 50 kg/ha of applied nitrogen (figure 2.3). Neither fungicide nor seed rate main effects were significant at Bridgets. However there was a trend for higher grain nitrogen at the lower seed rate, confirming seed rate effects seen in the variety seed rate interaction trials. On average at the highest nitrogen rate the lower seed rate had 3.75% higher grain nitrogen. At Bridgets in 2001 there was a significant interaction between nitrogen and seed rate (*p* = 0.020). At 100 seeds $m^{-2}$ grain nitrogen increased with fertiliser nitrogen rate whereas at 400 seeds $m^{-2}$ grain nitrogen content declined with fertiliser nitrogen rate. Grain nitrogen content varied considerably between sites ranging from 1.34 at NFC in 2000 to 1.86 at Bridgets in the same year from the highest nitrogen rate. Achieving the correct grain nitrogen specification is critical in achieving a malting premium, however there have been increases in this specification in recent years so that 1.6-1.8% is now acceptable. The data from these trials suggest that fertiliser nitrogen rates could be pushed to 120-130 kg/ha of N depending on residual soil nitrogen levels but increasing to 150 kg/ha would be at risk of pushing grain nitrogen above 1.8% and missing malting premium. Consideration should also be given to the established plant population as this has a significant affect on grain nitrogen.

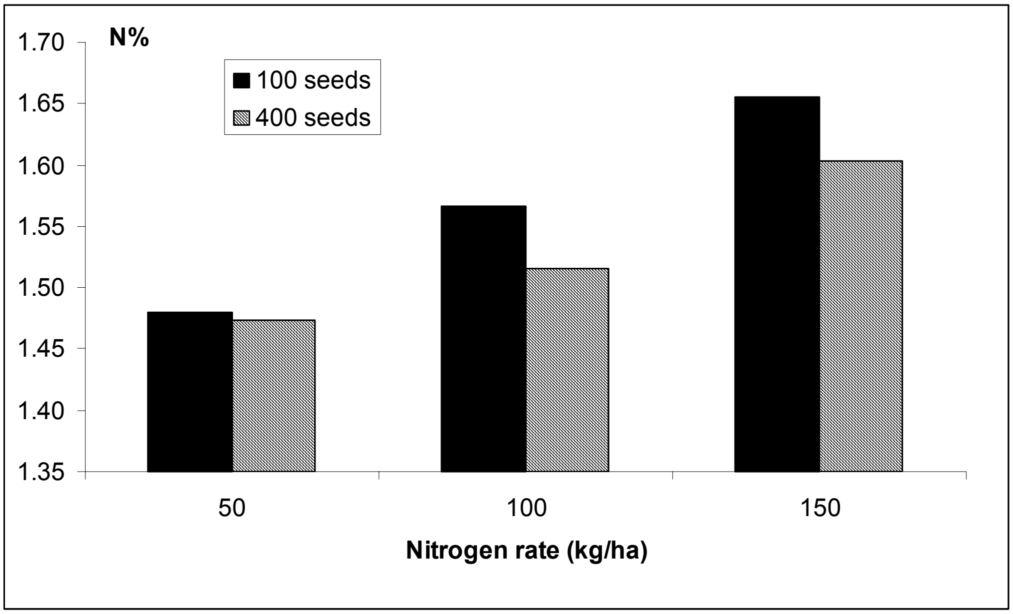


Figure 2.3. Average Grain nitrogen % in Optic spring barley from two seed rates (100 and 400 seeds m$^{-2}$) at three nitrogen rates from four site years (Bridgets and NFC 2000 and 2001).

## Appendix 3

## Variety typing

### Materials & Methods

At two sites (Rosemaund and NFC) in 2002 thirteen varieties were sown at a standard seed rate (400 seeds m$^{-2}$). The varieties evaluated were Optic, Chariot, Cellar, Tavern, Chalice, County, Pewter, Static, Colston, Cocktail, Vortex, Novello and Sebastien. The varieties were fully randomised in each block and replicated three times. Plots were drilled with an 'Oyjord type' tractor mounted seed drill and plot dimensions were 2m wide by 24m long at the ADAS site and 1.5m wide by 10m long at NFC. All plots received standard rates of agrochemicals and fertilisers with an aim to maintain undisturbed and healthy crop growth.

### Results and Discussion

### Plant establishment

Established plant populations from Rosemaund showed there was a significant difference ($p$=0.008) in plant establishment between the varieties. Plant populations ranged from 203 for Optic and Chariot to 274 for Static. From the seed rate x variety interaction data from the same site in the same year, the established population was slightly below the economic optimum population.

Table 3.1. Plant population of a range of varieties at ADAS Rosemaund in 2002.

| Variety | Established plant population (plants $m^{-2}$ |
|---|---|
| Optic | 203.46 |
| Chariot | 203.46 |
| Cellar | 207.90 |
| Tavern | 233.09 |
| Static | 274.57 |
| County | 219.75 |
| Chalice | 213.33 |
| Pewter | 213.83 |
| Colston | 214.32 |
| Cocktail | 232.59 |
| Vortex | 234.07 |
| Novello | 217.28 |
| Sebastien | 225.68 |
| Mean | 222.56 |
| CV% | 8.3 |
| Variety SED | 15.06 |
| p value | 0.008 |
| DF | 24 |

**Crop growth**

Growth analysis assessed carried out at mid-anthesis showed no significant differences between the varieties in shoot number, green area index or dry matter. Fertile shoot numbers ranged from 1064 for Colston to 768 for Vortex.  Green area index ranged from 7.45 for Novello to 5.05 for Sebastien. By the time of the harvest growth analysis significant differences between varieties were seen in a number of parameters (table 3.2). County and Tavern had significantly higher ear numbers than Static, Colston and Vortex. Tiller death in Colston was considerable as it had the highest shoot numbers at GS 65 but one of the lowest at harvest. On average, there was a loss of 158 shoots $m^{-2}$ between GS 65 and harvest. Significant differences seen in straw and grain dry matters resulted in the ratio of grain to straw and chaff biomass represented by harvest index (HI). Established varieties such as Optic and Chariot as well as Novello had significantly lower HI than the majority of varieties. The low HI of Optic and Chariot can attributed to some degree to the their low tgw. Vortex , Static and Pewter had significantly higher tgw's. Tavern had low grain weight and number per ear due to its high ear number and low tgw. Static, Cellar and Novello had high grain number and weight per ear due to moderate ear numbers and high tgw.

Table 3.2. Crop growth assessment at harvest from a range of varieties at ADAS Rosemaund in 2002.

| Variety | Final Ear number | Harvest Index % | Thousand grain weight g | Grain weight /ear g | Grain number /ear |
|---|---|---|---|---|---|
| Optic | 737.90 | 46.54 | 45.93 | 0.71 | 17.80 |
| Chariot | 712.11 | 43.26 | 44.24 | 0.74 | 19.18 |
| Cellar | 726.26 | 55.22 | 50.92 | 0.98 | 22.04 |
| Tavern | 920.38 | 52.78 | 47.10 | 0.67 | 16.31 |
| Static | 631.37 | 57.24 | 52.00 | 1.04 | 23.05 |
| County | 923.22 | 53.69 | 49.45 | 0.75 | 17.51 |
| Chalice | 781.06 | 52.49 | 49.52 | 0.87 | 20.27 |
| Pewter | 722.12 | 54.12 | 51.80 | 0.96 | 21.31 |
| Colston | 562.06 | 52.19 | 49.73 | 0.92 | 21.26 |
| Cocktail | 757.03 | 54.14 | 49.28 | 0.86 | 20.08 |
| Vortex | 560.10 | 51.75 | 53.03 | 0.97 | 21.03 |
| Novello | 539.30 | 48.21 | 51.61 | 0.98 | 21.86 |
| Sebastien | 818.07 | 55.61 | 47.88 | 0.83 | 20.00 |
| Mean | 722.38 | 52.10 | 49.42 | 0.87 | 20.13 |
| CV% | **19.5** | **4.9** | **3.6** | **8.5** | **6.1** |
| Variety SED | **115.0** | **2.084** | **1.47** | **0.060** | **1.005** |
| p value | **0.035** | **< 0.001** | **< 0.001** | **< 0.001** | **< 0.001** |
| DF | **24** | **24** | **24** | **24** | **24** |

**Yield and quality**

Significant varietal differences (*p* = <0.001) in yield were seen at both sites. The low HI and tgw detected in Optic and Chariot at the Rosemaund site in 2002, which indicated likely poor yield performance, were substantiated by the combine grain yields. Optic and Chariot were 6 and 14 % below average respectively (figure 3.1) and this loss of yield performance compared newer varieties is responsible for them no longer featuring on the recommended list. Some of the newer varieties such as Vortex, Colston and Cocktail performed well in yield terms. However to be considered for malting other quality characteristics and acceptance by the maltsters is required. Vortex had very low grain N in these trials which maybe of concern to the malsters, but may also indicate it needs higher rates of applied fertiliser nitrogen than other varieties.

Thousand grain weight assessed on combine grain sample in general agreed with those assessed on hand harvested samples with Optic and Chariot significantly lower. Novello, Cellar, Static and Pewter had the highest tgw’s (table 3.3). There was some agreement between sites in specific weight with Pewter having the lowest at both sites (table 3.3 and 3.4). Significantly higher screening losses were seen in Chariot, County and Chalice at Rosemaund but no differences were detected at NFC.

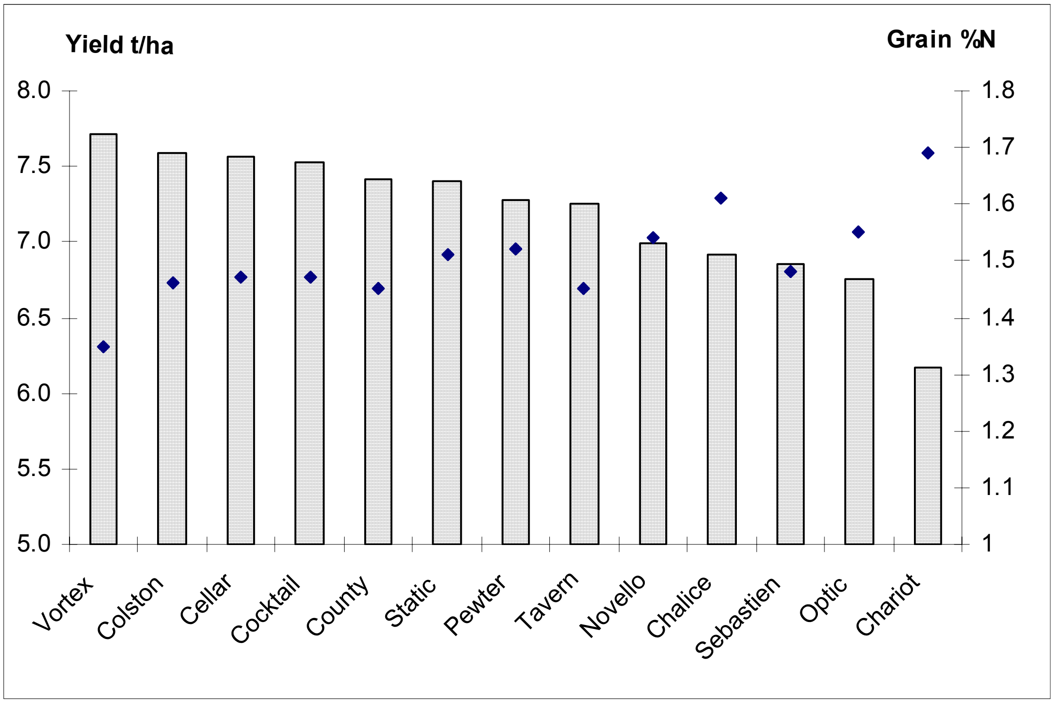


Figure 3.1. Average yield from a range of varieties from two site Rosemaund and New farm crops in 2002, Grain % nitrogen from NFC in 2002.

Table 3.3. Grain quality data from combine grain samples from Rosemaund in 2002

| Variety | Specific weight kg/hl | Thousand grain weight g | Grain size % > 2.2 mm |
|---|---|---|---|
| Optic | 73.50 | 46.89 | 97.07 |
| Chariot | 72.10 | 45.07 | 95.11 |
| Cellar | 71.83 | 54.33 | 98.21 |
| Tavern | 73.37 | 51.32 | 98.07 |
| Static | 71.10 | 53.20 | 98.10 |
| County | 72.10 | 51.66 | 96.90 |
| Chalice | 71.60 | 51.71 | 96.75 |
| Pewter | 70.60 | 52.71 | 98.30 |
| Colston | 72.60 | 49.94 | 98.35 |
| Cocktail | 72.43 | 50.33 | 97.42 |
| Vortex | 72.43 | 52.57 | 97.56 |
| Novello | 71.47 | 54.71 | 98.08 |
| Sebastien | 72.13 | 48.52 | 97.52 |
| Mean | 72.10 | 51.00 | 97.50 |

|  |  |  |  |
|---|---|---|---|
| CV% | **0.7** | **3.6** | **0.6** |
| Variety SED | **0.422** | **1.51** | **0.464** |
| p value | **< 0.001** | **< 0.001** | **< 0.001** |
| DF | **24** | **24** | **24** |

Table 3.3. Grain quality data from combine grain samples from NFC in 2002

| Variety | Specific weight kg/hl | Grain size % > 2.2 mm |
|---|---|---|
| Optic | 69.5 | 99 |
| Chariot | 67.3 | 98 |
| Cellar | 68.9 | 99 |
| Tavern | 69.1 | 99 |
| Static | 68.9 | 99 |
| County | 70.4 | 98 |
| Chalice | 68.4 | 98 |
| Pewter | 67.0 | 98 |
| Colston | 68.4 | 99 |
| Cocktail | 70.1 | 98 |
| Vortex | 69.2 | 99 |
| Novello | 67.6 | 99 |
| Sebastien | 67.6 | 99 |
| Mean | 68.6 | 98.6 |

# Appendix 4

## Sowing date x Variety interaction

### Materials & Methods

At a single site (Terrington) in 2002 seven varieties were sown at a standard seed rate (400 seeds m-2) on two sowing dates. A normal sowing on 18 February 2002 and a late sowing of 10 April 2002. The seven varieties evaluated were Optic, Cellar, Tavern, Chalice, County, Pewter and Static. The experimental design was a split plot plus factorial with sowing date as main plots and variety as fully randomised sub-plots. Plots were drilled with an 'Oyjord type' tractor mounted seed drill and plot dimensions were 2m wide by 24m long. All plots received standard rates of agrochemicals and fertilisers with an aim to maintain undisturbed and healthy crop growth.

### Results and Discussion

### Crop growth

Crop growth assessed just before harvest showed significant differences (*p*=0.046) in harvest index (HI) between sowing dates (table 4.1). A higher ratio of grain to straw and chaff biomass indicated by a higher HI was produced from the normal sowings compared to the later sowing date. On average, HI was 9% higher from a February sowing than an April sowing. From the individual components of crop growth, straw, grain and total biomass a significant interaction of sowing date and variety was seen (table 4.1). Variety County differed significantly in it's response in grain biomass at the different sowing dates, it has 2.17 t/ha lower hand harvested grain yield from an April sowing date compared to a February sowing date. Whereas Cellar had a grain yield 1.05 t/ha higher from an April sowing date compared to a February sowing. Cellar also showed a similar trend in straw and total biomass producing more from an April sowing compared to a February sowing. The grain yield interaction is linked to the number of ears produced as significant varietal interactions (*p*=0.053) are also seen in this component (table 4.2). From a February sowing date, where County had the highest hand harvested grain yield it also produced the highest ear numbers. At the later sowing where it had significantly lower yield it produced one of the lowest ear numbers. Cellar produces the highest number of ears and hand harvested yield from an April sowing but had the converse from a February sowing. On average, 78 more ears were produced from an April sowing compared to a February sowing. Varietal interactions with sowing date similar to these have been seen in wheat (J Spink, MJ Fouulkes et al, 2000). The differences in ear number with sowing date affected grain weight and number per ear. These were both significantly higher from a February sowing compared to an April sowing. Grain weight and grain number per ear were 16 % and 13% higher respectively from a February sowing compared to the later sowing. There was no significant interaction between sowing date and variety in hand harvested thousand grain weight (tgw) and only the varieties differed significantly in main effects. Although there was a trend for higher tgw's from the February sowing date.

Table 4.1. Crop growth assessment at harvest from a range of varieties and two sowing dates at ADAS Terrington in 2002.

| | | | Biomass t/ha at 100% dry matter | | |
|---|---|---|---|---|---|
| Sowing date | Variety | Harvest Index % | Straw | Grain | Total |
| February | Optic | 47.76 | 3.86 | 4.92 | 10.26 |
| | Cellar | 52.97 | 2.70 | 4.76 | 8.99 |
| | Tavern | 49.45 | 3.29 | 5.06 | 10.27 |
| | Static | 49.01 | 3.77 | 5.62 | 11.48 |
| | County | 53.14 | 4.21 | 7.06 | 13.26 |
| | Chalice | 48.76 | 3.48 | 4.72 | 9.74 |
| | Pewter | 49.57 | 2.69 | 4.19 | 8.46 |
| February | Mean | 50.10 | 3.43 | 5.19 | 10.35 |
| April | Optic | 43.90 | 4.28 | 4.59 | 10.48 |
| | Cellar | 45.36 | 4.94 | 5.81 | 12.73 |
| | Tavern | 47.48 | 4.23 | 5.60 | 11.81 |
| | Static | 48.26 | 4.56 | 5.59 | 11.58 |
| | County | 43.22 | 4.45 | 4.89 | 11.28 |
| | Chalice | 46.89 | 3.77 | 4.91 | 10.47 |
| | Pewter | 45.64 | 3.52 | 4.65 | 10.12 |
| April | Mean | 45.82 | 4.25 | 5.15 | 11.21 |
| Overall | Mean | 47.96 | 3.84 | 5.17 | 10.78 |
| CV% | | **2.4** | **9.0** | **2.3** | **4.8** |
| Sowing date SED | | **0.947** | **0.282** | **0.097** | **0.423** |
| p value | | **0.046** | **NS** | **NS** | **NS** |
| DF | | **2** | **2** | **2** | **2** |
| Variety SED | | **1.938** | **0.282** | **0.442** | **0.685** |
| p value | | **NS** | **0.005** | **0.026** | **0.006** |
| CV% | | **7.0** | **12.7** | **14.8** | **11.0** |
| Interaction SED | | **2.741** | **0.399** | **0.625** | **0.969** |
| p value | | **NS** | **0.027** | **0.036** | **0.017** |
| DF | | **24** | **24** | **24** | **24** |

Table 4.2. Crop growth assessment at harvest from a range of varieties and two sowing dates at ADAS Terrington in 2002.

| Sowing date | Variety | Thousand grain weight g | Grain weight /ear g | Grain number /ear | Final Ear number |
|---|---|---|---|---|---|
| February | Optic | 47.48 | 1.02 | 24.56 | 497.38 |
| | Cellar | 49.15 | 1.00 | 23.35 | 483.72 |
| | Tavern | 51.53 | 1.06 | 23.80 | 479.03 |
| | Static | 50.17 | 0.99 | 22.66 | 575.64 |
| | County | 50.70 | 0.95 | 21.58 | 744.23 |
| | Chalice | 51.80 | 0.95 | 20.96 | 512.31 |
| | Pewter | 52.65 | 1.04 | 22.72 | 421.62 |
| February | Mean | 50.50 | 1.00 | 22.80 | 530.56 |
| April | Optic | 46.93 | 0.81 | 19.99 | 565.53 |
| | Cellar | 49.52 | 0.80 | 18.63 | 736.10 |
| | Tavern | 50.21 | 0.84 | 19.31 | 672.75 |
| | Static | 48.39 | 0.88 | 20.97 | 639.71 |
| | County | 50.83 | 0.85 | 19.18 | 577.69 |
| | Chalice | 48.10 | 0.86 | 20.54 | 575.39 |
| | Pewter | 49.08 | 0.95 | 22.14 | 492.08 |
| April | Mean | 49.01 | 0.86 | 20.11 | 608.46 |
| Overall | Mean | 49.75 | 0.93 | 21.46 | 569.51 |
| CV% | | **1.9** | **3.9** | **1.7** | **4.6** |
| Sowing date SED | | **0.778** | **0.030** | **0.306** | **21.4** |
| p value | | **NS** | **0.039** | **0.013** | **0.068** |
| DF | | **2** | **2** | **2** | **2** |
| Variety SED | | **1.007** | **0.89** | **1.976** | **59.2** |
| p value | | **0.014** | **NS** | **NS** | **0.051** |
| CV% | | **3.5** | **16.6** | **15.9** | **18.0** |
| Interaction SED | | **1.425** | **0.126** | **2.794** | **83.8** |
| p value | | **NS** | **NS** | **NS** | **0.053** |
| DF | | **24** | **24** | **24** | **24** |

**Combine yield and quality**

The significant interactions and differences seen in hand harvested grain yield were not borne out by combine grain yields, which only detected significant differences (*p*= <0.001) in varietal main effects (table 4.3). The reason for this is unknown and further research to investigate the interaction of sowing date and variety would be required to understand more fully the effects on crop growth and grain yield. Varietal main effects in combine grain yield saw Tavern and Cellar giving the best yields of 7.45 and 7.19 t/ha respectively meaned across the two sowing dates. Similarly thousand grain weight assessed on combine grain samples saw significant differences between varieties only. Although there was a trend for higher tgw's from a February sowing which was consistent with that seen in the same assessment on hand harvested samples. County had the highest tgw of 50.64g and Optic the lowest of 43.89g averaged across the sowing dates.

There was an indication that there were varietal interactions in crop growth at different sowing dates although final yield results did not confirm this. A larger difference in sowing date than achieved in these trials may result in significant differences in combine grain yield being detected. The results suggest that a more thorough investigation of varietal suitability to certain sowing dates and effects on grain quality is required in order to quantify the effect on homogeneity of the barley sample.

Table 4.3. Yield and quality data from a range of varieties and two sowing dates at ADAS Terrington in 2002.

| Sowing date | Variety | Grain yield t/ha | Specific weight kg/hl | Thousand grain weight g |
|---|---|---|---|---|
| February | Optic | 6.03 | 63.76 | 46.88 |
| | Cellar | 6.87 | 64.23 | 49.64 |
| | Tavern | 7.19 | 64.65 | 50.03 |
| | Static | 6.78 | 61.97 | 49.83 |
| | County | 6.82 | 65.01 | 52.90 |
| | Chalice | 6.24 | 61.91 | 47.34 |
| | Pewter | 6.81 | 63.66 | 50.60 |
| February | Mean | 6.67 | 63.60 | 49.60 |
| April | Optic | 6.65 | 64.03 | 40.90 |
| | Cellar | 7.51 | 63.66 | 48.22 |
| | Tavern | 7.72 | 64.25 | 47.11 |
| | Static | 6.66 | 61.72 | 41.86 |
| | County | 6.94 | 63.50 | 48.38 |
| | Chalice | 6.62 | 63.22 | 43.89 |
| | Pewter | 7.03 | 62.54 | 47.46 |
| April | Mean | 7.02 | 63.27 | 45.40 |
| Overall | Mean | 6.85 | 63.44 | 47.50 |
| CV% | | **3.2** | **2.5** | **5.1** |
| Sowing date SED | | **0.178** | **1.276** | **1.98** |
| p value | | **NS** | **NS** | **NS** |
| DF | | **2** | **2** | **2** |
| Variety SED | | **0.196** | **0.910** | **1.287** |
| p value | | **<0.001** | **0.074** | **<0.001** |
| CV% | | **5.0** | **2.5** | **4.7** |
| Interaction SED | | **0.277** | **1.287** | **1.819** |
| p value | | **NS** | **NS** | **NS** |
| DF | | **24** | **24** | **24** |

## Appendix 5

## IMAGE ANALYSIS ASSESSMENTS

### Materials and Methods

*Field experiments*

Replicated experiments were conducted at White house farm, Sellack, Ross-on-Wye, Herefordshire in 2000, ADAS Rosemaund, Preston wynne, Herefordshire in 2001 and ADAS Bridgets, Martyr Worthy, Hampshire in 2000 and 2001. The experiments investigated the effects of a range of five seedrates (50, 100, 200, 400, 800 seeds/m$^2$) on four varieties.

*Grain samples*

At harvest, grain yield was determined using a plot combine harvester and associated weigh equipment, 3 kg samples were taken from all plots in both experiments. A sub-sample was then cleaned to the industry standard, moisture content (%), specific weight (kg/hl) and temperature ($^0$C) determined using a Dickey-John II moisture meter and thousand grain weight (g) using a numigral grain counter. A representative 50g sub-sample of the cleaned grain was taken for grain image analysis assessment from all the plots from one variety (Optic) at both sites. This gave a total of 15 samples per site (5 seedrates x 3 replicates).

*Grain Image Analysis*

The 50g sub-sample was carefully poured onto a modified 5mm slotted sieve plate situated on a substage illuminated light box. Grains were carefully brushed into the slots in the sieve plate and any excees grain removed. The sieve plate was then carefully removed without disturbing any grains to leave 150-160 spatially isolated grains in a 17cm x 17cm field on the light box. A solid state video camera mounted to a camera stand directly above the light box and connected to a Delta-T Image Analysis System (DIAS, Delta-T Devices, Burwell, Cambridge) was used to capture the silhouetted images. The DIAS digitised the images with 512 x 488 pixels with a spatial resolution of 0.33 mm/pixel. The minimum object area was set to 0.1 mm. Each grain was automatically identified and measured for area, perimeter, length, width and shape factor (ratio of actual perimeter to that of a circle with the same area). The mean value for each variate for the 150-160 grains was then subjected to analysis of variance.

**Results and Conclusions**

The image analysis data in table 1 for the Herefordshire site confirms the increase in grain size with seedrate seen in the thousand grain weight figures. Significant effects of seedrate are seen in all the image analysed grain size measurements. However the increases seen are much less than those detected in thousand grain weight. Thousand grain weight was seen to increase 20.6 % from 800 to 50 seeds/m$^2$ but grain area only increased by 10.8 % and grain width by 6.1 % for the corresponding seedrates (Fig 1.). Grain shape was not significantly influenced by seedrate as demonstrated by the shape factor variable.

Table 1. Grain size components obtained by Image Analysis of Optic Spring Barley from Sellack, Herefordshire in 2000.

| Seedrate m$^{-2}$ | Area mm$^{-2}$ | Perimeter mm | Length mm | Width mm | Shape Factor | Thousand grain wt (g) |
|---|---|---|---|---|---|---|
| 50 | 27.11 | 22.182 | 9.034 | 3.968 | 12.037 | 56.42 |
| 100 | 26.64 | 21.993 | 8.927 | 3.945 | 12.033 | 52.42 |
| 200 | 26.14 | 21.848 | 8.885 | 3.884 | 12.069 | 50.98 |
| 400 | 25.21 | 21.331 | 8.664 | 3.823 | 12.003 | 49.50 |
| 800 | 24.47 | 21.118 | 8.586 | 3.740 | 12.067 | 46.77 |
| Mean | 25.92 | 21.695 | 8.819 | 3.872 | 12.042 | 51.22 |
| Seedrate p value | <0.001 | 0.003 | <0.001 | <0.001 | ns | <0.001 |
| SED | 0.034 | 0.196 | 0.070 | 0.031 | 0.062 | 0.60 |
| df | 14 | 14 | 14 | 14 | 14 | 14 |
| cv% | 1.6 | 1.1 | 1.0 | 1.0 | 0.6 | 3.0 |

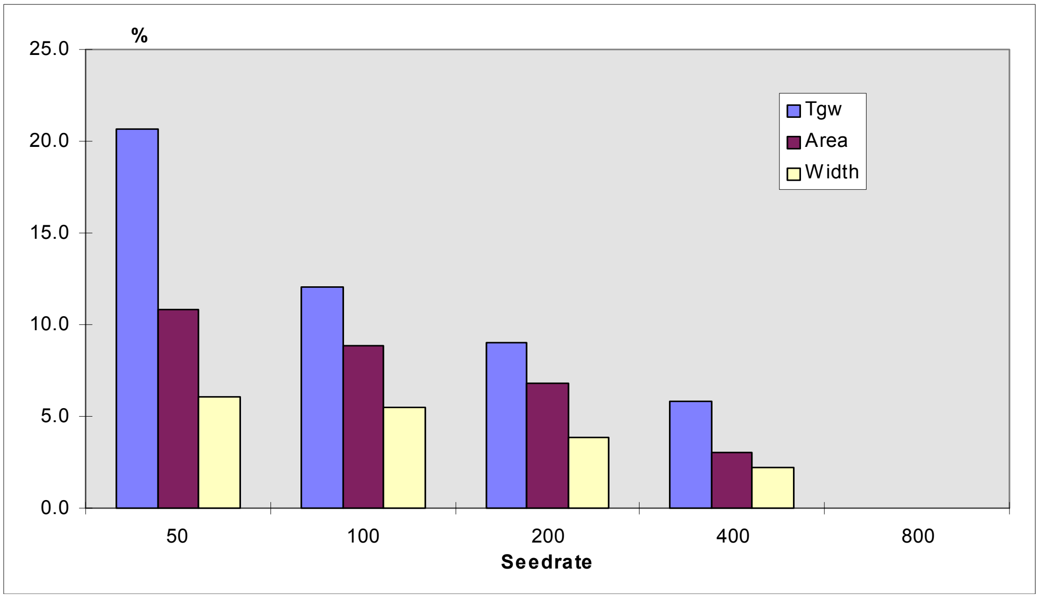


Figure 1. Response (% of 800) to seedrate of Tgw, grain area and grain width.

The data from the Hampshire site concurs with the Herefordshire site with significant increases in grain size with reduced seedrates, although some of the significance levels were less. The complete thousand grain weight data set was not available but the indication was that a similar trend to that seen at the other site was present. The increases in thousand grain weight seen when seedrates were reduced from 400 to 100 were about double what was detected in grain area and grain width. Again grain shape was not significantly influenced by seedrate.

Table 2. Grain size components obtained by Image Analysis of Optic Spring Barley from Bridgets, Hampshire in 2000.

| Seedrate $m^{-2}$ | Area $mm^{-2}$ | Perimeter mm | Length mm | Width mm | Shape Factor | Thousand grain wt (g) |
|---|---|---|---|---|---|---|
| 50 | 26.60 | 21.972 | 8.897 | 3.976 | 12.033 | |
| 100 | 25.99 | 21.671 | 8.790 | 3.927 | 12.002 | 45.03 |
| 200 | 25.48 | 21.505 | 8.723 | 3.854 | 12.031 | |
| 400 | 24.50 | 21.020 | 8.591 | 3.754 | 11.994 | 40.23 |
| 800 | 24.34 | 21.079 | 8.590 | 3.726 | 12.067 | |
| Mean | 25.38 | 21.449 | 8.718 | 3.847 | 12.026 | 42.63 |
| Seedrate p value | 0.003 | 0.003 | 0.016 | <0.001 | ns | |
| SED | 0.043 | 0.178 | 0.076 | 0.035 | 0.041 | |
| df | 14 | 14 | 14 | 14 | 14 | |
| cv% | 2.1 | 1.0 | 1.1 | 1.1 | 0.4 | |

A cross site analysis of the image analysis data shows that the site had a significant effect on grain area only at p<0.05 although some trends were seen in grain length and perimeter at lower significance levels. There were no significant site x seedrate interactions showing a consistency of the seedrate effect on grain size across the sites.

Table 3. Cross site analysis of grain size components for 2000.

| Seedrate $m^{-2}$ | Area $mm^{-2}$ | Perimeter mm | Length mm | Width mm | Shape Factor |
|---|---|---|---|---|---|
| 50 | 26.86 | 22.077 | 8.965 | 3.972 | 12.035 |
| 100 | 26.32 | 21.832 | 8.858 | 3.936 | 12.018 |
| 200 | 25.81 | 21.676 | 8.804 | 3.869 | 12.050 |
| 400 | 24.86 | 21.176 | 8.627 | 3.789 | 11.998 |
| 800 | 24.40 | 21.098 | 8.588 | 3.733 | 12.067 |
| Mean | 25.65 | 21.572 | 8.769 | 3.860 | 12.034 |
| Site p value | 0.034 | 0.095 | 0.171 | ns | ns |
| SED | 0.017 | 0.112 | 0.060 | 0.022 | 0.047 |
| df | 4 | 4 | 4 | 4 | 4 |
| cv% | 0.8 | 0.6 | 0.8 | 0.7 | 0.5 |
| Seedrate p value | <0.001 | <0.001 | <0.001 | <0.001 | ns |
| SED | 0.027 | 0.132 | 0.052 | 0.023 | 0.037 |
| Site x Seedrate p value | ns | ns | ns | ns | ns |
| SED | 0.038 | 0.202 | 0.089 | 0.036 | 0.066 |
| df | 16 | 16 | 16 | 16 | 16 |
| cv% | 1.8 | 1.1 | 1.0 | 1.0 | 0.5 |

The assessments were repeated on grain samples from the 2001 trials using the same analysis techniques. These results concurred with the first years findings with significant effects on all image analysed grain size measurements except width and shape factor from the Rosemaund site (table 4). In this year the Hampshire site showed greater significant differences (*p*=<0.001) than the Herefordshire site (table 5). Thousand grain weight was seen to increase 14.9% from 800 to 50 seed/m2 at Bridgets compared to 8.5% at Rosemaund.

Table 4. Grain size components obtained by Image Analysis of Optic Spring Barley from ADAS Rosemaund, Herefordshire in 2001.

| Seedrate $m^{-2}$ | Area $mm^{-2}$ | Perimeter mm | Length mm | Width mm | Shape Factor | Thousand grain wt (g) |
|---|---|---|---|---|---|---|
| 50 | 26.273 | 22.035 | 9.024 | 3.809 | 1.217 | 57.11 |
| 100 | 26.319 | 21.962 | 8.992 | 3.829 | 1.211 | 56.33 |
| 200 | 25.549 | 21.611 | 8.824 | 3.783 | 1.209 | 55.34 |
| 400 | 24.835 | 21.257 | 8.692 | 3.734 | 1.206 | 54.28 |
| 800 | 24.897 | 21.232 | 8.656 | 3.762 | 1.203 | 52.64 |
| Mean | 25.525 | 21.590 | 8.824 | 3.781 | 1.209 | 55.14 |
| Seedrate p value | 0.027 | 0.014 | 0.017 | 0.152 | 0.096 | - |
| SED | 0.449 | 0.205 | 0.196 | 0.036 | 0.004 | - |
| df | 13 | 13 | 13 | 13 | 13 | - |
| cv% | 2.1 | 1.2 | 1.3 | 1.2 | 0.4 | - |

Table 5. Grain size components obtained by Image Analysis of Optic Spring Barley from Bridgets, Hampshire in 2001.

| Seedrate $m^{-2}$ | Area $mm^{-2}$ | Perimeter mm | Length mm | Width mm | Shape Factor | Thousand grain wt (g) |
|---|---|---|---|---|---|---|
| 50 | 26.457 | 22.279 | 9.176 | 3.799 | 1.226 | 50.2 |
| 100 | 25.942 | 21.820 | 8.954 | 3.807 | 1.211 | 49.9 |
| 200 | 24.994 | 21.353 | 8.763 | 3.744 | 1.208 | 50.1 |
| 400 | 23.956 | 20.829 | 8.542 | 3.668 | 1.203 | 45.6 |
| 800 | 23.581 | 20.673 | 8.468 | 3.646 | 1.203 | 43.7 |
| Mean | 24.986 | 21.391 | 8.781 | 3.733 | 1.210 | 47.9 |
| Seedrate p value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | - |
| SED | 0.202 | 0.114 | 0.055 | 0.012 | 0.002 | - |
| df | 14 | 14 | 14 | 14 | 14 | - |
| cv% | 1.0 | 0.7 | 0.8 | 0.4 | 0.3 | - |

Table 6. Cross site analysis of grain size components in 2001

| Seedrate $m^{-2}$ | Area $mm^{-2}$ | Perimeter mm | Length mm | Width mm | Shape Factor |
|---|---|---|---|---|---|
| 50 | 26.383 | 22.181 | 9.115 | 3.803 | 1.222 |
| 100 | 26.131 | 21.891 | 8.973 | 3.818 | 1.211 |
| 200 | 25.272 | 21.482 | 8.794 | 3.763 | 1.209 |
| 400 | 24.396 | 21.043 | 8.617 | 3.701 | 1.205 |
| 800 | 24.239 | 20.952 | 8.562 | 3.704 | 1.203 |
| Mean | 25.246 | 21.487 | 8.802 | 3.756 | 1.209 |
| Site p value | <0.001 | 0.003 | 0.085 | <0.001 | 0.434 |
| SED | 0.145 | 0.068 | 0.032 | 0.012 | 0.001 |
| df | 4 | 4 | 4 | 4 | 4 |
| cv% | 0.4 | 0.2 | 0.1 | 0.3 | 0.1 |
| Seedrate p value | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| SED | 0.230 | 0.108 | 0.050 | 0.018 | 0.002 |
| Site x Seedrate p value | 0.060 | 0.021 | 0.034 | 0.083 | 0.153 |
| SED | 0.325 | 0.153 | 0.071 | 0.026 | 0.003 |
| df | 17 | 17 | 17 | 17 | 17 |
| cv% | 1.6 | 0.9 | 1.0 | 0.9 | 0.3 |

The preceeding discussion and results have been concerned with differences in grain size between seedrates detected by the image analysis technique. However more interesing for this project is to understand whether different seedrates produce a grain sample of more or less uniform or homogeneous grain size than others. Hence to explore the hypothesis 'that physical grain uniformity does not change with changes in seed rate'. Further statistical analysis of the data is required to verify this hypothesis.

In the following frequency distribution graphs, data are presented for the whole sample of between 450-470 grains per treatment for two grain size components, grain area and width. These suggest that reducing seed rate increases grain size so that there are more larger grains. However it has an adverse affect on the grain size distribution in that there is a larger variation in grain size indicated by the higher standard deviations at lower seed rates. This would possibly lead to a less homogenous sample.

This seedrate effect on grain size distribution is worthy of further analysis particularly the relationship to malt homogeneity. The image analysis technique may be able to developed further using new digital camera or scanner technology, which would improve throughput and accuracy. It then may have utility in grain intake as a rapid analysis method.

Frequency distribution graphs for grain area ($mm^{-2}$) all sample (450-60 grains) from Herefordshire site in 2000.

Figure 1. 50 seeeds/$m^2$

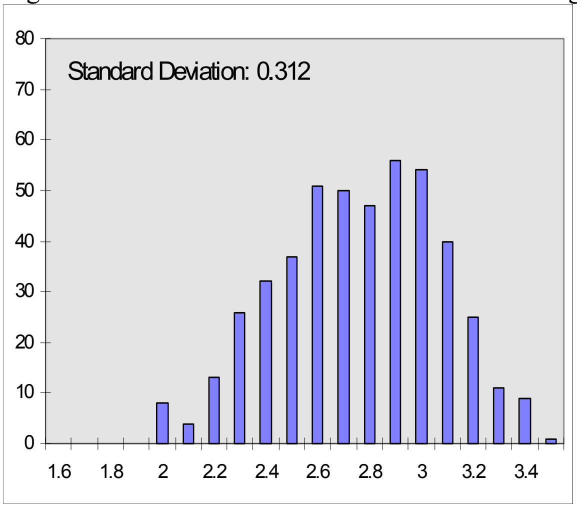


Figure 2. 100 seeeds/$m^2$

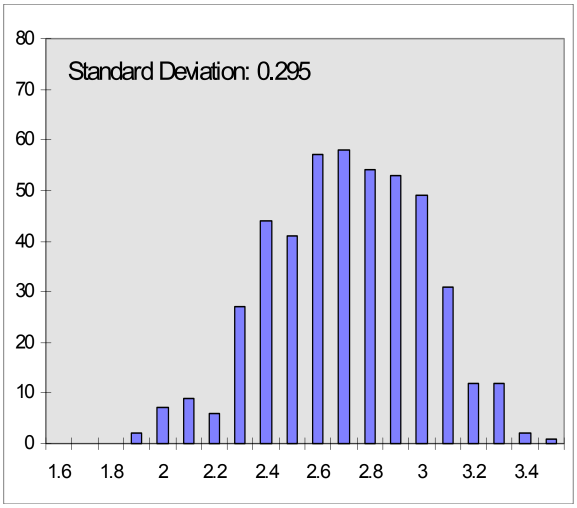


Figure 3. 200 seeeds/$m^2$

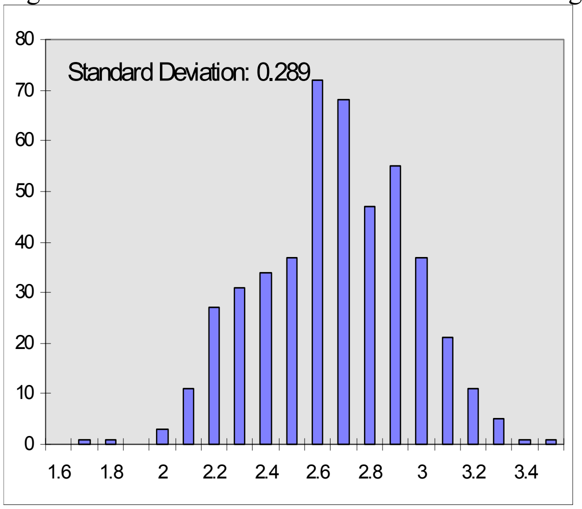


Figure 4. 400 seeeds/$m^2$

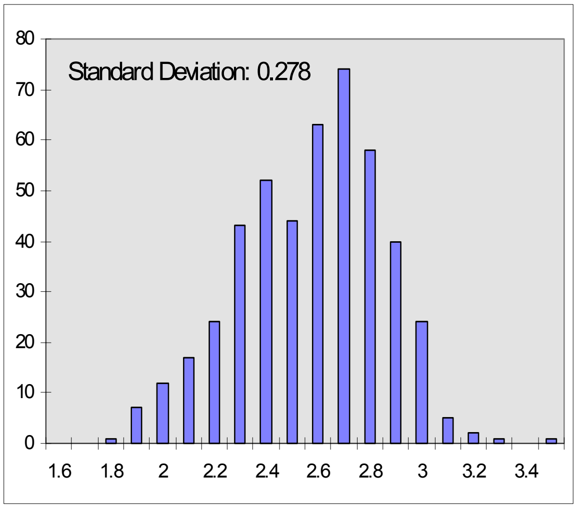


Figure 5. 800 seeeds/$m^2$

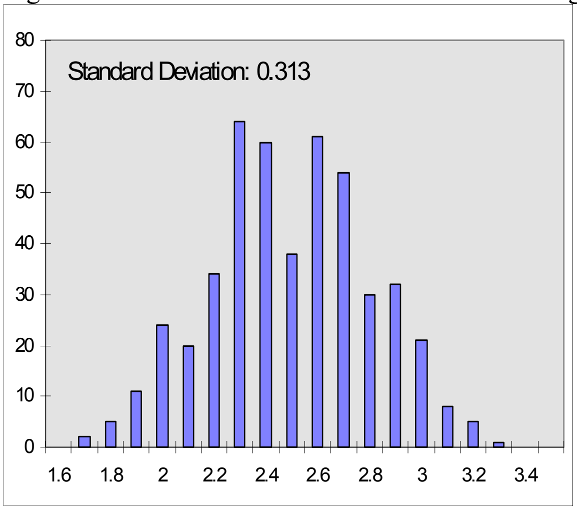
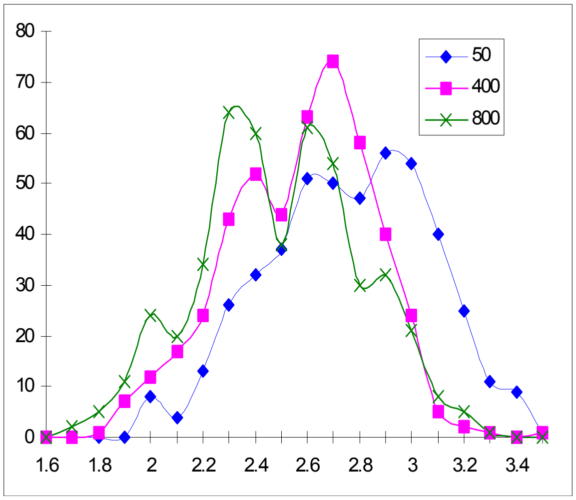


Figure 6. Comparison of three seedrates



Frequency distribution graphs for grain area (mm$^{-2}$) all sample (450-60 grains) from Hants site in 2000

Figure 1. 50 seeeds/m$^2$

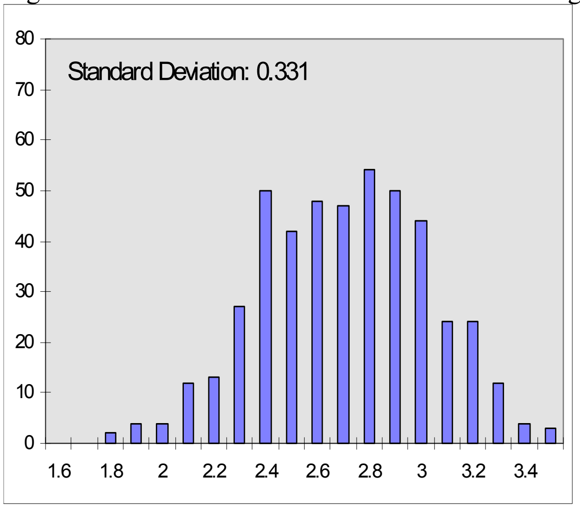


Figure 2. 100 seeeds/m$^2$

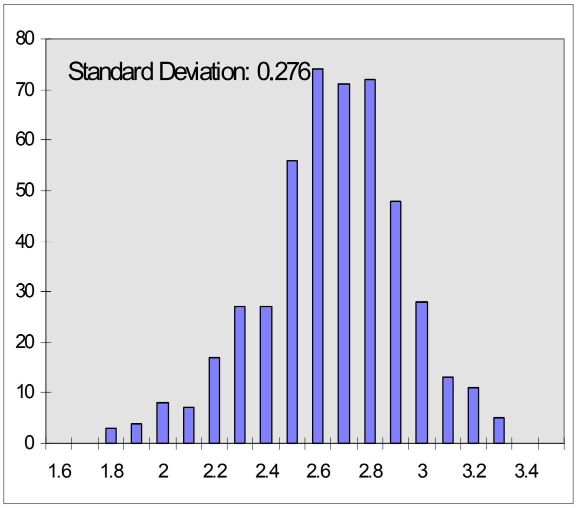


Figure 3. 200 seeeds/m$^2$

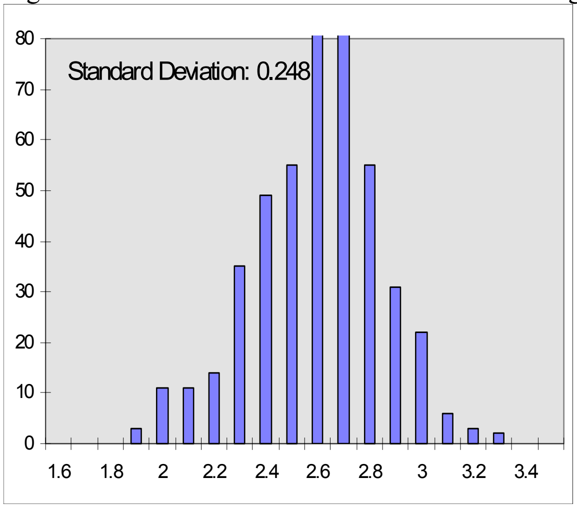


Figure 4. 400 seeeds/m$^2$

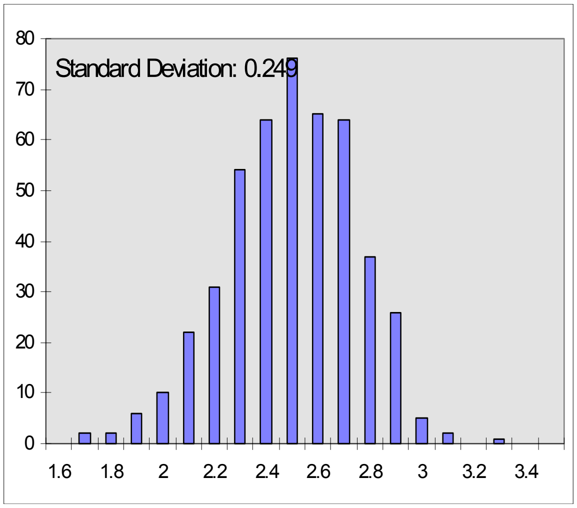


Figure 5. 800 seeeds/m$^2$

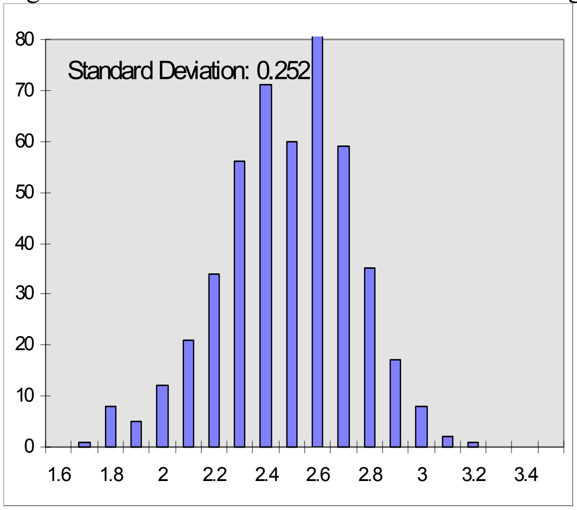
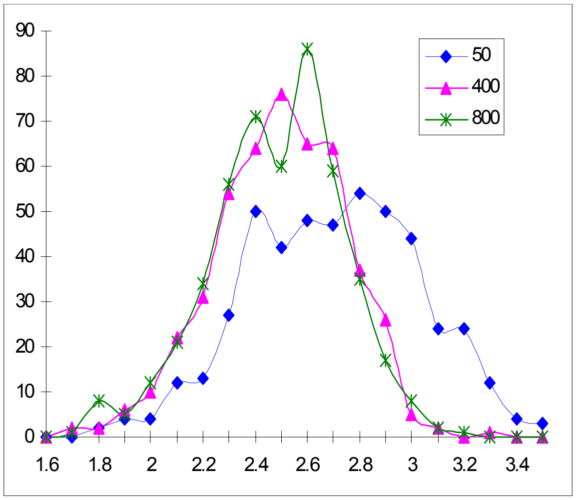


Figure 6. Comparison of three seedrates



Frequency distribution graphs for grain width (mm) all sample (450-60 grains) from Herefordshire site in 2000

Figure 1. 50 seeeds/m$^2$

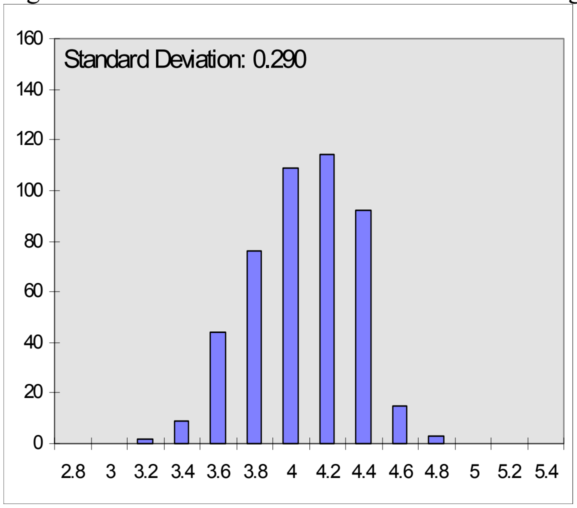


Figure 2. 100 seeeds/m$^2$

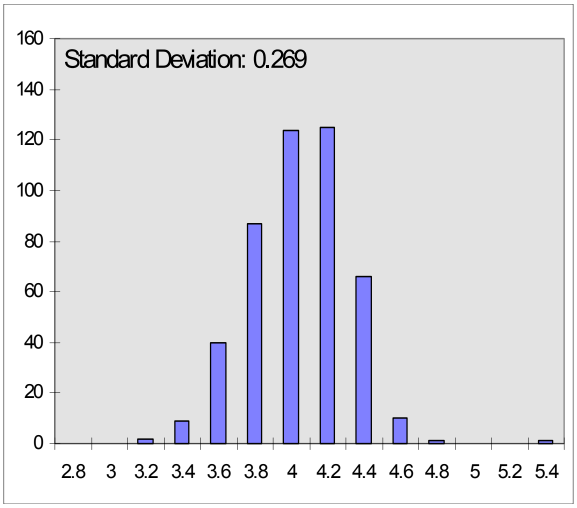


Figure 3. 200 seeeds/m$^2$

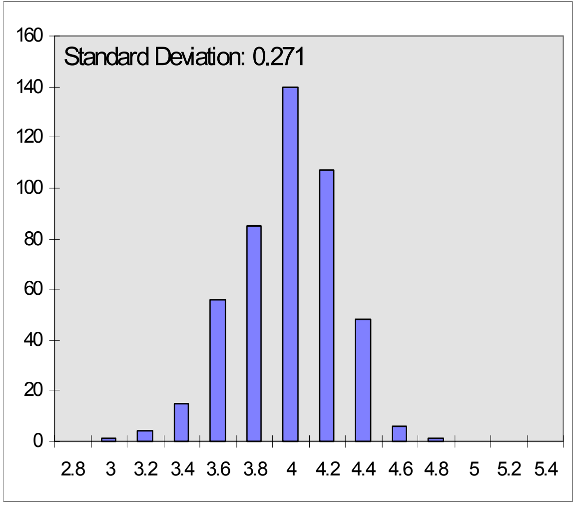


Figure 4. 400 seeeds/m$^2$

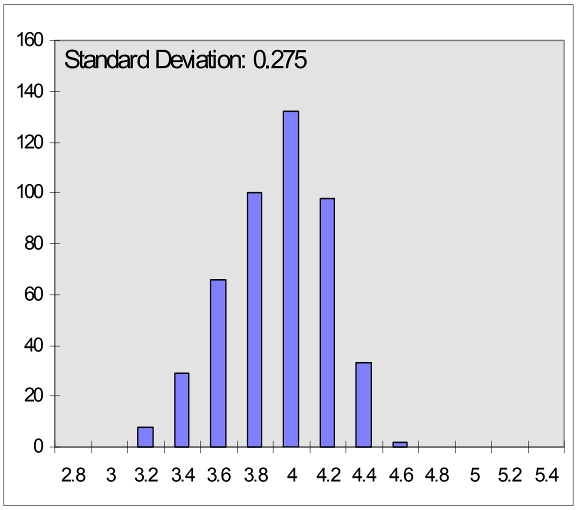


Figure 5. 800 seeeds/m$^2$

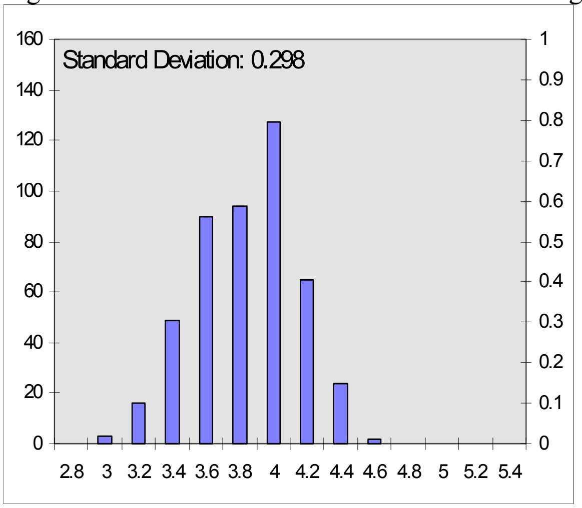
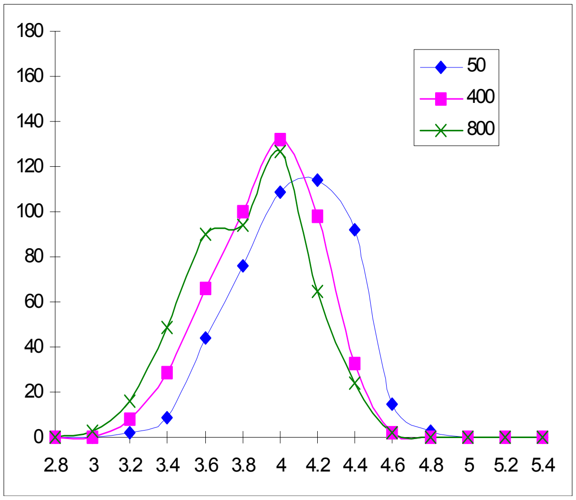


Figure 6. Comparison of three seedrates



Frequency distribution graphs for grain width (mm) all sample (450-60 grains) from Hants site in 2000

Figure 1. 50 seeeds/$m^2$

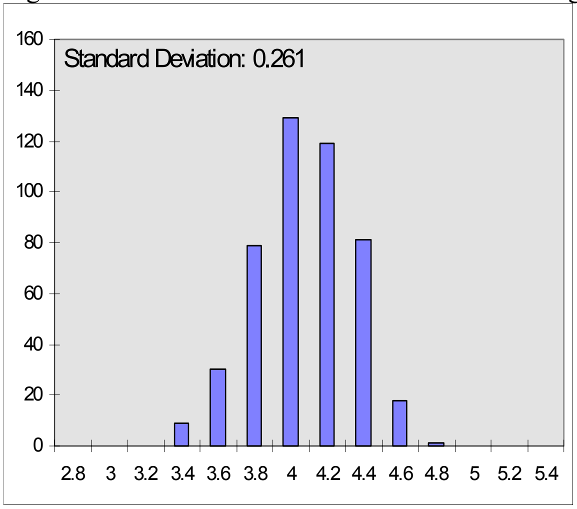


Figure 2. 100 seeeds/$m^2$

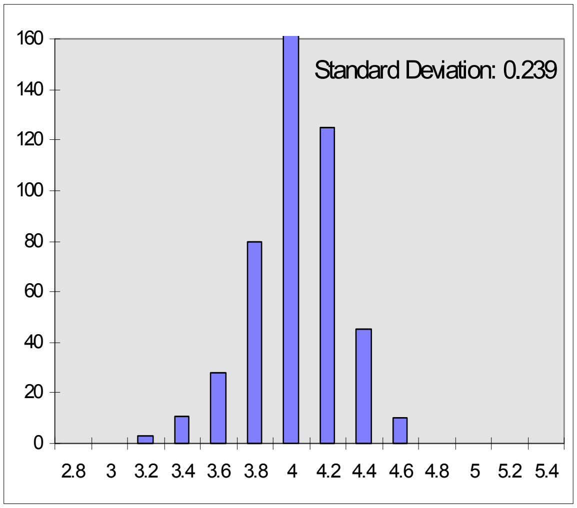


Figure 3. 200 seeeds/$m^2$

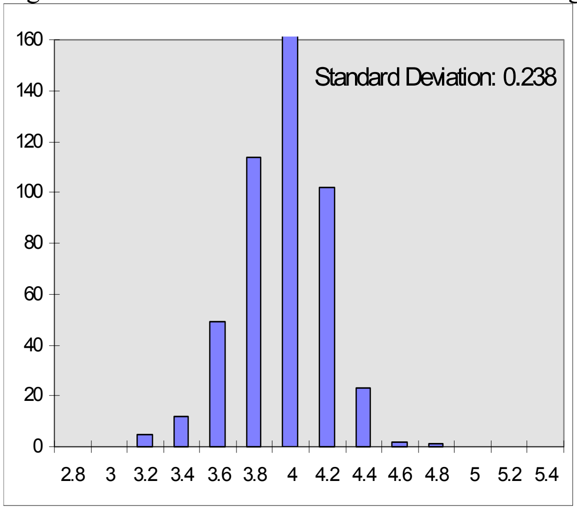


Figure 4. 400 seeeds/$m^2$

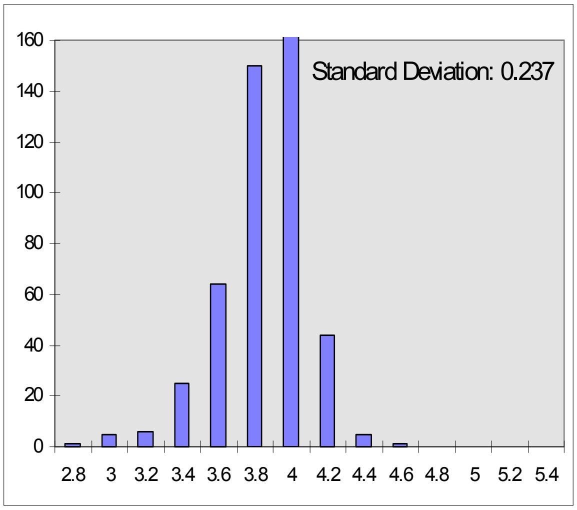


Figure 5. 800 seeeds/$m^2$

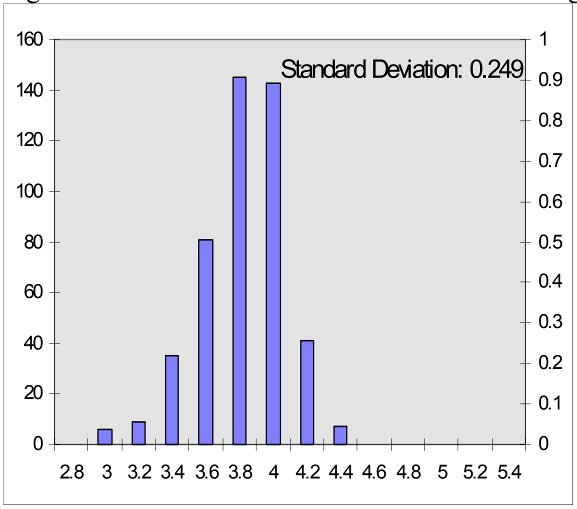
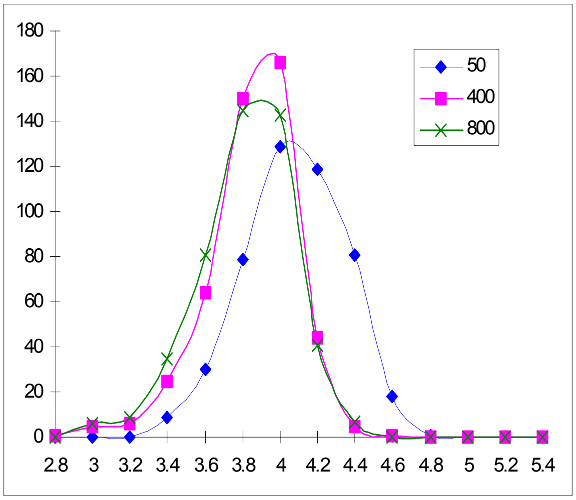


Figure 6. Comparison of three seedrates



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