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Updating N fertiliser management guidelines for winter barley

S. Kendall[1], H.F. Holmes[2] and P.M. Berry[3],

[1]ADAS Gleadthorpe, Meden Vale, Mansfield, Nottingham, NG20 9PD

[2]ADAS Boxworth, Boxworth, Cambridge CB234NN

[3]ADAS High Mowthorpe, Duggleby, Malton, N Yorkshire YO178BP

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CONTENTS

1. Abstract

The aim of this project was to review existing evidence and generate new data in order to provide evidence for updating the RB209 N management guidelines for winter barley. Specific objectives included:

1) Review existing data on optimum N rate and N timing for winter barley.
2) Determine experimentally how the optimum N rate varies between different variety types (2-row feed, 2-row malting, 6-row feed and hybrid feed) and compare against older varieties from the 1980s and before.
3) Investigate the optimum N timing for different variety types (2-row feed, 2-row malting, 6-row feed and hybrid feed).
4) Transfer new knowledge to farmers and agronomists.

The project demonstrated that the 2010 edition of the RB209 Fertiliser Manual underestimates the N fertiliser requirement for winter barley with a yield of more than the UK farm average winter barley yield of 6.5 t/ha. For each tonne of expected yield above 6.5 t/ha the crop was shown to require an additional 20 kg N/ha. The project showed that higher yielding feed and malting varieties required more N to achieve their full yield potential compared with lower yielding varieties.

The project showed that N fertiliser timings should be earlier than recommended by the 2010 edition of RB209. It was demonstrated that a greater percentage of the total N should be applied before the start of stem extension (GS31). On average, applying between 50% and 100% or the total N between tillering and GS30 increased yield by 0.3 t/ha compared with applying the RB209 recommendation of about 30% of total N before stem extension. All variety types investigated responded similarly to earlier N and there was no evidence that different N timings are required for specific varietal types (i.e. 2-row, conventional 6-row and hybrid 6-row). There was no evidence that autumn fertiliser N applied in the seed bed increased yield above applying all of the N after winter.

The earlier N strategy described above reduced the grain N concentration by almost 0.1% which, together with the greater understanding of how N rate and N timing affects grain N developed by the project, will help growers to achieve malting specification whilst maximising yield. Applying a greater proportion of N before GS31 did not reduce specific weight. Earlier N increased straw yield by 0.5 t/ha on average and increased height by several centimetres. The increase in height is likely to result in a greater lodging risk and the requirement of a robust PGR programme.

Growers will benefit from this research by being able to grow more profitable winter barley. Based on the results of this project it has been estimated that optimising N timing will lead to an increased gross margin over costs of £48/ha, rising to £58/ha where RB209 under-estimated the fertiliser N requirement by 40 kg N/ha, and rising further to £83/ha if the strategy enables the malting premium to be achieved.

2. Introduction

The last extensive set of trials on nitrogen (N) fertiliser rates and timings for winter feed and malting barley was carried out in the 1980s (Lord and Vaughan, 1987). Results from these trials form the basis of the current RB209 Fertiliser Manual (8th edition) (Anon. 2010) for both the N rate and N timing. For feed barley, N rates range from zero for soils with a soil N supply (SNS) index of 5 or 6, 140 kg N/ha for medium soils with an SNS index of 2, to 210 kg N/ha for shallow soils with an SNS index of 0. For malting barley with a target grain N% of 1.8% the feed barley rates are generally reduced by 30-40 kg N/ha. N timings for winter barley are as follows:

1) Where the total N applied over the season is less than 100 kg N/ha, it should be applied as a single dressing, between late March and early stem extension (GS 31).
2) Where more than 100 kg N/ha is to be applied, 40 kg N/ha should be applied between mid-February and early March, and the remainder by early stem extension but not before late March.

The British Survey of Fertiliser practice shows that the average N rate for winter barley (feed and malting combined) was 141 kg N/ha between 2009 and 2011, and has changed relatively little since the 1980s when it was 150 kg N/ha. Between 2006 and 2008, 69% of winter barley crops received two N splits, 14% of crops received one N split, 14% of crops received three N splits and 3% of crops received no fertiliser N. Of the crops receiving two N splits, the first split averaged 60 kg N/ha and the second split averaged 80 kg N/ha. In general the first split was applied in March and the second split in April, with only 11% of crops receiving their second (final split) before April. It therefore appears farmers generally follow current RB209 guidelines in terms of the number of N applications and the timings, but proportionally more is often applied at the first split timing than recommended with 60 kg N/ha applied against the recommended 40 kg N/ha.

Since the 1980s there have been very few experiments to investigate the optimum rate and timing of N fertiliser for winter barley in the UK. A series of six experiments was carried out in harvest years 2008, 09 and 10, which investigated 6 N rates (0 to 300 kg N/ha) and 2 N timings (RB209 and 50% in early March and 50% end of March) for 2-row feed variety Saffron and 6-row feed variety Pelican. These experiments were funded by CF Fertilisers UK Ltd and carried out by ADAS UK Ltd. These trials showed that the measured optimum N rate averaged 32 kg N/ha more than recommended by RB209. For high yielding crops of over 9 t/ha the optimum was up to 60 kg N/ha more than RB209 recommendations. Applying N earlier than recommended increased the yield of the 2-row variety by 0.23 t/ha and increased the yield of the 6-row variety by 0.68 t/ha, reduced the grain N by 0.1% and increased the straw yield by 0.3 to 1.0 t/ha.

In Scotland fourteen N response experiments were carried out on winter barley between 2007 and 2009 (Gilchrist et al., 2012, AHDB Report 484). In all but two of the experiments it was not possible to calculate the optimum N rate because the optimum N was greater than the highest experimental N rate treatment used of 240 kg N/ha. In these experiments it could be concluded that the N rate was greater than 240 kg N/ha. In the other two experiments the optimum N rate was 156 and 163 kg N/ha. The N Max limit for winter barley in Scotland is 180 kg N/ha and these experiments provide further evidence that the fertiliser N requirement of modern winter barley varieties is greater than current N fertiliser guidelines recommend. Scotland accounts for less than 10% of the UK winter barley grown.

Farm yields of winter barley increased by approximately 20% since the 1980s (Figure 2.1). The greater yield potential of new winter barley varieties is likely to increase crop N demand by 30-40 kg N/ha which, in turn, may increase the N fertiliser requirement as was found for winter wheat (Sylvester-Bradley et al., 2008). Alternatively it may be the case that the greater yield potential of new varieties does not affect the N fertiliser requirement due for example to greater N uptake efficiency or lower grain N concentration, as was found for spring malting barley (Sylvester-Bradley et al., 2008). Husbandry changes are also likely to have impacted N fertiliser requirements in recent years, for example there have been reductions in seed rates, greater use of minimal tillage and significant changes in fungicides used. It is therefore important to determine what the N requirements of modern varieties are under the conditions in which they are commonly grown. It is also possible that sub-optimal N fertiliser rates are currently limiting yields and preventing the greater potential of new varieties from being realised.

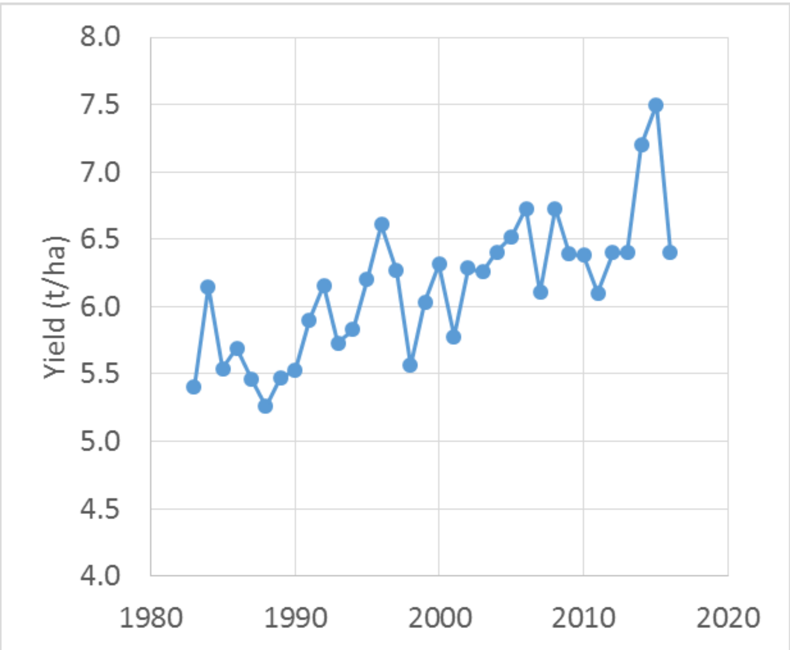

Figure 2.1 UK winter barley yield (Defra statistics).

The AHDB Barley Growth Guide and Bingham et al. (2007a,b) show that spring and winter barley yields are strongly dependent on crops intercepting as much light as possible between emergence and flowering, with maximising grains/m^2 and ears/m^2 very important criteria for achieving high yield. This helps to explain why earlier N increased yield in the CF Fertilisers funded experiments. It is possible that even greater yield increases could be achieved if more than 50% of the N was applied at the 1st split, or there may even be a case for autumn applications of N. 6-row variety Pelican may have responded more to early N because it generally produces fewer shoots than a 2-row variety and therefore responds strongly to inputs that increase tillering. The introduction of high yielding hybrid varieties such as Volume add further uncertainty to the optimum N rate and timing for winter barley. N timing experiments funded and carried out by Syngenta indicate that optimal N timings for hybrid barley are earlier than RB209 recommendations.

The aim of this project was to review existing evidence and generate new data in order to update N management guidelines for different types of winter barley (2-row feed, 2-row malting, 6-row feed and hybrid feed).

Specific Project Objectives:

1) Review existing data on optimum N rate and N timing for winter barley.
2) Determine experimentally how the optimum N rate varies between different variety types (2-row feed, 2-row malting, 6-row feed and hybrid feed) and compare against older varieties from the 1980s and older.
3) Investigate the optimum N timing for different variety types (2-row feed, 2-row malting, 6-row feed and hybrid feed).
4) Transfer new knowledge to farmers and agronomists.

3. Materials and methods

3.1. Experimental information

Experiments were done over three seasons: 2013/14, 2014/15 and 2015/16 and included N rate experiments and N timing experiments. In 2013/14, three N rate and three N timing experiments were done, and in each of 2014/15 and 2015/16, two N rate and three N timing experiments were done. The three experimental sites were located near ADAS High Mowthorpe (HM), ADAS Rosemaund (RM) and in Scotland by Scottish Agronomy (SAG) (Table 3.1). For the 2013-14 N rate experiments, six varieties were investigated at HM and RM (Venture (modern 2-row malting), Cassia (modern 2-row feed), Meridian (modern 6-row feed), Volume (modern 6 row hybrid feed), Maris Otter (old 2-row malting introduced in 1966) and Halcyon (old 2-row malting introduced in

1985). At the SAG in 2013/14 four varieties were included (Venture, Cassia, Meridian, Volume). In the N rate experiments in 2014/15 and 2015/16 Halcyon was replaced with Pastoral (old 2-row feed introduced in 1985) after its seed had been multiplied during the first year. This was to provide a representative variety of an old feed variety as Halcyon is a malting variety. A split plot design was used with six N rates (0-360kg N/ha) as the main plots and the varieties were fully randomised as sub plots. The N splits were as described in Tables 3.2 and 3.3. There were three replicates of each treatment combination. A fully randomised trial design was used at SAG with six N rate treatments and four varieties with three replicates. Seed rates were 350 seeds/m^2 for conventional varieties and 200 seeds/m^2 for Volume in the ADAS experiments, whilst seed rates of 400 seeds/m^2 and 230 seeds/m^2 were used for conventional and hybrids respectively in the SAG experiment.

For the N timing experiments, four varieties were investigated at the three sites (Venture (modern 2-row malting), Cassia (modern 2-row feed), Meridian (modern 6-row feed), and Volume (modern 6-row hybrid feed)). A split plot design was used at RM and HM with four N timing treatments as the main plots and the varieties fully randomised as sub plots. There were three replicates of each treatment combination. Seed rates were 350 seeds/m^2 for conventional varieties and 200 seeds/m^2 for Volume in the ADAS experiments, whilst seed rates of 400 seeds/m^2 and 230 seeds/m^2 were used for conventional and hybrids respectively in the SAG experiments. The total amount of N applied to each N timing experiment was estimated from RB209 based on measurements of SMN and crop N made in late winter. The four N timing treatments consisted of RB209, medium, early and autumn. For the RB209 treatment, 40 kg N/ha was applied at GS25-29, with the remaining N applied at GS31. For the medium treatment, the N was split approximately equally between three applications at GS25-29, GS30 and GS31. For the early treatment, approximately 65% was applied at GS25-29 and the remainder applied at GS30. Finally, for the autumn treatment, 30 kg N/ha was applied at drilling, with approximately 45% of the remaining N applied at GS 25-29 and the final application made at GS30. See Appendices 7.1 to 7.8 for dates of all N applications.

A fully randomised trial design was used at SAG with four N timing treatments and four varieties with three replicates of each treatment combination. The SAG timings were different to those used in the ADAS experiments to represent Scottish practice and to be appropriate for environmental conditions as follows: very late, late, medium, early. The very late treatment involved 75% of N applied at GS30, followed by the remaining N at GS33. For the late treatment, 20% was applied at GS23-25, 50% at GS30 and 30% at GS33. In the medium treatment, 30% was applied at GS23-25, 50% at GS30 and the final 20% at GS33. For the early treatment, 40% was applied at GS23-25 and 60% was applied at GS30. Dates and application rates can be found in Tables 7.3 to 7.9 in the Appendix.

Table 3.1 Site details for experiments.

Identifier	Year	Site	Grid Reference	Soil type	Sow date
HM14	2013/14	High Mowthorpe North Yorks	SE 904 699	Shallow silty clay loam over chalk	7/10/13
RM14	2013/14	Rosemaund Herefordshire	SO 50065 59974	Silty Clay Loam	22/9/13
SAG14	2013/14	Fife	NT 322 996	Sandy loam	26/9/13
HM15	2014/15	High Mowthorpe North Yorks	SE 9341 4055	Shallow silty clay over chalk	2/10/14
RM15	2014/15	Rosemaund Herefordshire	SO 47617 55688	Silty Clay Loam	3/10/14
SAG15	2014/15	Fife	NT 296 988	Sandy Loam	26/9/14
HM16	2015/16	High Mowthorpe North Yorks	SE 904 699	Shallow silty clay loam over chalk	30/9/15
RM16	2015/16	Rosemaund Herefordshire	SO 62249 47039	Silty Clay Loam	3/10/15
SAG16	2015/16	Fife	NT 314 993	Sandy Loam	30/9/15

ADAS experiments were all done on sites which followed winter wheat, with the exception of HM15 and HM16 which followed winter oats. All crops were ploughed before drilling.

Table 3.2 Application timings for N rate experiments at Rosemaund and High Mowthorpe.

1st split GS25-29	2nd split GS30	3rd split GS31	Total (kg N/ha)
0	0	0	0
30	30	0	60
60	60	0	120
70	70	60	200
90	100	90	280
120	120	120	360

Table 3.3 Application timings for N rate experiments at Scottish Agronomy.

1st split GS23-25	2nd split GS30	3rd split GS33	Total (kg N/ha)
0	0	0	0
21	35	14	70
42	70	28	140
63	105	42	210
84	140	56	280
105	175	70	350

3.2. Assessments

3.2.1. Plant Establishment

Plant establishment was determined visually for each plot on a 1-5 scale. A poorly established plot and a well-established plot were identified. The poorly established plot was given a plant establishment score of 1 (out of 5) and the well-established plot was given a score of 5 (out of 5). The remaining plots were scored relative to these selected plots. Three plots with an establishment score of 1, three plots with a score of 3 and three plots with a score of 5 were selected. For each plot the plants/m^2 was determined by counting the number of plants in six 0.5m x 0.5m quadrats per plot.

3.2.2. Soil and Crop N Measurements

In January ten soil cores randomly distributed around the whole of the N rate and N timing trial areas were taken. Each soil core was taken to 90 cm (or to the depth of soil for shallow soils). The cores were bulked together, care being taken to keep each 30 cm horizon separate. Soil cores were sent in a cool box to Hill Court Farm Research for measurement of soil mineral N and Additionally Available N.

To estimate crop N, a 0.5 m x 0.5 m area from the end of one discard plot in each of the 3 replicate blocks of the N rate trial were sampled. Samples were taken by digging up the plants. The samples were then taken back to the lab, where the roots and below ground stem at the point where the stem turns from white to green were cut off. The fresh weight and dry weight of the above ground plant tissue was recorded. The dry sample was sent to NRM labs for total N content analysis.

3.2.3. Shoot number, Green area index and light interception

At HM14, additional measurements were made in the N timing experiment by a summer student from York University including shoot number, light interception and green area index (GAI). At GS31 a crop sample from a 0.25 m^2 quadrat was taken at the end of each plot for varieties Volume and Cassia for the four N timing treatments. The same number of rows were included in each quadrat by arranging the quadrat so that a plant row ran from one corner to the diagonally opposite corner. The plants were pulled up and taken back to the lab for analysis.

The soil was washed away from the roots and the fresh weight of the sample was recorded. A 25% sub sample was taken and the fresh weight measured. The roots were removed at the point where the stem changed from green to white and the sub sample was re-weighed. The number of tillers in the sub sample was counted. If dead/dying shoots were present, the number of dead/dying shoots was also counted. The leaves were separated from the stem. A moving belt leaf area meter (Li-Cor Model 3100, Delta-T Devices, Burwell, Cambridge, UK) was used to determine the area of the leaves followed by the stems. Leaves and stems were placed in an oven tray and dried until there was no further reduction in weight (approximately 48 hours).

The sampling was repeated approximately 3-4 weeks later and again 3-4 weeks later. The growth stage of the crop was recorded at each assessment date.

3.2.4. Light interception

A ceptometer was used to measure the ambient light intensity above the crop and the light interception by the crop canopy. This procedure was carried out at 10 different places in the plot and then averaged.

3.2.5. Height

At GS 85 (in 2014) or GS61-69 (in 2016) height was measured on five tillers per plot. The ear was included, but awns were not. If the crop had lodged, it was picked up and held vertically against the rod to obtain the measurement. Where ears had 'necked' the ears were held upright while the measurement was taken.

3.2.6. Pre Harvest Sampling

Just before harvest, samples of about 20 shoots cut at ground level from 5 randomly chosen positions per plot were taken to give a sample of around 100 shoots to take back to the lab. The ears and straw were then separated. The ears and straw were dried and their weights recorded. The ears were threshed and the dry weight of the grain recorded. Sub-samples (300-500 g) of grain and straw/chaff were sent to NRM for N concentration analysis.

3.2.7. Lodging at Harvest and Yield

The percentage areas affected by leaning (displaced by 9º and less than 45º from the vertical) and lodging (displaced by greater than 45º from the vertical) was recorded. The grain yield of all plots was recorded using a small plot combine. The moisture content and specific weight was determined using a Dickey John GAC 2000 grain analysis computer.

3.2.8. Agronomic Inputs

All ADAS experiments received 16 kg/ha of sulphur in the spring as magnesium sulphate (Keiserite 23%S) or potassium sulphate (18%S). All SAG experiments received 25 kg/ha of N and 5 kg of sulphur in the autumn and 12 kg/ha of sulphur in the spring. All other crop management inputs were according to commercial farm practice to ensure that other nutrients were not limiting, and to control weed, pest, disease and lodging incidence. All crops received 2 or 3 fungicide doses and 1 or 2 PGR doses.

3.2.9. Statistical analysis

Analysis of variance

Each experiment was analysed for grain yield and grain nitrogen concentration as well as other measures, as either a randomised block design (SAG experiments), or as a split-plot design with N rate or N timing as the main plot and variety as the sub-plot (RM, HM experiments). The analyses tested for differences between varieties, differences between N rates or N timings and for the interaction between varieties and N rates or N timings, i.e. whether the response to N was different for each variety.

REML analysis

Data from the seven N rate experiments were analysed together using a REML analysis to account for differences in varieties used between the sites and seasons. The fixed model was variety and the random model was site. The REML analysis determines predicted means based on the variance between varieties, and is useful when experiments use different sets of varieties.

The apparent recovery of fertiliser N and N utilisation efficiencies were calculated as follows for the N rate closest to the economically optimum N rate in each N experiment for each variety:

Apparent fertiliser recovery (%) =

$$\frac{\text{Total N uptake (kg/ha)} - \text{Total N uptake (at NIL N) (kg/ha)} \times 100}{\text{Rate of fertiliser N applied (kg/ha)}} \qquad \text{(Equation 1)}$$

$$\text{N utilisation efficiency} = \frac{\text{Dry matter grain yield (kg/ha)}}{\text{Total N uptake (kg/ha)}} \qquad \text{(Equation 2)}$$

$$\text{Fertiliser N use efficiency} = \frac{\text{Dry matter grain yield (kg/ha)}}{\text{Rate of fertiliser N applied (kg/ha)}} \qquad \text{(Equation 3)}$$

$$\text{N use efficiency} = \frac{\text{Dry matter grain yield (kg/ha)}}{\text{Total available N from soil and fertiliser (kg/ha)}} \qquad \text{(Equation 4)}$$

Grain yield response curves and deriving economic optimum (Nopt) rates

The N requirement or economically optimal N rate (Nopt) is the rate at which any further increase in N rate will result in greater N fertiliser costs than the value of the additional grain produced. This is therefore dependent on the relative price of the grain and N fertiliser, or the breakeven ratio (BER): the amount of grain (kg) required to pay for one kg of fertiliser. In order to calculate the optimum N rate it is necessary to mathematically describe the response of crop yield to N fertiliser. The relationship between applied N and yield is complex and usually typified by a rapid increase in yield at low N rates, followed by a levelling off of the yield response, and often a reduction of yield at super-optimal N rates due to factors such as lodging. A linear plus exponential (LpE) function (Equation 5) was chosen carefully as being best at describing the range of N responses of UK cereals (George, 1984) and it has remained the standard for 30 years. The LpE function has four fitted parameters a, b, c & r which approximately (because they are strongly correlated) describe respectively the asymptote, the effect of omitting N, the slope of the asymptote, and the curvature of the response. In order to fit an LpE function information about the effects of five to seven levels of N on grain yield is required.

$$Y = a + br^{N} + cN \qquad \text{(Equation 5)}$$

The fitting process did not use common values of parameters between sites or seasons, thus it was assumed that responses were unique to a site. In order to determine Nopt for each variety at each site the LpE function was fitted using a ‘Parallel curve’ approach. This involved a four-stage procedure:

i) Fit a common curve to all varieties (i.e. keeping a, b, c and r constant for all varieties at a site).
ii) Fit separate curves for each variety, with a common response but different intercepts (i.e. varying a but keeping b, c and r constant).
iii) Fit separate curves for each variety allowing a, b and c all to vary (i.e. just keeping r constant).

iv) Fit separate curves for each variety, allowing all parameters to vary.

The sums of squares explained at each stage was calculated, and a test was made of the improvement in fit over the previous model. If there was no significant improvement between two stages, then the previous model was taken as the best description of the data.

Estimates of Nopt values were derived from the fitted LpE parameters as follows:

$$Nopt = \frac{[\ln(k/1000 - c) - \ln(b(\ln r))]}{\ln r} \qquad \text{(Equation 6)}$$

where k is the breakeven price ratio between fertiliser N (p/kg) and grain (p/kg). A breakeven ratio of 5 was used in this study because this is used as a standard for fertiliser recommendations in the UK for cereals. The yield at each Nopt rate (Yopt) was calculated from the fitted parameters.

Grain N response curves

A response curve was fitted independently to each set of grain N data for each variety. A Normal Type curve with Depletion (NTD) function was used.

The function for the NTD curve is:-

$$y = (d+c*EXP(a*(N-b)^2)) \qquad \text{(Equation 7)}$$

where y is grain N (%), a, b, c and d are fitted parameters determined by fitting, and N is applied N (kg/ha).

4. Results

4.1. Objective 1: Review existing data on optimum N rate and N timing for winter barley

4.1.1. Nitrogen timing

Yield data supplied by ADAS, CF Fertilisers and Syngenta was reviewed for a total of 25 experiments carried out between 2004 and 2016 (including the experiments described in this report) where there was information on the time of N application. Multiple yield data points, totaling 939, were collated, which represented multiple site, season, N rate and variety combinations. Of these 939 yield data points, a total of 152 represented sites, season, N rate and variety combinations in which there was a corresponding early or late N timing comparison.

For situations when 100 kg N/ha or more is to be applied, RB209 would recommend that 40 kg/ha is applied during late February or early March, whilst the remainder is applied at stem extension (not before the end of March). Many of the experiments reviewed gave the date of N application, but did not specify the growth stage when the N was applied. In order to include the maximum number of datasets in the analysis the date of stem extension was assumed to be 1st April based the AHDB Barley Growth Guide. In this analysis, the following scenarios were compared: 30% or less of the total N applied before 1st April (approximating to RB209 guidelines) against more than 50% of the total N applied before 1st April. A paired t-test was carried out to test whether these N timing strategies resulted in statistically significant yield differences. Yield data from a total of 8 different N rates: 60, 120, 170, 180, 190, 210, 240 and 300 kg N/ha and 6 different varieties: Pelican, Saffron, Cassia, Meridian, Venture and Volume was included. Across all total N rates, yield was improved by 0.26 t/ha ($P<0.05$) when more than 50% of the N was applied early, in comparison to less than 30% applied early (Table 4.1). At total N rates which are likely to be close to the economic optimum (170 to 240 kg N/ha) the yield increase from earlier N averaged 0.32 t/ha.

Table 4.1 Average yield of winter barley trials for different N application timings and a range of total N rates. Data from 25 experiments.

N timing	N rate (kg/ha)								
	60	120	170	180	190	210	240	300	Mean
	Yield (t/ha)								
30% or less of total N applied before 1st April	5.44	7.20	7.98	7.96	8.53	9.08	8.36	8.68	7.88
More than 50% of total N applied before 1st April	5.57	7.34	8.14	8.37	8.94	9.24	8.83	8.78	8.14

4.1.2. Nitrogen rate

To evaluate how the economically optimum N rate (Nopt) compares with the RB209 recommended rate for winter barley, a database of N response experiments was collated and analysed. The database included UK experiments from 2008-2016 (Table 4.2). All experiments included in the database used between five and seven N rates (including nil N), to allow the fitting of linear plus exponential response curves. Data on harvest year, location of experiment, soil type, variety and soil test results were included in the database where available.

The Nopt was calculated using a break-even ratio of 5 for the cost of N fertiliser (£ per kg N) and the grain price (£ per kg). The SNS for each site was either taken from measured soil mineral nitrogen (SMN) plus crop N data in winter/spring, or from total crop N at harvest in nil fertiliser N plots; if both spring/winter SMN with crop N and total harvest crop N uptake at nil fertiliser N were available, an average was taken to give site SNS. This was then used to estimate the RB209 recommended N rate for each experiment. On average RB209 underestimated the Nopt by 18 kg N/ha. Regression analysis of yield at Nopt against the difference between Nopt and the RB209 recommended N rate revealed a positive relationship with high yielding crops having a greater measured Nopt compared with the RB209 recommended N rate, compared with low yielding crops (Figure 4.1). Crops with a yield of about 7 t/ha had a similar measured Nopt and RB209 recommended N rate. On average, each additional tonne per hectare of yield was associated with an increased difference between measured Nopt and RB209 recommendation of 18 kg N/ha. It should be recognised that this dataset includes older lower yielding varieties which had a low Nopt. There were examples in the dataset where the deviation was in excess of 100 kg N/ha and numerous examples where the deviation was more than 40 kgN/ha.

To further evaluate the effects of yield potential on N requirement, a more detailed estimation of N requirement was made. N requirement was defined as SNS + 0.6 * Nopt. By definition SNS represents the amount of soil N available for crop uptake during the growing season. Uptake efficiency of soil-applied manufactured N fertiliser is known to vary depending on a range of factors, and is typically around 60% (Bloom et al., 1988; King et al., 2001). N requirement was plotted against yield at Nopt, giving a positive correlation (Figure 4.2). An additional 13.1 kg/ha extra N required for each t/ha extra yield, or 21.8 kg N/ha extra fertiliser applied (after accounting for a fertiliser uptake efficiency of 60%).

Table 4.2 Data sources for review of winter barley N requirements.

Project	Reference	Harvest years	No. site seasons	No. site x season x treatment combinations
Nitric database		1981-1993	77	77
Scottish agronomy trials	Gilchrist *et al*. 2012	2007-2009	9	14
ADAS N x Species trials	Commercial in confidence	2009-2010	2	5
ADAS N x fungicide trials	Commercial in confidence	2010	2	2
MIN-NO	Sylvester-Bradley *et al*., 2015	2010-2012	2	2
ADAS trials for CF Fertilisers	Commercial in confidence	2008-2010	6	24
Updating WB N guidance	AHDB Current Project 216-0006	2014-2016	7	40

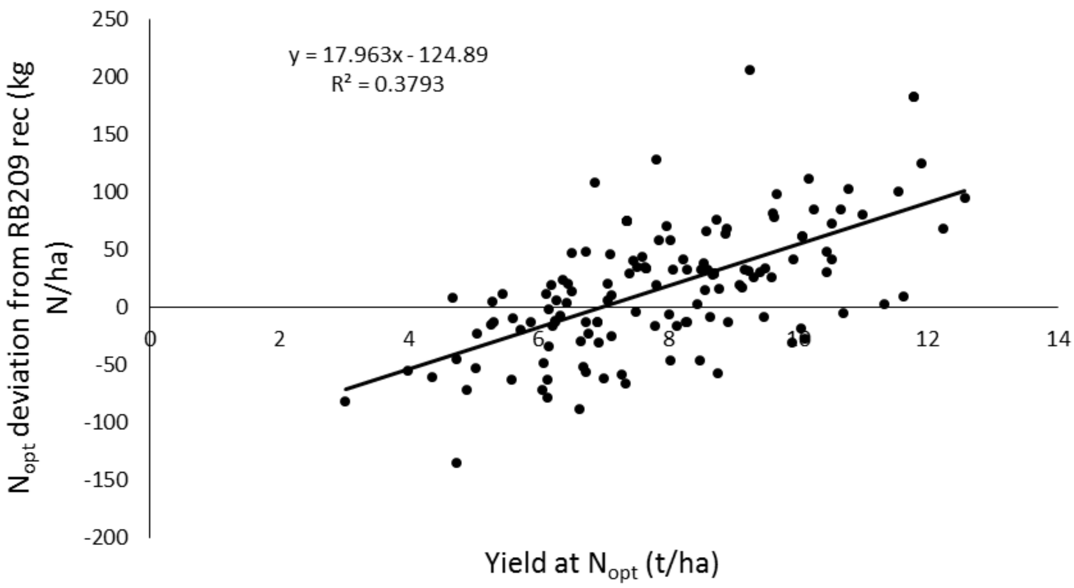

Figure 4.1 The effects of winter barley yield potential (yield at the economically optimal N rate (Nopt)) in t/ha on the deviation of Nopt from the RB209 recommended N rate. R^2 =0.38.

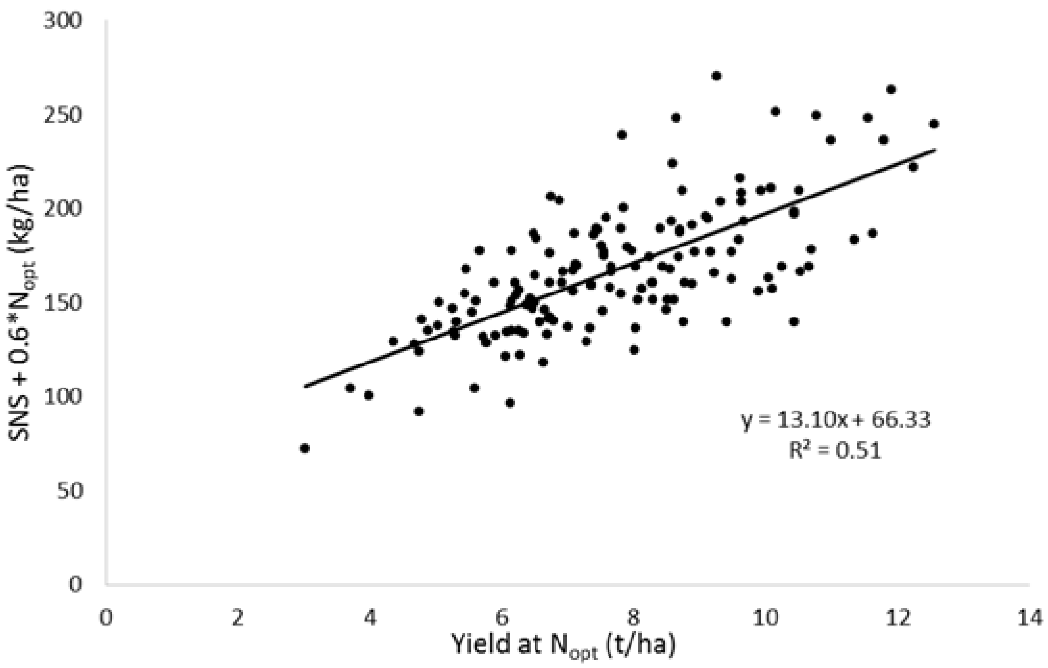

Figure 4.2 Effects of yield potential (yield at the economically optimal N rate (Nopt)) on N requirement (site soil nitrogen supply + 0.6 * Nopt) for winter barley. R^2 =0.51.

4.1.3. Economic benefits

Economic benefits resulting from applying more than 50% of the N before 1st April would amount to £30/ha based on a 0.3 t/ha yield increase and a feed barley price of £100/t. Using the data described in the results section of this report, early application of N increased straw biomass by 0.5 t/ha on average. Based on a barley straw price of £65/t (Nix, 2017), the increase in straw yield would bring an additional £32/ha revenue. There would be additional costs associated with bailing the extra straw that may amount to approximately £5/ha based on contractor baling costs (NIX, 2017). Across the three ADAS experiments where height was measured, the height increase from early application of N was several centimetres. Although evidence was not found for increased lodging due to early application of N in the experiments reported in this report, increasing height by 5cm is known to decrease the varietal lodging resistance score of wheat by 1 point (Berry et al., 2003) and therefore it is likely that the height increase could increase lodging risk. Therefore, it would be recommended that an additional PGR application should be made when N is applied early, with an approximate cost of £10/ha (Nix, 2017). Early application of N reduced grain N% by approximately 0.1%. For winter barley grown for malting, the early application of N could be used as a tool for ensuring grain N% is not too high to meet the brewing market requirement of 1.66-1.85%. By applying N early, it may allow growers to maximise their yield through application of higher rates of N, whilst maintaining the quality premium of £25/t. This project will also help growers avoid under-fertilising their crops. Section 6 shows that under-fertilising by 40 kg N/ha would be expected to reduce yield by 0.26 t/ha and reduce profit by £10/ha.

Overall economic benefits from applying N early amount to £48/ha for feed barley, rising to £58/ha where RB209 under-estimated the fertiliser N requirement by 40 kg N/ha, and rising further to £83/ha if the strategy enables the malting premium to be achieved.

4.2. Objective 2. Determine experimentally how the optimum N rate varies between different variety types (2-row feed, 2-row malting, 6-row feed and hybrid feed) and compare against older varieties from the 1980s.

4.2.1. Soil N supply

The soil N supply for each ADAS experimental site is shown in Table 4.3. SNS indexes were suitably low for N response experiments ranging from 0 to 1.

Table 4.3 SMN, AAN and Crop N content for each ADAS experiment.

Site	SMN (0-30)	SMN (30-60)	SMN (60-90)	AAN	Crop N (kg N/ha)	SNS (kg N/ha)	SNS Index
HM14	22	27		42	11	60	0
RM14	21	14	13	22	31	79	1
HM15	13	17		24	12	42	0
RM15	10	14	23	22	24	71	1
HM16	17	10		29	19	46	0
RM16	10	12	14	25	40	76	1

4.2.2. 2014 Experiments

In the HM14 experiment, Nopt ranged from 139 kg N/ha for Maris Otter to 286 kg N/ha for Meridian with yields of 6.05 t/ha and 8.74 t/ha respectively (Figure 4.3). There was a significant effect of N rate and variety on yield, and also a significant interaction between the two (Table 7.10). At the Nopt, grain N% ranged from 1.57% to 2.16% for Maris Otter and Meridian respectively (Figure 4.4). There was a significant effect of N rate on grain N%, and also a significant interaction between both N rate and variety (Table 7.11). There was no significant effect of N rate, variety or interaction between the two factors on specific weight (Table 4.4). Average specific weight for the experiment was 60.6kg/hl.

In the RM14 experiment statistics supported changing the variance of only the A curve parameter between the varieties, supporting the calculation of a single Nopt for all varieties of 157 kg N/ha (Figure 4.5). Yield at the Nopt ranged from 5.88 t/ha for Maris Otter to 8.29 t/ha for Volume. There was a significant effect of both N rate and variety on yield, but no significant interaction between the two (Table 7.12). Grain N% at the Nopt ranged from 1.88% for Meridian to 1.97% for Halcyon (Figure 4.6). There was a significant effect of N rate and variety on grain N%, but there was no significant interaction between them (Table 7.13). There was no significant effect of N rate on specific weight (Table 4.5), whilst variety had a significant effect. Halcyon had the greatest specific weight of 62.4 kg/hl whilst Meridian had the lowest of 53.0 kg/hl. There was also a significant interaction between N rate and variety on specific weight (Table 4.5).

In the SAG14 experiment, Nopt ranged from 153 kg N/ha for Cassia to 235 kg N/ha for Meridian, with yields of 11.04 t/ha and 11.94 t/ha respectively (Figure 4.7). There was a significant effect of both N rate and variety on yield, and a significant interaction between the two (Table 7.14). Grain N% at the Nopt ranged from 1.52% for Cassia to 1.75% for Volume (which had an Nopt of 181 kg N/ha) (Figure 4.8). Grain N% was significantly affected by both N rate and variety, but there was no significant interaction between the two (Table 7.15) There was a significant effect of variety on specific weight, with Meridian having a significantly lower specific weight than the three other varieties (Table 4.6).

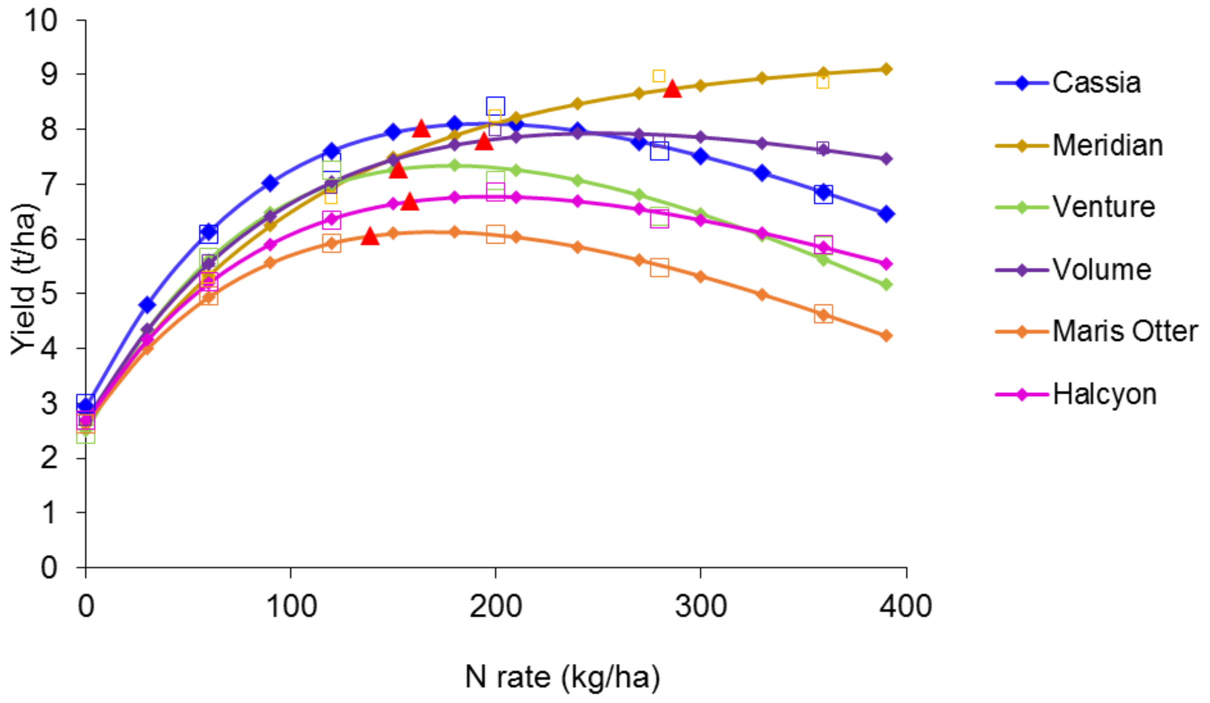

Figure 4.3 Fitted linear plus exponential N response curves for HM14 at a BER of 5:1. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

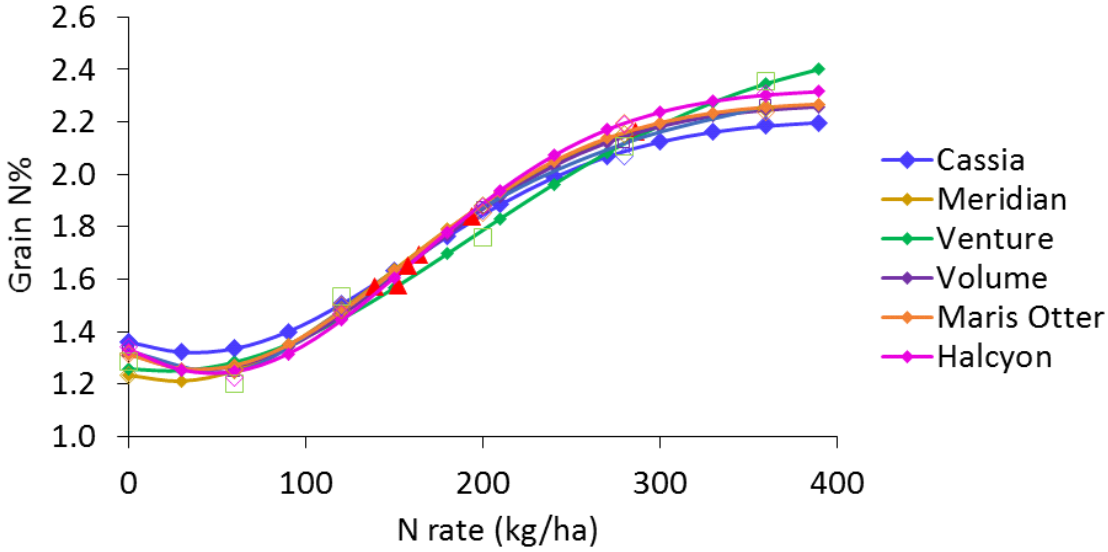

Figure 4.4 Fitted normal type curve with depletion curves for HM14. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

Table 4.4 Specific weight (kg/hl) for the HM14 trial

	N rate (kg/ha)						
Variety	0	60	120	200	280	360	Grand Mean
Cassia	63.5	64.7	61.1	60.5	60.2	58.3	61.4
Meridian	60.1	59.2	54.6	57.9	57.2	57.6	57.7
Venture	63.6	64.2	60.5	62.1	58.1	59.6	61.4
Volume	61.8	60.7	58.6	60.7	57.8	60.7	60.1
Halcyon	66.0	40.8	65.3	64.5	61.6	62.8	60.2
Maris Otter	65.7	64.1	64.3	61.0	59.0	61.4	62.8
Grand Total	63.5	59.0	60.7	61.1	59.0	60.1	60.6
	P	SED	LSD				
N rate	0.830	3.6	7.98				
Variety	0.383	2.4	4.74				
N rate x Variety	0.307	6.4	12.81				

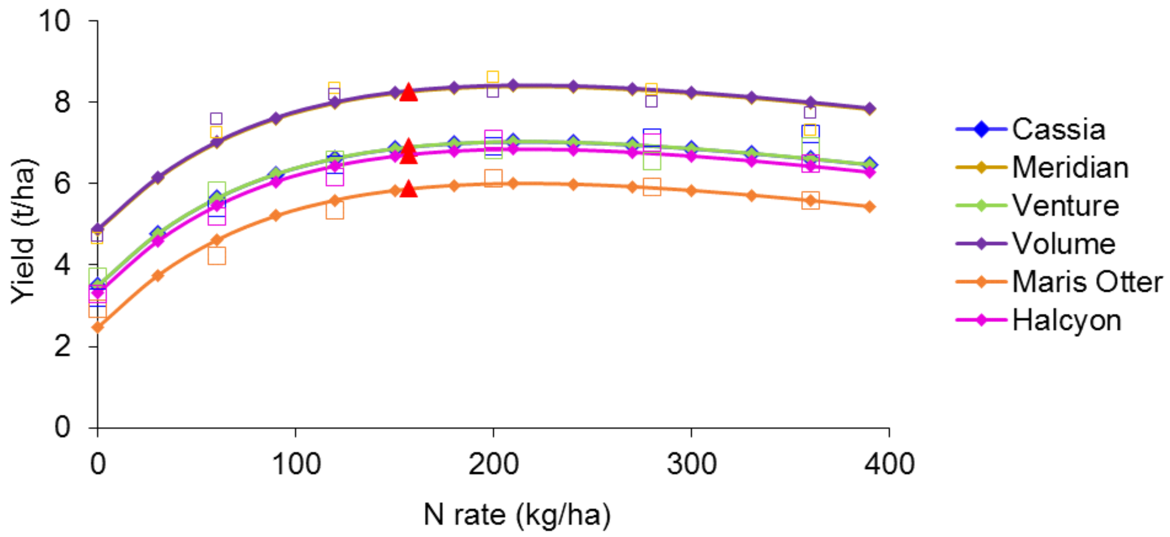

Figure 4.5 Fitted linear plus exponential N response curves for RM14 at a BER of 5:1. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

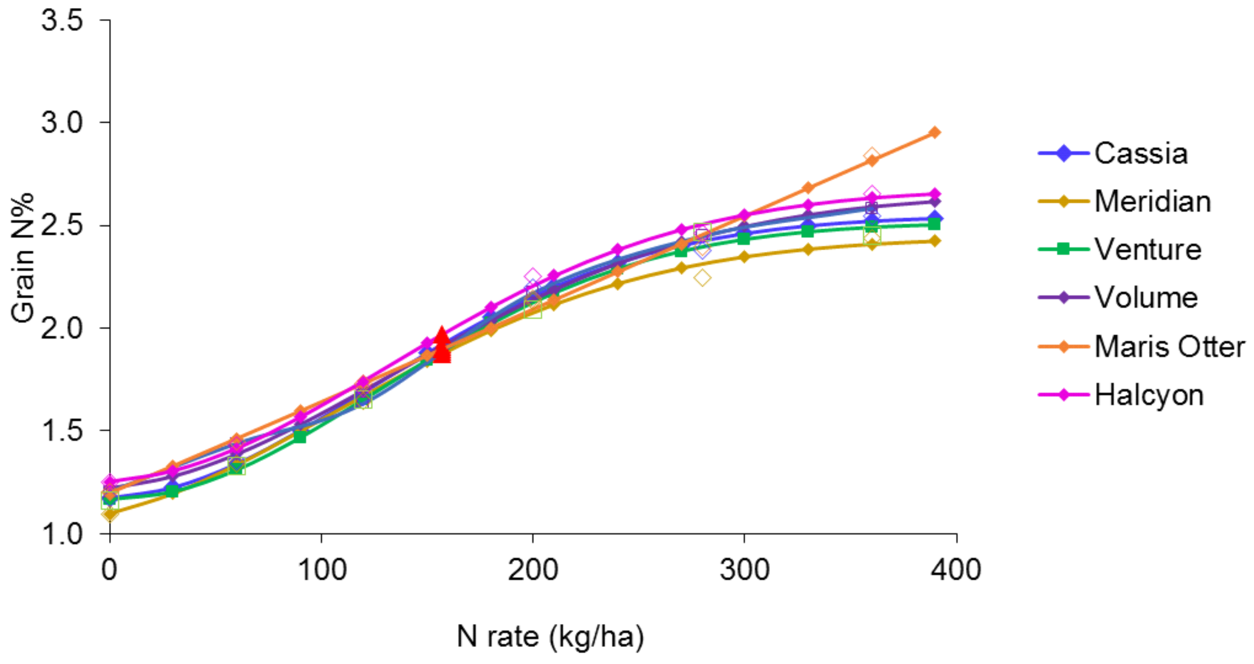

Figure 4.6 Fitted normal type curve with depletion curves for RM14. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

Table 4.5 Specific weight (kg/hl) for the RM14 trial

	N rate (kg/ha)						
Variety	0	60	120	200	280	360	Grand Mean
Cassia	58.7	57.5	59.5	59.6	59.6	60.4	59.2
Meridian	51.3	51.9	52.5	53.5	54.2	54.8	53.0
Venture	55.3	56.9	58.2	59.5	59.1	59.9	58.2
Volume	54.5	54.1	52.2	52.4	51.9	52.7	53.0
Halcyon	60.4	61.8	62.0	63.9	63.7	62.4	62.4
Maris Otter	59.8	62.7	62.9	62.1	62.4	61.5	61.9
Grand Total	56.7	57.5	57.9	58.5	58.5	58.6	57.9
	P	SED	LSD				
N rate	0.233	0.9	1.89				
Variety	<.001	0.4	0.83				
N rate x Variety	0.001	1.3	2.54				

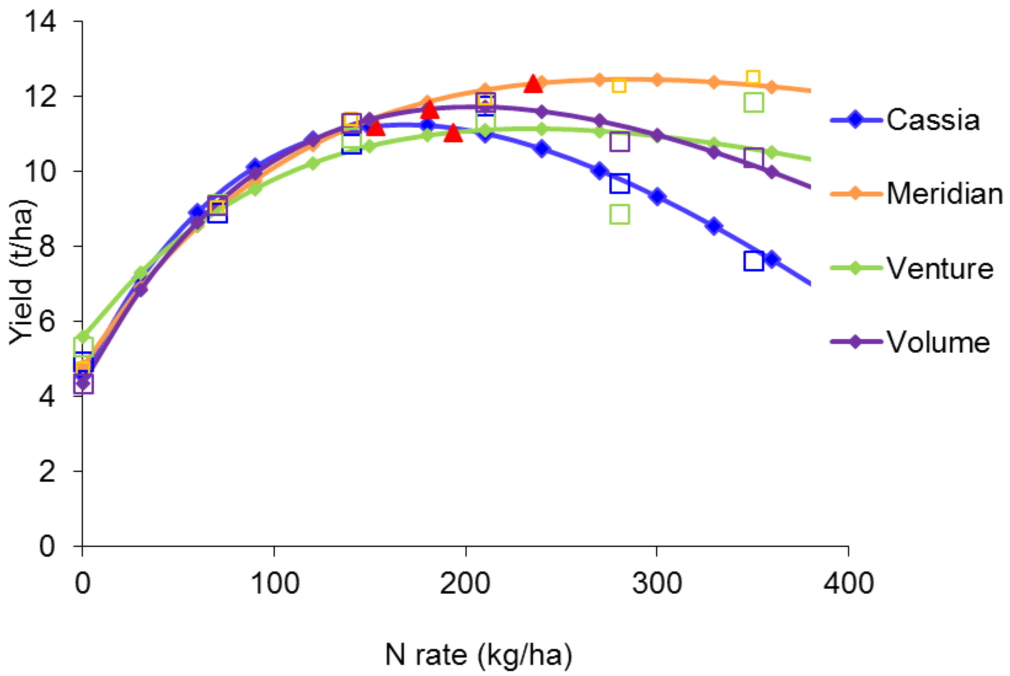

Figure 4.7 Fitted linear plus exponential N response curves for SAG14 at a BER of 5:1. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints. Nopts do not take account of 25kg N/ha applied in Autumn.

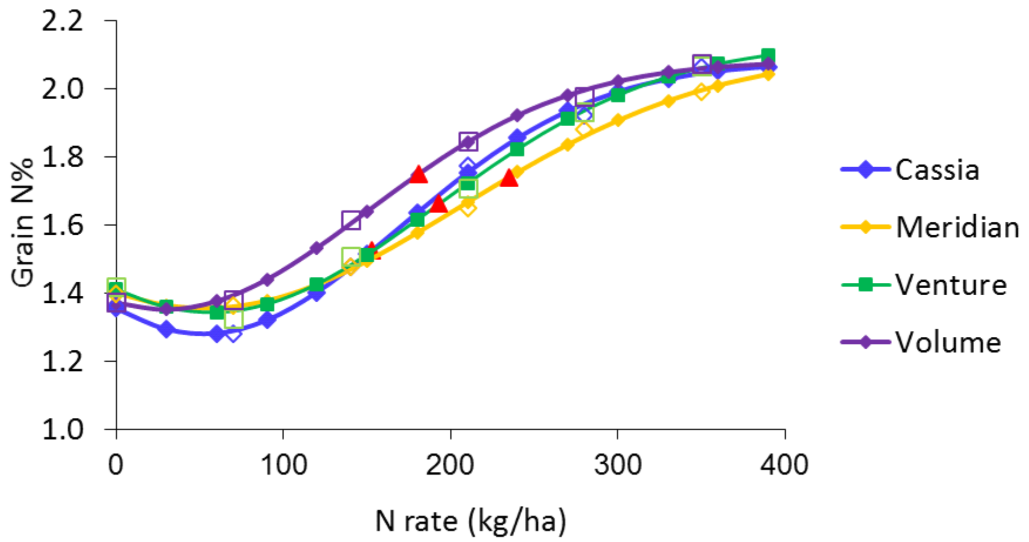

Figure 4.8 Fitted normal type curve with depletion curves for SAG14. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

Table 4.6 Specific weight (kg/hl) for the SAG14 trial

	N rate (kg/ha)						
Variety	0	70	140	210	280	350	Grand Mean
Cassia	68.1	69.6	68.5	68.8	68.0	67.8	68.5
Meridian	67.2	64.9	65.9	64.5	66.9	64.9	65.7
Venture	67.3	69.3	69.6	67.6	68.6	67.7	68.4
Volume	68.5	68.1	70.6	70.2	67.2	68.7	68.9
Grand Total	67.8	68.0	68.6	67.8	67.7	67.3	67.8
	P	SED	LSD				
N rate	0.611	0.8	1.50				
Variety	<.001	0.6	1.23				
N rate x Variety	0.422	1.5	3.01				

4.2.3. 2015 Experiments

The Nopt determined for the HM15 experiment ranged from 165 kg N/ha for Maris Otter to 302 kg N/ha for Meridian, with yields of 7.13 t/ha and 10.16 t/ha respectively (Figure 4.9). There was a significant effect of N rate and variety on yield, as well as a significant interaction between the two (Table 7.16). Grain N% at the Nopt ranged from 1.73% for Volume (with an Nopt of 178 kg N/ha) and 2.24% for Meridian (Figure 4.10). In this experiment, grain N% was also significantly affected by both N rate and variety on yield, and there was also a significant impact of N rate on the variety effect on grain N% (Table 7.17). There was a significant effect of variety on specific weight (Table 4.7). Meridian had the lowest specific weight of 59.4 kg/hl and this was significantly lower than that of Maris Otter at 69.1 kg/hl. The specific weight obtained at 120 kg N/ha and 200 kg N/ha was 65.0 kg/hl, there was no significant effect of N rate on specific weight.

In the RM15 experiment, the Nopts ranged from 166 kg N/ha for Maris Otter to 265 kg N/ha for Meridian, with yields of 9.31 t/ha and 11.91 t/ha respectively (Figure 4.11). There was a significant effect of N rate and variety on yield, as well as a significant interaction between the two (Table 7.18). Grain N% at the Nopt ranged from 1.88% for Maris Otter to 2.30% for Pastoral (which had a Nopt of 242 kg N/ha) (Figure 4.12). Grain N% was significantly affected by N rate and variety, and there was also a significant effect of variety on the impact of variety on grain N% (Table 7.19). There was a significant effect of N rate and variety on specific weight (Table 4.8). The greatest specific weight was obtained at 200 kg N/ha (63.1 kg/hl). Once again, Meridian was the variety with the lowest specific weight at 53.8 kg/hl and this was significantly lower than the other five varieties.

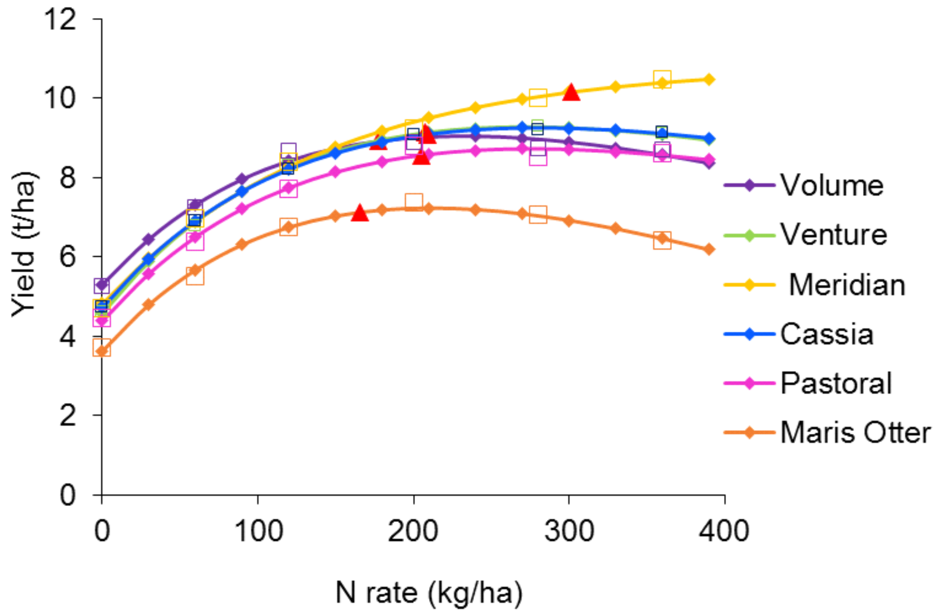

Figure 4.9 Fitted linear plus exponential N response curves for HM15 at a BER of 5:1. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

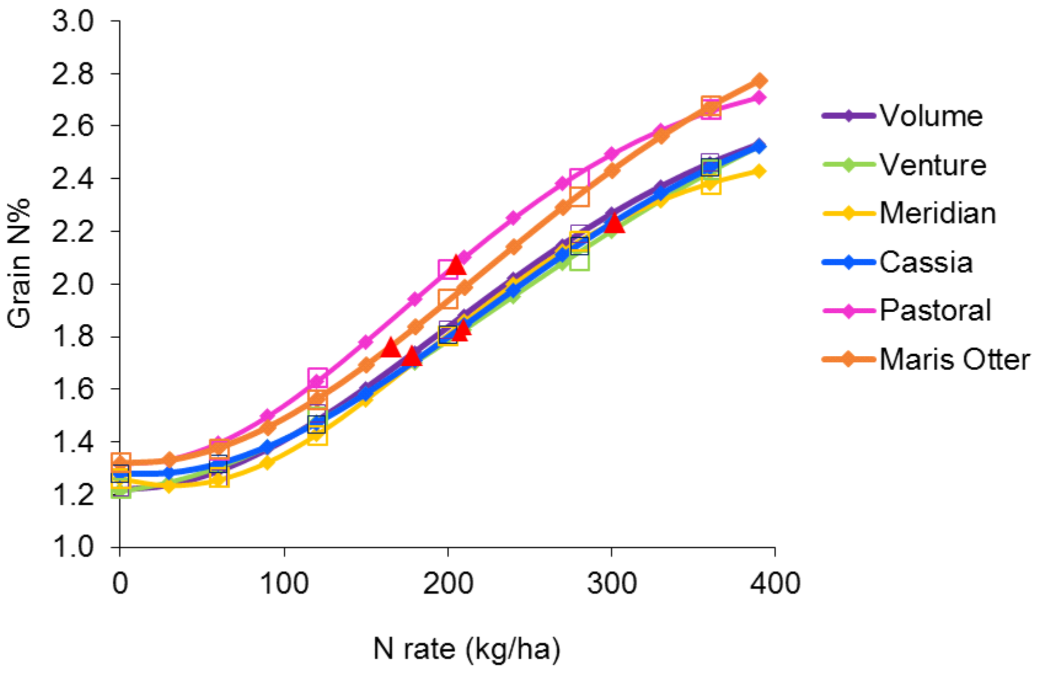

Figure 4.10 Fitted normal type curve with depletion curves for HM15. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

Table 4.7 Specific weight (kg/hl) for the HM15 trial

	N rate (kg/ha)						
Variety	0	60	120	200	280	360	Grand Mean
Cassia	62.5	65.6	67.5	67.0	66.3	66.4	65.9
Meridian	59.5	58.4	59.3	59.2	60.2	60.1	59.4
Venture	64.2	65.1	66.7	66.5	66.0	65.8	65.7
Volume	60.2	60.7	60.5	61.0	59.5	59.3	60.2
Pastoral	63.1	64.5	*65.7*	66.4	65.2	64.9	65.0
Maris Otter	67.5	70.0	70.4	70.2	68.8	67.8	69.1
Grand Total	63.0	64.0	65.0	65.0	64.3	64.0	64.3
	P	SED	LSD				
N rate	<.001	0.4	0.83				
Variety	<.001	0.4	0.79				
N rate x Variety	0.001	1.0	1.90				

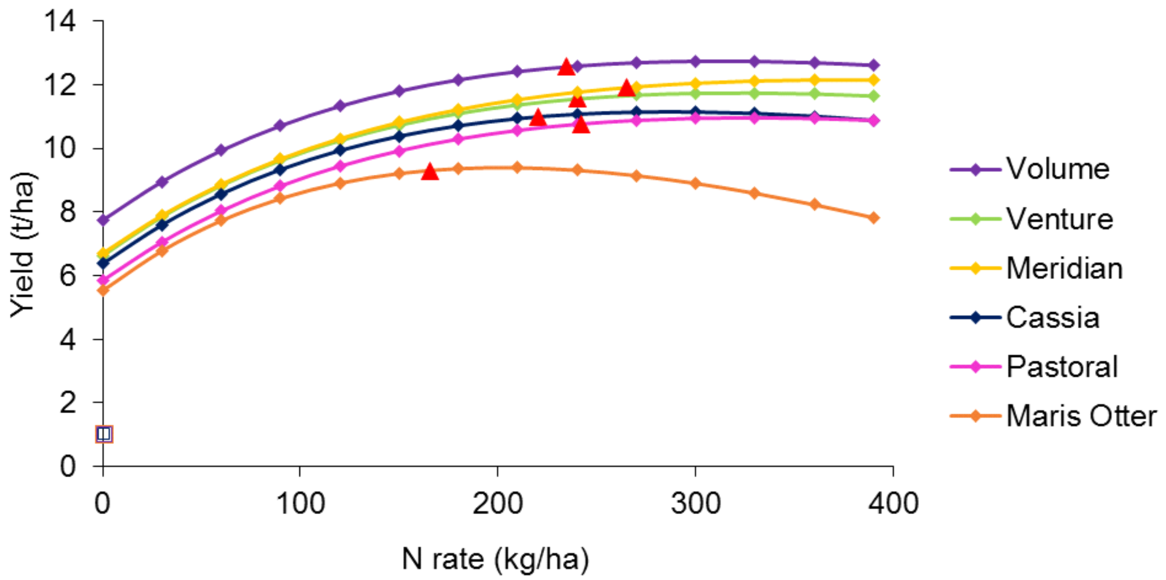

Figure 4.11 Fitted linear plus exponential N response curves for RM15 at a BER of 5:1. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

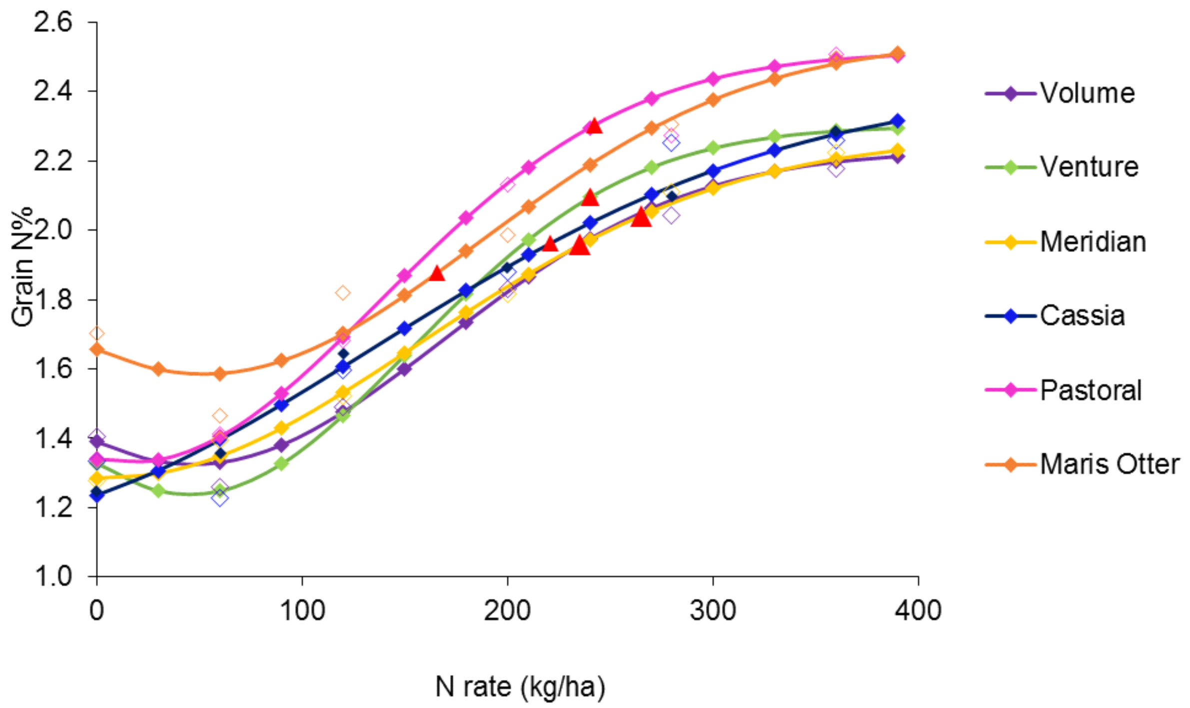

Figure 4.12 Fitted normal type curve with depletion curves for RM15. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

Table 4.8 Specific weight (kg/hl) for the RM15 trial

	N rate (kg/ha)						
Variety	0	60	120	200	280	360	Grand Mean
Cassia	52.7	57.5	62.5	63.4	61.3	60.9	59.6
Meridian	52.0	53.3	54.0	51.4	55.5	54.6	53.8
Venture	55.9	62.7	55.4	64.5	59.3	63.1	60.6
Volume	52.1	57.8	61.8	61.5	58.0	56.8	58.2
Pastoral	54.9	61.6	62.6	64.6	61.2	63.1	61.0
Maris Otter	56.1	55.6	64.6	65.7	62.7	58.6	60.6
Grand Total	54.1	58.1	60.7	63.1	59.4	59.5	59.0
	P	SED	LSD				
N rate	0.013	1.7	3.83				
Variety	<.001	1.1	2.18				
N rate x Variety	0.098	3.0	5.97				

4.2.4. 2016 Experiments

In the HM16 experiment, the Nopts ranged from 187 kg N/ha for Maris Otter to 251 kg N/ha for Meridian, with yields of 5.04 t/ha and 7.45 t/ha respectively (Figure 4.13). There was a significant effect of N rate and variety on yield, but no significant interaction between the two (Table 7.20). Grain N% at the Nopt ranged from 1.64% for Venture (with an Nopt of 194 kg N/ha) and 1.91% for Meridian (Figure 4.14). Similarly, both N rate and variety had a significant impact on grain N% (Table 7.21). There was no significant effect of N rate on specific weight, whilst variety was significantly affected (Table 4.9). In common with other experiments, Meridian was the variety with the lowest specific weight at 57.7kg/hl, and this was significantly lower than the five other varieties. There was a significant interaction between variety and N rate on specific weight.

In the RM16 experiment, Nopt ranged from 79 kg N/ha for Maris Otter to 122 kg N/ha for Volume with yields of 7.01 t/ha and 10.04 t/ha respectively (Figure 4.15). There was a significant effect of N rate and variety on yield, and a significant interaction between the two (Table 7.22). Grain N% was lowest at the Nopt for Venture at 1.48% and greatest for Volume at 1.75% (Figure 4.16). Similarly, both N rate and variety had a significant impact on grain N% (Table 7.23). There was a significant effect of both N rate and variety on specific weight (Table 4.10). In contrast to other experiments, Volume was the variety with the lowest specific weight at 56.1kg/hl. There was no significant interaction between variety and N rate on specific weight.

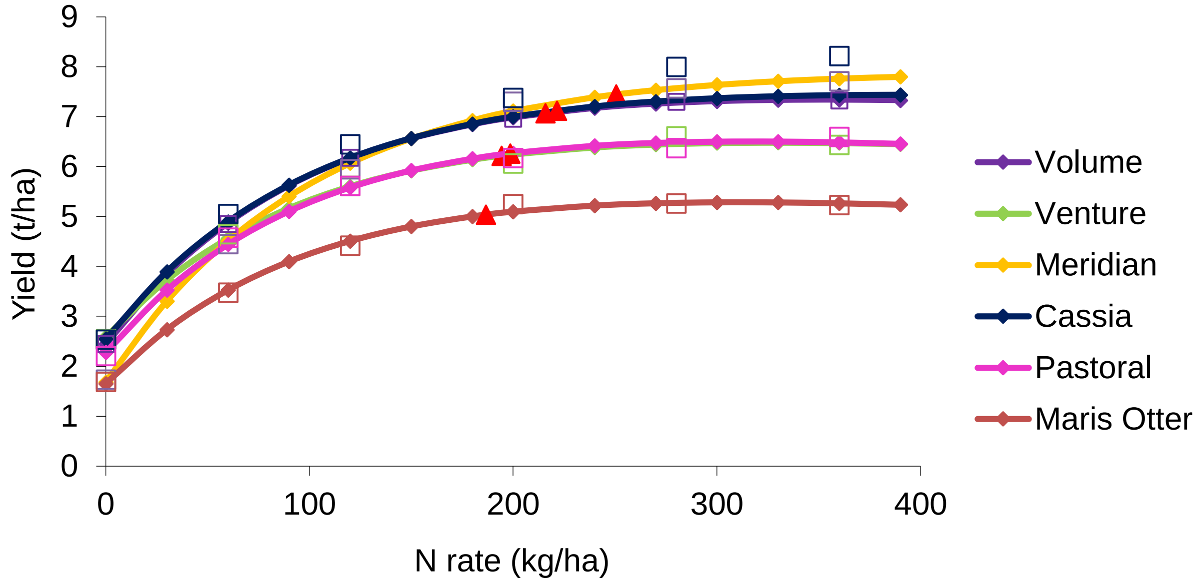

Figure 4.13 Fitted linear plus exponential N response curves for HM16 at a BER of 5:1. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

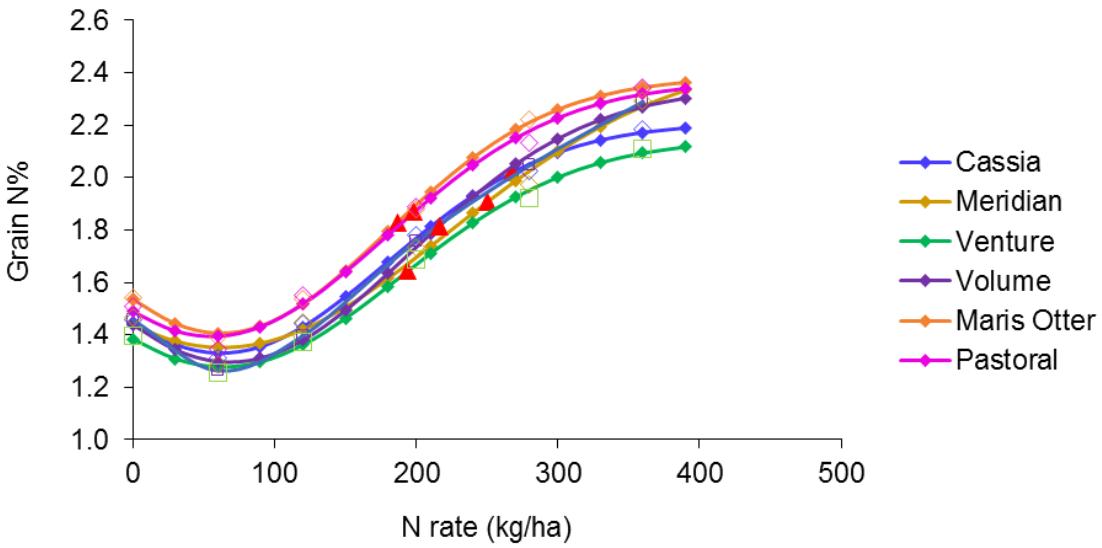

Figure 4.14 Fitted normal type curve with depletion curves for HM16. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

Table 4.9 Specific weight (kg/hl) for the HM16 trial

	N rate (kg/ha)						
Variety	0	60	120	200	280	360	Grand Mean
Cassia	64.1	63.7	64.6	65.5	65.5	65.0	64.7
Meridian	58.4	58.2	57.4	59.5	58.6	54.3	57.7
Venture	63.8	62.1	63.1	63.9	64.2	63.3	63.4
Volume	63.2	62.1	61.4	61.3	61.3	60.3	61.6
Pastoral	64.6	63.5	64.6	65.1	64.9	64.0	64.4
Maris Otter	66.5	66.7	67.4	67.8	67.4	66.4	67.0
Grand Total	63.4	62.7	63.1	63.9	63.7	62.2	63.1
	P	SED	LSD				
N rate	0.141	0.6	1.36				
Variety	<.001	0.4	0.70				
N rate x Variety	0.013	1.0	2.00				

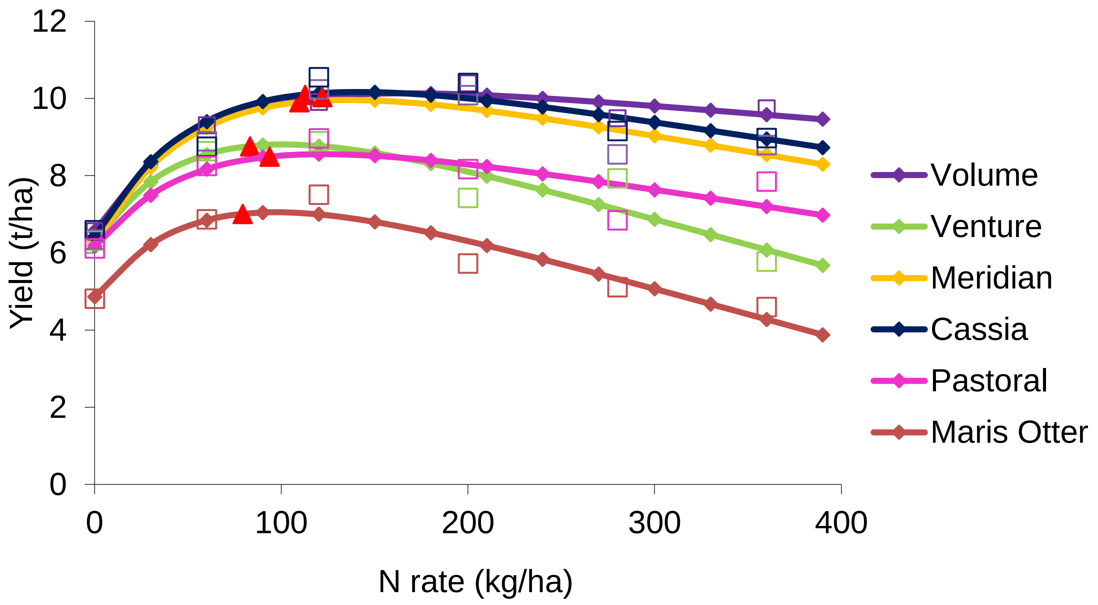

Figure 4.15 Fitted linear plus exponential N response curves for RM16 at a BER of 5:1. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

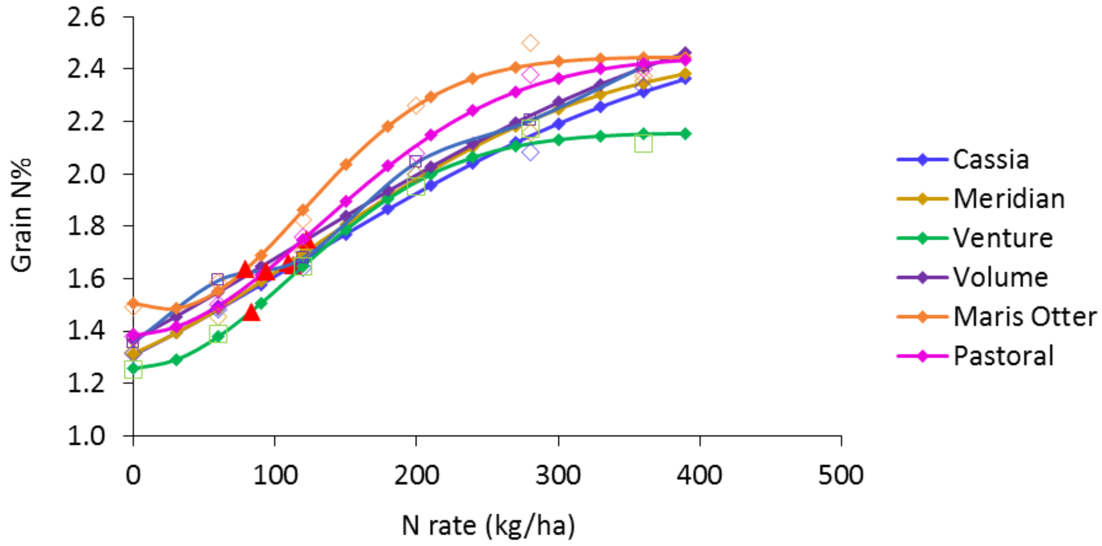

Figure 4.16 Fitted normal type curve with depletion curves for RM16. Red triangles indicate Nopt for each variety. Open symbols indicate experimental datapoints, closed symbols indicate fitted datapoints.

Table 4.10 Specific weight (kg/hl) for the RM16 trial

	N rate (kg/ha)						
Variety	0	60	120	200	280	360	Grand Mean
Cassia	62.1	63.1	61.7	59.3	58.9	56.5	60.3
Meridian	62.4	63.3	62.9	60.6	58.1	57.0	60.7
Venture	62.4	61.3	60.2	57.7	57.0	55.8	59.1
Volume	59.8	58.3	57.1	55.4	53.5	52.5	56.1
Pastoral	62.8	61.9	61.1	60.2	58.0	57.4	60.1
Maris Otter	65.6	67.0	65.1	61.5	59.2	58.8	62.9
Grand Total	62.5	62.5	61.4	59.1	57.5	56.3	59.9
	P	SED	LSD				
N rate	<.001	0.8	1.67				
Variety	<.001	0.4	0.84				
N rate x Variety	0.484	1.2	2.43				

4.2.5. Cross Site Analysis

N rate

Across the seven experiments average optimum N rates ranged from 149 kg N/ha for Maris Otter to 229 kg N/ha for Meridian with yields ranging from 7.11 t/ha to 9.82 t/ha respectively (Table 4.11). Significant effects of variety on Nopt and yield at Nopt were obtained. On average, modern varieties had a Nopt which was 28 kg N/ha greater than the old varieties (Maris Otter, Pastoral and Halcyon) and yielded 1.42 t/ha more. There was a positive relationship between yield at the Nopt and Nopt, suggesting that higher yielding modern varieties do require more N than lower yielding older varieties to achieve their full yield potential (Figure 4.17).

Grain N%

There was a significant impact of variety on grain N at the Nopt (P=0.042) across the seven experiments (Table 4.11). Grain N at the Nopt ranged from 1.74% for Maris Otter and Venture to 1.95% for Meridian and Pastoral. There was a positive relationship between the varietal means for grain N% at the Nopt and the Nopt, with 52% of the variation explained (Figure 4.18). At OptN there was a weak positive relationship between yield and grain N% (Figure 4.19), probably because the higher yielding varieties had a greater Opt N. At a fixed N rate of 200 kg N/ha, there was a negative relationship between yield and grain N% (Figure 4.20), which was probably due to grain N dilution for the higher yielding varieties.

Table 4.11 Predicted means for Nopt, yield at Nopt and grain N% at Nopt from seven N rate experiments done in 2014-2016.

Variety	Nopt (kg/ha)	Yield at Nopt (t/ha)	Grain N% at Nopt	Yield at 200kg N/ha[a] (t/ha)	Grain N% at 200 kg N/ha[a]
Cassia	184	9.17	1.80	8.82	1.91
Meridian	229	9.82	1.95	9.17	1.90
Venture	175	8.70	1.74	8.11	1.87
Volume	183	9.48	1.82	9.02	1.91
Halcyon	167	8.13	1.79	7.87	1.99
Pastoral	179	8.36	1.95	7.72	2.08
Maris Otter	149	7.11	1.74	6.84	2.01
Grand Total	181	8.68	1.83	8.22	1.95
	P	SED			
Nopt	0.001	17.74			
Yield at Nopt	<0.001	0.28			
Grain N% at Nopt	0.042	0.09			
Yield at 200 kg N/ha	<0.001	0.52			
Grain N% at 200 kg N/ha	<0.001	0.04			

[a] Data for 200kg N/ha excludes SAG14 dataset which did not include this N rate.

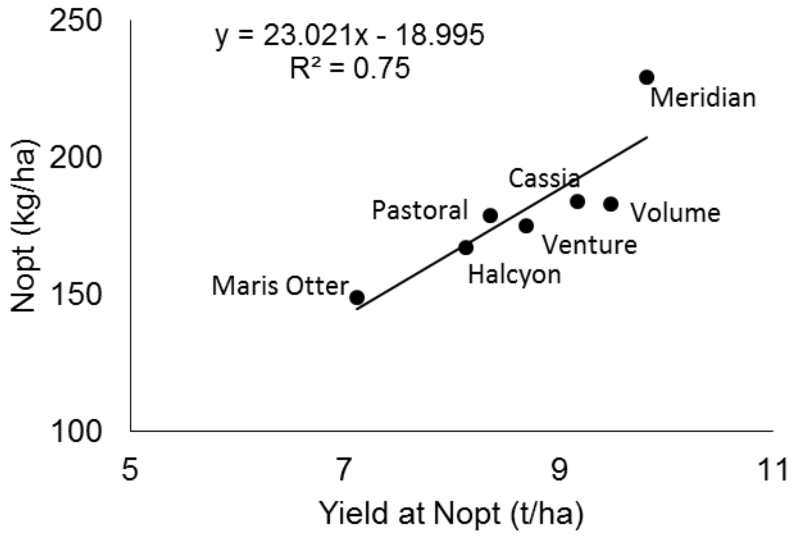

Figure 4.17 Relationship between the mean Nopt and grain yield at Nopt.

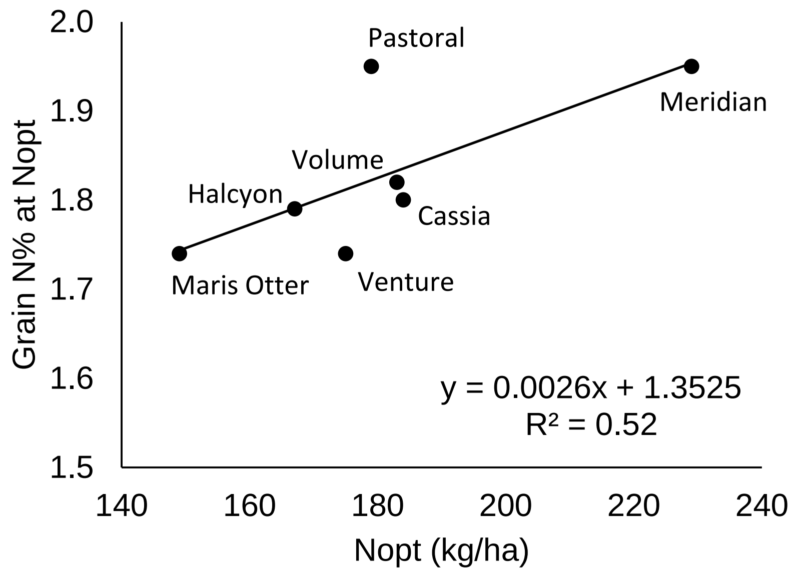

Figure 4.18 Relationship between Nopt and grain N% at the Nopt.

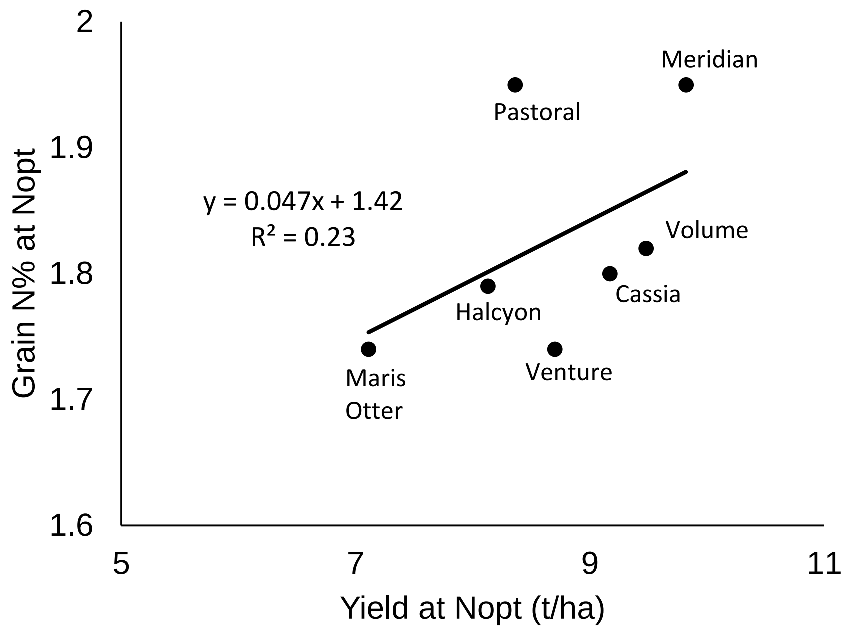

Figure 4.19 Relationship between yield (t/ha) and grain N% at Opt N.

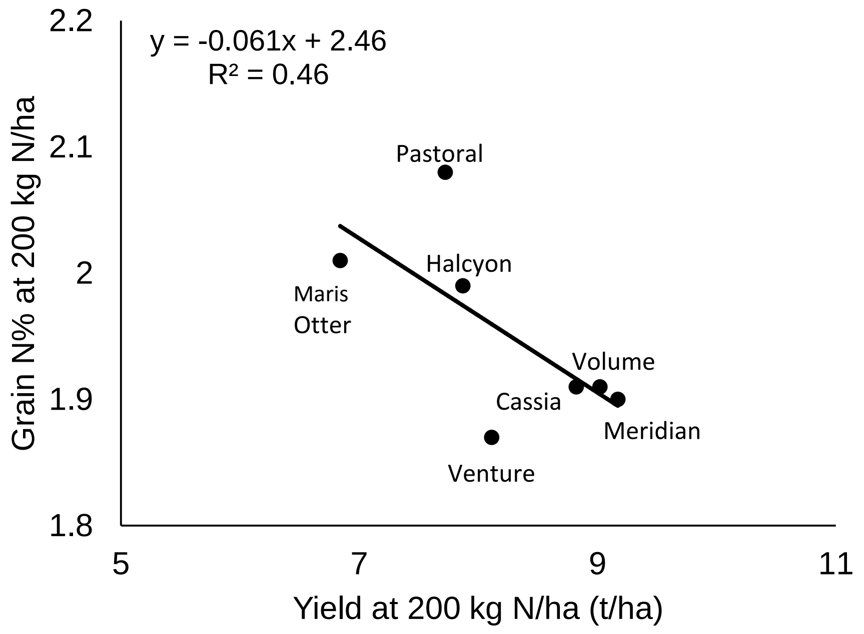

Figure 4.20 Relationship between yield (t/ha) and grain N% at 200kg N/ha.

Apparent fertiliser Recovery and N utilisation efficiency

Apparent fertiliser recovery, N uptake efficiency of soil and fertiliser N, N utilisation efficiency and N use efficiency (NUE) were determined for the N rate closest to the Nopt in six N rate experiments (Table 4.12). Average apparent fertiliser recovery at Nopt was 65% and average N uptake efficiency of soil and fertiliser N was 0.73 kg N taken up per kg N available. Average N utilisation efficiency was 40.1 kg grain dry matter per kg N taken up and average NUE was 28.6 kg grain per kg of available N. None of these parameters were significantly affected by variety when they were calculated at Nopt. At a standard N rate of 200kg N/ha, there was a significant effect of variety on NUE. The NUE of Cassia and Meridian was significantly greater than Venture. All four modern varieties had significantly greater NUEs than Maris Otter and Halcyon, but not Pastoral. This analysis shows that breeders have improved NUE when this is calculated for a fixed N fertiliser rate. However, there is no detectable breeding improvement in NUE when this is calculated at the Nopt because the positive effect on NUE of increasing yield is counteracted by the negative effect of increasing the optimum N rate.

Table 4.12 Predicted means for Apparent fertiliser recovery, N uptake efficiency, N utilisation efficiency and N use efficiency (NUE), across the N rate experiments done at HM and RM in 2014-2016. Values were determined for the N rate closest to the Nopt for each variety or 200kg N/ha.

Variety	Apparent Fertiliser Recovery (%)	N uptake efficiency (kg N taken up per kg N available)	N utilisation efficiency (kg grain per kg N taken up)	N use efficiency (kg grain per kg of available N)	N use efficiency (kg grain per kg of available N) at 200kg N/ha
Cassia	66.7	0.75	42.0	30.9	30.1
Meridian	68.4	0.75	38.1	28.1	29.4
Venture	67.6	0.76	44.0	33.1	27.2
Volume	64.1	0.74	40.6	28.7	27.7
Halcyon	65.6	0.74	41.5	29.5	24.5
Pastoral	55.9	0.67	44.1	28.3	28.2
Maris Otter	68.8	0.73	38.5	26.9	22.6
Grand Total	65.3	0.73	41.4	29.4	26.4
		P	SED		
Fertiliser Recovery		0.893	10.3		
N uptake Efficiency		0.874	0.1		
N utilisation efficiency		0.634	4.3		
NUE		0.255	3.0		
NUE (200 kgN/ha)		0.005	2.0		

4.3. Objective 3. Investigate the optimum N timing for different variety types (2-row feed, 2-row malting, 6-row feed and hybrid feed).

4.3.1. 2014 Experiments

In the HM14 experiment, yield was significantly affected by both N timing and variety (Table 4.13). Across the four varieties, the medium N timing treatment was the highest yielding, which was significantly greater than the RB209, early and Autumn N timing treatments, for which there was no significant difference in yield. In contrast, in the RM14 experiment, variety and N timing had no significant effect on yield (Table 4.14). However, it is notable that the early N timing treatment led to a 0.6 t/ha yield increase over the RB209 treatment. N timing and variety had a significant effect on yield in the SAG14 experiment, with the earliest N treatment yielding 0.8 t/ha more than the latest N treatment (Table 4.15).

Table 4.13 Yield (t/ha) for HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	7.28	7.92	7.51	7.58	7.57
Meridian	7.96	7.79	7.57	7.34	7.67
Venture	6.36	7.13	6.81	6.81	6.78
Volume	7.04	7.14	6.62	6.63	6.86
Grand Total	7.16	7.49	7.13	7.09	7.22
	P	SED	LSD		
Timing	0.125	0.16	0.381		
Variety	<.001	0.12	0.247		
Timing x Variety	0.077	0.26	0.533		

Table 4.14 Yield (t/ha) for RM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	8.22	7.91	8.98	7.28	8.10
Meridian	7.47	7.84	8.35	8.10	7.94
Venture	8.30	8.31	8.10	8.55	8.31
Volume	7.78	8.68	8.79	8.84	8.53
Grand Total	7.94	8.19	8.56	8.19	8.22
	P	SED	LSD		
Timing	0.354	0.31	0.760		
Variety	0.609	0.46	0.947		
Timing x Variety	0.838	0.85	1.745		

Table 4.15 Yield (t/ha) for SAG14 N timing trial.

	Timing				
Variety	V.Late	Late	Medium	Early	Grand Mean
Cassia	10.15	10.78	10.58	10.93	10.61

Variety	Timing				Grand Mean
	V.Late	Late	Medium	Early	
Meridian	11.27	11.91	11.79	12.05	11.75
Venture	9.86	9.96	10.62	10.56	10.25
Volume	10.82	11.76	10.88	11.74	11.30
Grand Total	10.53	11.10	10.97	11.32	10.98
	P	SED	LSD		
Timing	0.001	0.18	0.367		
Variety	<.001	0.18	0.367		
Timing x Variety	0.406	0.36	0.734		

There was no significant impact of N timing on specific weight in either the HM or RM experiments (Tables 4.16 and 4.17). Variety had a significant impact on specific weight in the HM experiment, but there was no effect in the RM experiment. The specific weights of Meridian, Venture and Volume were all lower than that of Cassia. In the SAG trial, both N timing and variety had significant effects on specific weight, with both medium and early N timing treatments having greater specific weights than the very late timing treatment (Table 4.18).

Table 4.16 Specific Weight for the HM14 N timing trial.

Variety	Timing				Grand Mean
	RB209	Medium	Early	Autumn	
Cassia	62.5	62.9	64.6	66.8	64.2
Meridian	60.4	59.5	57.2	56.6	58.4
Venture	62.9	55.8	60.9	63.3	60.7
Volume	61.8	56.1	61.3	59.4	59.7
Grand Total	61.9	58.6	61.0	61.5	60.8
	P	SED	LSD		
Timing	0.457	2.1	5.20		
Variety	0.007	1.5	3.18		
Timing x Variety	0.347	3.4	7.03		

Table 4.17 Specific Weight for the RM14 N timing trial.

Variety	Timing				Grand Mean
	RB209	Medium	Early	Autumn	
Cassia	56.3	53.5	55.7	60.2	56.4
Meridian	58.3	57.8	57.0	54.5	56.9
Venture	55.4	52.2	56.8	51.4	53.9

Variety	Timing				Grand Mean
	RB209	Medium	Early	Autumn	
Volume	57.2	54.4	55.0	57.7	56.1
Grand Total	56.8	54.5	56.1	55.9	55.8
	P	SED	LSD		
Timing	0.101	0.8	1.51		
Variety	0.435	1.9	3.80		
Timing x Variety	0.689	3.4	7.75		

Table 4.18 Specific Weight for SAG14 N timing trial.

Variety	Timing				Grand Mean
	V. Late	Late	Medium	Early	
Cassia	63.1	65.3	66.0	65.9	65.1
Meridian	58.5	60.1	61.6	64.1	61.1
Venture	64.8	66.3	67.9	66.5	66.4
Volume	64.8	66.3	67.9	63.1	62.9
Grand Total	62.0	63.8	64.7	64.9	63.8
	P	SED	LSD		
Timing	0.001	0.7	1.34		
Variety	<.001	0.7	1.34		
Timing x Variety	0.406	1.3	2.69		

There was no significant impact of N timing on grain N% in the HM14 (Table 4.19) and RM14 (Table 4.20) experiments, whilst variety did have a significant impact on the N content of the grain in the HM14 experiment, with Meridian having a greater grain N% than Volume. In the SAG14 experiment, both N timing and variety significantly affected grain N%, with the earliest N timing having a greater grain N% than the medium timing, and Volume higher than the other varieties (Table 4.21).

Table 4.19 Grain N% for HM14 N timing trial.

Variety	Timing				Grand Mean
	RB209	Medium	Early	Autumn	
Cassia	1.68	1.68	1.72	1.58	1.66
Meridian	1.72	1.67	1.77	1.55	1.68
Venture	1.64	1.58	1.63	1.42	1.57
Volume	1.74	1.73	1.72	1.57	1.69
Grand Total	1.69	1.66	1.71	1.53	1.65

	P	SED	LSD
Timing	0.072	0.06	0.144
Variety	<.001	0.02	0.042
Timing x Variety	0.509	0.07	0.151

Table 4.20 Grain N% for RM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	2.06	2.06	1.97	2.19	2.07
Meridian	2.14	1.99	2.10	2.19	2.11
Venture	1.95	2.06	2.05	2.19	2.06
Volume	2.09	2.07	1.82	1.96	1.99
Grand Total	2.06	2.05	1.98	2.13	2.06
	P	SED	LSD		
Timing	0.613	0.11	0.263		
Variety	0.109	0.05	0.098		
Timing x Variety	0.095	0.14	0.290		

Table 4.21 Grain N% for SAG14 N timing trial.

	Timing				
Variety	V. Late	Late	Medium	Early	Grand Mean
Cassia	1.57	1.59	1.54	1.63	1.58
Meridian	1.60	1.56	1.62	1.62	1.60
Venture	1.60	1.58	1.54	1.63	1.59
Volume	1.68	1.68	1.58	1.66	1.65
Grand Total	1.61	1.60	1.57	1.63	1.60
	P	SED	LSD		
Timing	0.03	0.02	0.041		
Variety	0.009	0.02	0.041		
Timing x Variety	0.287	0.04	0.082		

Straw biomass was determined for the HM14 and RM14 experiments (Appendix Table 7.24 and 7.25). At HM, there was a significant effect of both N timing treatment and variety on the straw biomass. The early N timing led to a significant 1 t/ha increase in straw yield in comparison to the RB209 treatment. Although not statistically significant, the early N timing treatment at RM14 also led to a large increase in straw yield over the RB209 treatment, 0.5 t/ha in this case.

At both HM and RM in 2014, there was no significant effect of the N timing treatment on total N uptake, whilst variety had a significant effect at HM (Appendix Table 7.26 and Table 7.27). The total N uptake of both Cassia and Meridian was greater than that of Venture and Volume.

There was an almost significant effect of N timing on the lodging index measured at harvest (P=0.064) in the HM14 experiment (Appendix Table 7.28), with the RB209, medium and early treatments showing a higher amount of lodging than the autumn treatment. There was no significant impact of N timing on the lodging index at RM14 (Appendix Table 7.29).

Additional Physiology Measurements

In the HM14 experiment, a number of physiological measurements were made throughout the season to understand the effects of the N timing treatments on factors contributing to yield. There was a significant effect of both N timing treatment and variety, and a significant interaction between the two factors on height (Appendix Table 7.42). The early N timing treatment increased height by 13.7 cm on average compared with the RB209 N timing treatment. The greatest increase in height was for Volume, where the early application of N increased height by 17 cm. In contrast, there was only a 10 cm increase in height for Venture.

Light interception at GS37 was significantly increased by applying N early, with an increase of 13.2% for the early N timing treatment in comparison to the RB209 treatment (Appendix Table 7.43). The medium and autumn treatments also significantly increased light interception over the RB209 treatment. Similarly, at GS57 light interception was still significantly increased with an increase for the early N treatment of 8.3% over the RB209 treatment (Appendix Table 7.44).

At GS87, the percentage of green leaf area (GLA) remaining on both the shoots and the flag leaf was assessed (Appendix Table 7.45). There was a significant effect of both the N timing treatment and variety on the GLA, with the RB209 treatment having a greater GLA remaining than the other timing treatments.

GAI, shoots/m^2 and dry weight was measured on three occasions: GS31, GS41-59 and GS71-73 (Appendix Table 7.47). At GS31 and GS41-59 the N timing treatment had a significant effect on GAI, with increases of 1.45 and 1.15 units for Volume and Cassia respectively at GS31 and increases of 2.78 and 2.38 for each variety at GS41-59. There was no significant impact on GAI at GS71-73. There was no significant effect of N timing treatment on the number of shoots/m^2. However, at GS31 for both varieties the number of shoots/m^2 was greater for the early N timing treatment than for the RB209 timing treatment. However, assessment of the number of shoots at later growth stages showed that the increased shoot number at GS31 was not sustained. There was often an increased number of dead shoots when the N had been applied early in comparison to the RB209 recommended timing. Generally, the medium timing treatment tended to have a similar number of total shoots/m^2 at the second and third assessment timings to the early timing treatment, with reduced tiller death. Although the effect was not statistically significant, the total dry weight was increased with the early N treatment in comparison to RB209 at each of the three assessment timings.

A disease assessment done on 25/6/14 indicated that crops where N had been applied earlier may be more prone to disease. In the HM14 experiment, where data was collected from one replicate of the N timing trial, data showed that the early and medium N treatments had a higher area of flag leaf affected by Net blotch and Brown rust.

4.3.2. 2015 Experiments

In the HM15 trial, yield was significantly affected by variety but not by N timing (Table 4.22). Across the four varieties, the early N timing treatment was the highest yielding. There was an almost significant interaction between N timing and variety (P=0.066). In contrast, in the RM14 trial, variety and N timing had no significant effect on yield (Table 4.23). However, it is notable that the early N timing treatment led to a 0.5 t/ha yield increase over the RB209 treatment. N timing and variety had a significant effect on yield in the SAG15 experiment, with the latest N treatment yielding significantly less than the other N timing treatments (Table 4.24).

Table 4.22 Yield (t/ha) for HM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	9.18	9.35	9.21	9.22	9.24
Meridian	9.52	9.80	9.81	9.84	9.74
Venture	8.90	8.73	9.02	8.81	8.87
Volume	8.85	8.71	9.30	9.23	9.02
Grand Total	9.11	9.15	9.33	9.23	9.22
	P	SED	LSD		
Timing	0.105	0.08	0.204		
Variety	<.001	0.08	0.165		
Timing x Variety	0.066	0.16	0.330		

Table 4.23 Yield (t/ha) for RM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	11.0	11.4	11.2	11.4	11.3
Meridian	11.0	11.7	11.8	11.2	11.4
Venture	11.4	11.7	11.5	11.1	11.4
Volume	11.5	11.3	12.1	11.4	11.6
Grand Total	11.2	11.5	11.7	11.3	11.4
	P	SED	LSD		
Timing	0.283	0.2	0.54		
Variety	0.63	0.3	0.53		
Timing x Variety	0.839	0.5	1.01		

Table 4.24 Yield (t/ha) for the SAG15 N timing trial.

	Timing				
Variety	V.Late	Late	Medium	Early	Grand Mean
Cassia	12.5	13.3	13.2	13.1	13.1
Meridian	14.1	14.2	14.2	14.1	14.1
Venture	11.5	11.5	12.0	11.8	11.7
Volume	12.6	13.3	13.4	13.2	13.2
Grand Total	12.7	13.1	13.2	13.0	10.98
	P	SED	LSD		
Timing	<.001	0.1	0.21		
Variety	<.001	0.1	0.21		
Timing x Variety	0.166	0.2	0.43		

There was no significant impact of N timing on specific weight in either the HM15 or RM15 experiments (Table 4.25 and 4.26). Variety had a significant impact on specific weight in the HM15 experiment, but there was no effect in the RM15 experiment. The specific weights of Meridian and Venture were significantly greater than that of Cassia and Volume in the HM15 experiment. In the SAG trial, both N timing and variety had significant effects on specific weight, with both late, medium and early N timing treatments having greater specific weights than the very late timing treatment (Table 4.27).

There was no significant impact of N timing on grain N% in the HM15 (Table 4.28) and RM15 (Table 4.29) experiments, whilst variety did have a significant impact on the N content of the grain in the HM14 experiment. In the SAG15 experiment only one rep was tested for grain N% and therefore a statistical analysis could not be performed (Table 4.30). Numerically, the early N timing treatment led to the lowest grain N%.

Table 4.25 Specific Weight for the HM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	59.4	59.1	58.7	59.5	59.2
Meridian	65.9	67.2	67.0	65.7	66.5
Venture	65.1	65.6	65.7	65.5	65.5
Volume	59.6	60.2	59.9	59.1	59.7
Grand Total	62.5	63.0	62.8	62.5	62.7
	P	SED	LSD		
Timing	0.708	0.6	1.35		
Variety	<.001	0.3	0.63		
Timing x Variety	0.304	0.8	1.60		

Table 4.26 Specific Weight for the RM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	66.6	62.9	63.0	61.1	63.4
Meridian	59.0	61.1	61.7	61.1	60.7
Venture	64.5	64.3	63.6	61.0	63.3
Volume	60.8	62.8	63.2	63.3	62.5
Grand Total	62.7	62.8	62.9	61.6	62.5
	P	SED	LSD		
Timing	0.924	2.2	5.25		
Variety	0.118	1.2	2.46		
Timing x Variety	0.403	3.0	6.25		

Table 4.27 Specific Weight for the SAG15 N timing trial.

Variety	Timing				Grand Mean
	V.Late	Late	Medium	Early	
Cassia	66.8	68.3	67.5	68.2	67.7
Meridian	62.1	64.8	65.7	65.3	64.5
Venture	66.9	67.1	67.4	67.8	67.3
Volume	65.3	66.1	66.3	65.7	65.9
Grand Total	65.3	66.6	66.7	66.8	63.84
	P	SED	LSD		
Timing	<.001	0.3	0.64		
Variety	<.001	0.3	0.64		
Timing x Variety	0.029	0.6	1.27		

Table 4.28 Grain N% for the HM15 N timing trial.

Variety	Timing				Grand Mean
	RB209	Medium	Early	Autumn	
Cassia	2.00	1.87	1.87	1.75	1.87
Meridian	1.87	1.89	1.79	1.77	1.83
Venture	1.86	1.87	1.87	1.77	1.84
Volume	1.98	1.96	1.90	1.74	1.89
Grand Total	1.93	1.90	1.85	1.76	1.86
	P	SED	LSD		
Timing	0.235	0.05	0.133		
Variety	0.015	0.02	0.041		
Timing x Variety	0.149	0.06	0.141		

Table 4.29 Grain N% for the RM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	1.99	1.88	1.88	1.82	1.89
Meridian	1.81	1.83	1.85	1.75	1.81
Venture	1.99	1.91	1.83	1.78	1.88
Volume	1.97	1.79	1.87	1.81	1.86
Grand Total	1.94	1.85	1.86	1.79	1.86
	P	SED	LSD		
Timing	0.322	0.07	0.181		
Variety	0.171	0.04	0.076		
Timing x Variety	0.637	0.10	0.208		

Table 4.30 Grain N% for the SAG15 N timing trial.

	Timing				
Variety	V Late	Late	Medium	Early	Grand Mean
Cassia	1.66	1.69	1.57	1.63	1.64
Meridian	1.7	1.7	1.65	1.67	1.68
Venture	1.74	1.74	1.89	1.67	1.76
Volume	1.77	1.72	1.69	1.68	1.72
Grand Total	1.72	1.71	1.7	1.66	1.70

Straw biomass was not significantly affected by the N timing treatment in either the HM15 or RM15 experiments (Appendix Tables 7.30 and 7.31). There was also no significant effect of N timing treatment on total N uptake in the HM15 experiment (Appendix Table 7.32), whilst in the RM15 experiment there was a significant impact (Appendix Table 7.33). The autumn N timing treatment had a significantly lower total N uptake than the RB209, medium or early timing treatments. There was also no significant effects of N timing treatment on the lodging index at either site (Appendix Tables 7.34 and 7.35).

4.3.3. 2016 Experiments

In the HM16 trial, yield was significantly affected by variety but not by N timing (Table 4.31). Across the four varieties, the Medium N timing treatment was the highest yielding. In the RM14 trial, both variety and N timing had a significant effect on yield (Table 4.32). The Medium N timing treatment yielded significantly more than either the RB209 or autumn timing treatments. There was no significant effect of N timing in the SAG16 experiment, whilst variety had a significant effect (Table 4.33). There was a significant interaction between variety and N timing on yield.

Table 4.31 Yield (t/ha) for the HM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	7.22	7.27	7.27	6.88	7.16
Meridian	7.27	8.29	7.31	7.20	7.51
Venture	6.16	5.96	5.87	5.45	5.83
Volume	6.96	7.15	6.80	7.13	7.02
Grand Total	6.97	7.17	6.81	6.62	6.90
	P	SED	LSD		
Timing	0.071	0.16	0.378		
Variety	<.001	0.17	0.345		
Timing x Variety	0.237	0.33	0.669		

Table 4.32 Yield (t/ha) for the RM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	8.92	10.12	9.53	9.35	9.48
Meridian	8.98	10.09	9.61	9.26	9.48
Venture	8.09	9.02	8.52	8.08	8.43
Volume	9.18	10.58	10.02	9.78	9.89
Grand Total	8.79	9.95	9.42	9.12	9.32
	P	SED	LSD		
Timing	0.054	0.33	0.796		
Variety	<.001	0.18	0.373		
Timing x Variety	0.992	0.45	0.948		

Table 4.33 Yield (t/ha) for the SAG15 N timing trial.

Variety	Timing				Grand Mean
	V. Late	Late	Medium	Early	
Cassia	11.06	10.71	10.67	11.26	10.93
Meridian	11.35	11.39	11.39	11.44	11.40
Venture	10.38	10.07	10.60	9.53	11.15
Volume	10.19	10.81	10.33	11.73	11.01
Grand Total	11.00	10.75	10.75	10.99	10.87
	P	SED	LSD		
Timing	0.414	0.20	0.412		
Variety	<.001	0.20	0.412		
Timing x Variety	0.041	0.40	0.825		

There was a significant impact of N timing on specific weight in the HM16 experiment whereby the RB209 timing treatment led to a greater specific weight than the autumn N treatment. There was no significant impact of N timing on specific weight in the RM16 or SAG16 trials (Tables 4.34 – 4.36). Variety had a significant impact on specific weight in the RM16 experiment, but there was no effect in the HM16 or SAG16 experiments. The specific weight of Volume was significantly lower than that of Cassia, Meridian and Venture in the HM16 experiment.

There was a significant impact of N timing on grain N% in the HM16 (Table 4.37) experiment, with the Medium and RB209 timing treatments having greater grain N% than the early and autumn timing treatments. There was no significant effect of N timing on grain N% in the RM16 experiment (Table 4.38), whilst in the SAG16 experiment there was a significant impact (Table 4.39). Here, the early and very late timing treatments had a significantly higher grain N% than the medium and late treatments.

In the HM16 experiment, there was also a significant effect of variety on grain N% and a significant interaction between the two factors (Table 4.37). Venture had a significantly lower grain N% than the other three varieties. The grain N% of both Volume and Cassia was significantly greater than Meridian. Variety had no significant effect on grain N% in either the RM16 (Table 4.38) or SAG16 (Table 4.39) experiments.

Straw biomass was significantly affected by the N timing treatments and variety in the HM16 trial (Appendix Table 7.36) but not in the RM16 trial (Appendix Table 7.37). The medium, early and autumn treatments all had significantly higher straw yields than the RB209 treatment. Total N uptake at harvest was significantly affected by N timing in both the HM16 and RM16 experiments (Appendix Tables 7.38 and 7.39). The autumn timing treatment took up significantly less N than the RB209 and Medium N timing treatments in the HM16 experiment. In the RM16 experiment, the Medium N timing treatment took up significantly more N than RB209, early or autumn treatments.

In the HM16 experiment, brackling was identified in the trial at harvest, although there was no significant effect of the N timing treatments on brackling (Appendix Table 7.40). In contrast, in the RM16 experiment, the lodging index at harvest was significantly affected by the N timing treatment, with the medium timing treatment showing a higher lodging index than both the early and autumn treatments (Appendix Table 7.41). No lodging or leaning occurred in the SAG16 experiment (Appendix Table 7.42).

Height was measured in the HM16, RM16 and SAG16 experiments where the Early application of N significantly increased height by 8.1 cm and 8 cm respectively in the HM16 (Table 7.48) and RM16 experiments compared with the RB209 treatment (Table 7.49). The Medium N timing treatment led to a 5.3 cm and 11.7 cm increase respectively at HM16 and RM16 over the RB209 treatment. In the SAG16 experiment, the effect of N timing on height was significant, with the height difference between the earliest and latest N timing treatments being 7 cm (Appendix Table 7.50).

The number of ears/m^2 was also measured in the SAG16 experiment (Appendix Table 7.51). There was no significant effect of the N timing treatment on ear number. There was a significant effect of variety, with Cassia and Venture having significantly more ears/m^2 than both Meridian and Volume.

Table 4.34 Specific Weight for the HM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	65.2	64.7	65.2	64.5	64.9
Meridian	58.7	59.1	57.5	58.4	58.4
Venture	64.3	63.2	62.7	60.4	62.5
Volume	60.9	60.3	60.6	61.2	60.7
Grand Total	62.1	61.8	61.6	61.1	61.7
	P	SED	LSD		
Timing	0.034	0.3	0.77		
Variety	<.001	0.4	0.88		
Timing x Variety	0.045	0.80	1.64		

Table 4.35 Specific Weight for the RM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	60.3	61.7	63.0	62.4	61.9
Meridian	61.7	63.0	63.9	63.1	62.9
Venture	60.7	60.7	61.8	60.9	61.0
Volume	57.6	58.3	57.2	58.6	57.9
Grand Total	60.1	60.9	61.5	61.3	60.9
	P	SED	LSD		
Timing	0.164	0.6	1.37		
Variety	<.001	0.5	1.12		
Timing x Variety	0.679	1.1	2.24		

Table 4.36 Specific Weight for the SAG16 N timing trial.

	Timing				
Variety	V. Late	Late	Medium	Early	Grand Mean
Cassia	70.1	70.7	71.0	70.9	70.7
Meridian	67.2	67.6	67.7	67.1	67.4
Venture	69.2	68.6	69.7	68.9	69.1
Volume	68.6	69.2	68.1	68.1	68.5
Grand Total	68.8	69.0	69.1	68.8	68.9
	P	SED	LSD		
Timing	0.691	0.4	0.74		
Variety	<.001	0.4	0.74		
Timing x Variety	0.688	0.7	1.47		

Table 4.37 Grain N% for the HM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	1.92	1.76	1.70	1.69	1.77
Meridian	1.83	1.74	1.70	1.61	1.72
Venture	1.86	1.75	1.65	1.59	1.70
Volume	1.90	1.77	1.74	1.60	1.77
Grand Total	1.88	1.76	1.69	1.62	1.74
	P	SED	LSD		
Timing	0.001	0.03	0.078		
Variety	<.001	0.01	0.021		
Timing x Variety	0.03	0.04	0.081		

Table 4.38 Grain N% for the RM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	1.78	1.68	1.69	1.66	1.71
Meridian	1.81	1.73	1.75	1.76	1.76
Venture	1.72	1.73	1.70	1.76	1.73
Volume	1.72	1.69	1.73	1.75	1.72
Grand Total	1.76	1.71	1.72	1.74	1.73
	P	SED	LSD		
Timing	0.302	0.03	0.062		
Variety	0.504	0.04	0.079		
Timing x Variety	0.935	0.07	0.145		

Table 4.39 Grain N% for the SAG16 N timing trial.

	Timing				
Variety	V Late	Late	Medium	Early	Grand Mean
Cassia	1.76	1.58	1.56	1.65	1.64
Meridian	1.70	1.53	1.52	1.61	1.59
Venture	1.67	1.54	1.54	1.56	1.58
Volume	1.77	1.48	1.55	1.65	1.61
Grand Total	1.73	1.53	1.54	1.62	1.60
	P	SED	LSD		
Timing	<.001	0.03	0.056		
Variety	0.112	0.03	0.056		
Timing x Variety	0.693	0.06	0.112		

4.3.4. Cross Site Analysis

Yield

Across the 6 site seasons, N timing was found to have a significant impact on yield (Table 4.40). The Medium N timing treatment out yielded both the RB209 and autumn timing treatments by 0.39 t/ha and 0.31 t/ha respectively. The Early N timing treatment significantly out yielded the RB209 treatment by 0.29 t/ha. There was no significant difference in yield between the Early and Medium N timing treatments. Variety had a significant impact on yield, with all three modern feed varieties significantly out yielding Venture, the malting variety. There was no significant interaction between N timing and variety, demonstrating that varieties did not require different N timing regimes to maximise yield.

Across the three trials done in Scotland, the early treatment significantly out yielded the very late treatment by 0.46 t/ha (Table 4.41). Variety had a significant impact on yield. Meridian significantly out yielded all other varieties and all three modern feed varieties significantly out yielded Venture, the malting variety. There was no significant interaction between N timing and variety, demonstrating that varieties did not require different N timing regimes to maximise yield.

Table 4.40 Mean yield (t/ha) averaged across 6 site seasons (ADAS trials only).

	Timing				
Variety	Autumn	Early	Medium	RB209	Grand Mean
Cassia	8.61	8.94	9.00	8.63	8.80
Meridian	8.82	9.07	9.25	8.71	8.96
Venture	8.14	8.30	8.47	8.20	8.28
Volume	8.84	8.95	8.92	8.54	8.81
Grand Total	8.60	8.81	8.91	8.52	8.71
	P	SED	LSD		
Timing	0.018	0.14	0.270		
Variety	<.001	0.14	0.270		
Timing x Variety	0.989	0.27	0.540		

Table 4.41 Mean yield (t/ha) averaged across 3 site seasons (SAG trials only).

	Timing				
Variety	Early	Medium	Late	V. Late	Grand Mean
Cassia	11.76	11.49	11.61	11.24	11.52
Meridian	12.53	12.45	12.50	12.24	12.43
Venture	10.62	11.06	10.53	10.58	10.70
Volume	12.22	11.54	11.95	11.21	11.73
Grand Total	11.78	11.64	11.64	11.32	11.59
	P	SED	LSD		
Timing	0.049	0.16	0.333		
Variety	<.001	0.16	0.333		
Timing x Variety	0.423	0.33	0.666		

Specific Weight

Across the six ADAS experiments, there was no significant effect of N timing on specific weight (Table 4.42). There was a significant varietal effect on specific weight and no significant interaction between variety and N timing treatment. Volume had a significantly lower specific weight than Cassia or Venture. Across the three SAG experiments, applying the N at the latest timing significantly reduced specific weight in comparison to the earlier treatments (Table 4.43). There was a significant effect of variety on specific weight, with Venture and Cassia having greater specific weights than Meridian and Volume. The specific weight of Volume also significantly exceeded that of Meridian.

Table 4.42 Mean specific weight (kg/hl) averaged across 6 site seasons (ADAS experiments only).

	Timing				
Variety	Autumn	Early	Medium	RB209	Grand Mean
Cassia	61.7	60.7	61.8	62.4	61.7
Meridian	60.6	61.3	60.8	59.9	60.6
Venture	62.2	60.3	61.9	60.4	61.2
Volume	59.6	58.6	59.6	60.0	59.4
Grand Total	61.0	60.2	61.0	60.7	60.7
	P	SED	LSD		
Timing	0.694	0.8	1.51		
Variety	0.029	0.8	1.51		
Timing x Variety	0.906	1.5	3.03		

Table 4.43 Mean specific weight (kg/hl) averaged across 3 site seasons (SAG trials only).

	Timing				
Variety	Early	Medium	Late	V. Late	Grand Mean
Cassia	68.3	68.2	68.1	66.7	67.8
Meridian	65.5	65.0	64.2	62.6	64.3
Venture	67.7	68.3	67.3	67.0	67.6
Volume	65.6	67.4	67.2	66.2	66.6
Grand Total	66.8	67.2	66.7	65.6	66.6
	P	SED	LSD		
Timing	0.022	0.5	1.03		
Variety	<.001	0.5	1.03		
Timing x Variety	0.544	1.0	2.07		

Grain N%

Application of 30 kg N/ha in the autumn significantly reduced grain N% in comparison to the other N timing treatments in the ADAS experiments (Table 4.44). The earlier spring N treatments significantly reduced grain N% in comparison to RB209 by 0.07%. There was no varietal effect on grain N%, and no interaction between variety and N timing treatment. Across the three SAG experiments, applying the N at the latest timing significantly increased grain N% in comparison to the Medium and late N timing treatments (Table 4.45).

Table 4.44 Mean grain N% averaged across 6 site seasons (ADAS trials only).

	Timing				
Variety	Autumn	Early	Medium	RB209	Grand Mean
Cassia	1.79	1.80	1.81	1.90	1.83
Meridian	1.76	1.83	1.81	1.87	1.82
Venture	1.76	1.79	1.81	1.84	1.80
Volume	1.73	1.80	1.83	1.90	1.82
Grand Total	1.76	1.81	1.81	1.88	1.82
	P	SED	LSD		
Timing	<.001	0.02	0.045		
Variety	0.656	0.02	0.045		
Timing x Variety	0.877	0.05	0.090		

Table 4.45 Mean grain N% averaged across 3 site seasons (SAG trials only).

	Timing				
Variety	Early	Medium	Late	V. Late	Grand Mean
Cassia	1.64	1.56	1.62	1.66	1.62
Meridian	1.63	1.60	1.60	1.66	1.62
Venture	1.62	1.66	1.62	1.67	1.64
Volume	1.66	1.61	1.63	1.74	1.66
Grand Total	1.64	1.60	1.62	1.69	1.64
	P	SED	LSD		
Timing	0.033	0.03	0.057		
Variety	0.468	0.03	0.057		
Timing x Variety	0.879	0.06	0.114		

5. Discussion

5.1. Optimum N rate

5.1.1. Yield

This project has shown higher yielding varieties had a greater optimum N rate. On average, each tonne of yield increase caused by varietal improvement resulted in an increase in fertiliser N requirement of approximately 23 kg N/ha (Figure 4.17). Varietal yield improvement of 2.3 t/ha were observed when measured at a common N rate, but greater yield improvement of 2.7 t/ha was measured when each variety was compared at its respective Nopt. The analysis carried out by this report shows that breeders have improved N use efficiency (NUE) when varieties are compared at a common rate of N fertiliser. However, there is no detectable breeding improvement in NUE when this is calculated at the Nopt because the improvement in NUE that results from greater yield is counter-balanced by the negative effect on NUE of increasing the optimum N rate. If plant breeders could produce new varieties with High Yield and Low Nopt (HYLO) then this would give far more substantial gains in NUE than are currently achieved.

The relationship between N fertiliser rate and yield for Venture grown in a high yielding environment is illustrated in Figure 5.1. For this crop the Nopt was 240 kg N/ha at a break even ratio (BER) of 5:1, which gave a yield of 11.5 t/ha. The full yield response to N fertiliser was just under 5 t/ha which was not atypical for the experiments in this study. The RB209 recommended N rate for this experimental site was 170 kg N/ha. Under-fertilising by 70 kg N/ha would have reduced yield by 0.56 t/ha and reduced the gross margin over N cost by £28/ha. The financial cost of under-fertilising winter barley is illustrated in Figure 5.2 based on the yield response to N observed for Venture at RM15. This shows that under-fertilising by 40 kg N/ha would result in a yield loss of 0.26 t/ha and a profit loss of £10/ha. Under-fertilising by 100 kg N/ha would reduce yield by 1 t/ha and reduce profit by £67/ha. Over-fertilising by 40 kg N/ha would increase yield by 0.15 t/ha and reduce profit by £7/ha. Greater profit losses are predicted due to under-fertilising compared with over-fertilising due to the diminishing yield response at progressively greater N rates (assuming no difference in lodging).

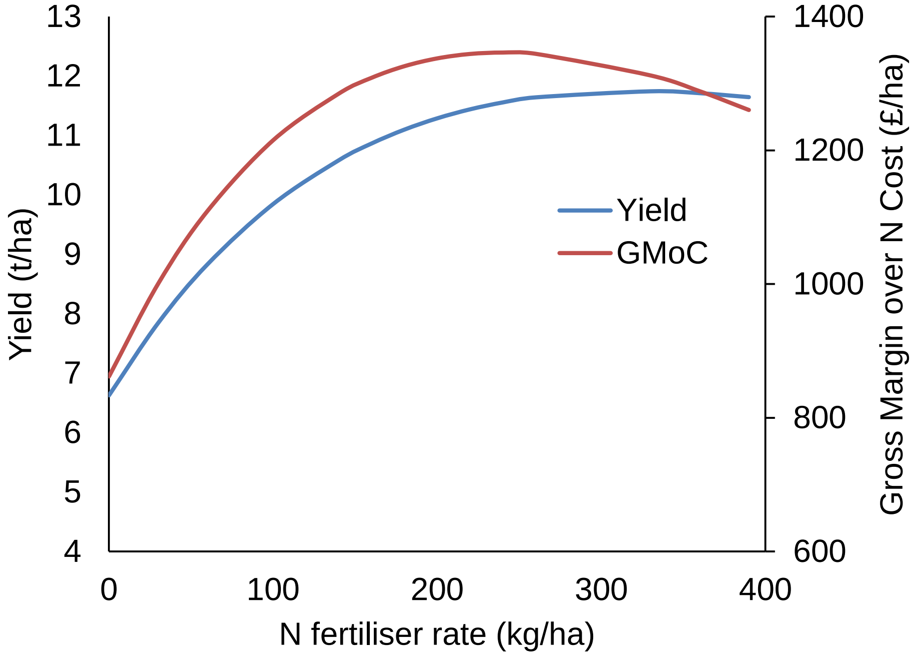

Figure 5.1. Relationship between N fertiliser rate, yield and gross margin over N cost (GMoC) based on a BER of 5:1 for Venture grown at RM15.

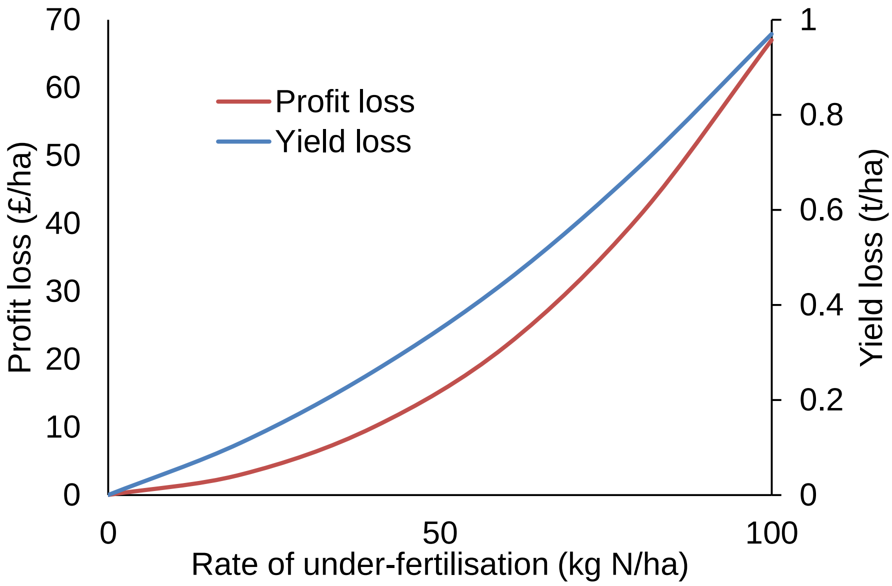

Figure 5.2. Relationship between the rate of under-fertilisation, profit loss and yield loss based on a BER of 5:1 for Venture grown at RM15.

5.1.2. Grain N%

Winter malting barley growers are often cautious about applying too much N fertiliser to avoid missing out on malting quality premiums due to grain N% being too high. The typical relationship between N fertiliser and grain N concentration is described in Figure 5.3, which shows that the initial doses of N fertiliser often reduce grain N% because the rapid rate of yield increase that occurs for crops with low SNS dilutes the grain N concentration. Heavier doses of N fertiliser increase the grain N%, then super-optimal doses of N fertiliser cause a diminishing increase in grain N because the crop is not able to take up all of the applied N. Nopt for the malting variety Venture are shown in Table 5.1 along with grain N% at the Nopt and the change required to meet the brewing grain N% requirement of 1.66 to 1.85%. At the average Nopt of 175 kg N/ha, grain N% averaged 1.74%, which would have met the brewing specification. However, at two sites fertilising for optimum yield would have exceeded the grain N% target and at three sites the grain N% would have been too low. These results illustrate that fertilising for optimum yield can result in a wide range of grain N concentrations of between 1.48% and 2.10%. It is clear from this that growers require improved methods of predicting grain N concentration so they can achieve the target more reliably without losing significant amounts of yield by reducing N rates to minimise the risk of exceeding the grain N target.

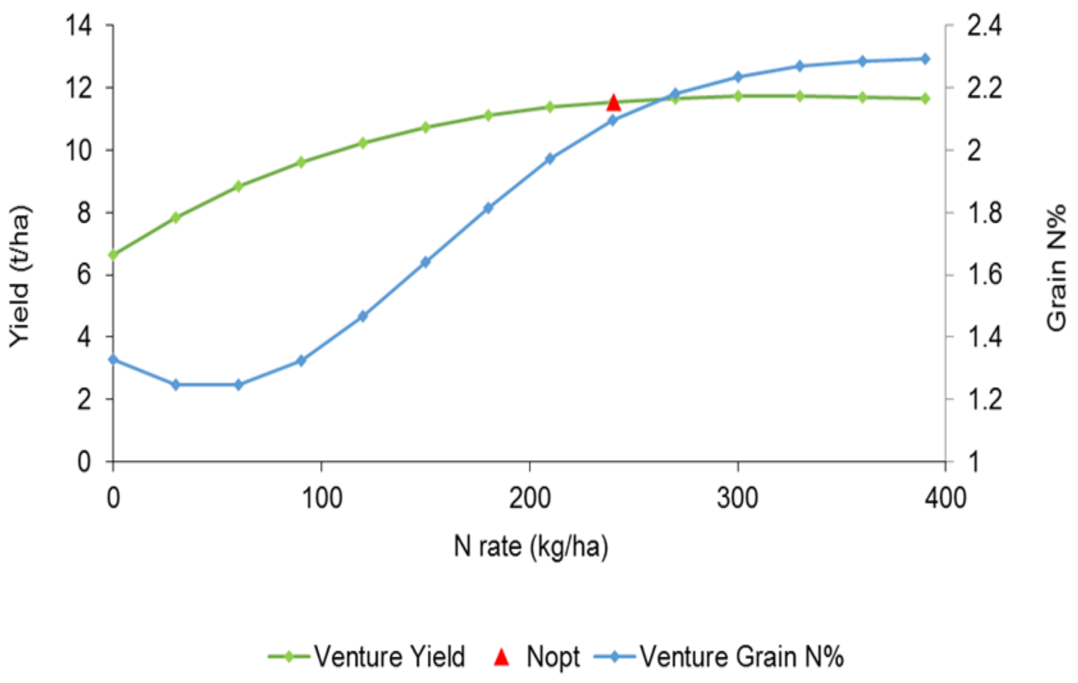

Figure 5.3. Effect of N fertiliser on grain N concentration and grain yield for Venture grown at RM15.

Table 5.1. Impact of Nopt for yield on grain N% and the deviation required from Nopt to meet the brewing grain N% specification of 1.66 – 1.85%.

Site	Nopt (kg N/ha)	Grain N%	Deviation from Nopt (kg N/ha)
HM16	194	1.64	+2
RM16	83	1.48	+37
HM15	207	1.82	0
RM15	240	2.10	-53
HM14	152	1.59	+18
RM14	157	1.89	-7
SAG14	193	1.66	0
Grand Total	175	1.74	0

5.1.3. Specific Weight

The results from the experiments reported here show that there was generally little impact on specific weight from changing N rate from the RB209 recommended rate to the optimum N rate measured in each experiment. N rate had a statistically significant effect on specific weight in only two experiments (RM15 and RM16). In the RM15 experiment, Nopt ranged from 166 – 265 kg N/ha between varieties and specific weight was significantly increased when N rate was increased from 60 kg N/ha to 200 kg N/ha. In the RM16 experiment, Nopt ranged from just 79-122 kg N/ha whilst specific weight was significantly reduced when N rate was increased from 120 kg N/ha to 200 kg N/ha. Both of these experiments show that optimising N rate is likely to result in a greater specific weight.

5.2. Optimum N timing

The data review done for Objective 1 (results section 4.1) has indicated that a yield increase of 0.3 t/ha can be obtained when more than 50% of the N is applied by stem extension (defined at GS31 occurring on 1st April) in comparison to current RB209 recommendations in which 30% or less would be applied before stem extension. The experiments from this present study showed that both ‘Early’ and the ‘Medium’ N timing strategies with 100% or 67% of N applied before GS31 significantly increased yield by 0.29 or 0.39 t/ha respectively, compared with the RB209 timed N treatment. The mechanism by which early N increases the yield of winter barley is most likely to be related to the physiological yield formation process in barley. It is now well understood that in order to maximise the yield potential of barley it is necessary to maximise grains/m^2. This is because barley is strongly sink limited which means the main constraint on increasing yield is usually the number of grains to fill (sink), rather than the ability to fill them with carbohydrate (source). The most effective ways of maximising grains/m^2 is to maximise ears/m^2. This is because both 2-row and 6-row barley have limited potential to increase grains per ears since they can only produce 1 or 3 grains per spikelet compared with up to about nine grains per spikelet in wheat. It has been shown that the amount of light intercepted by the green canopy between plant emergence and flowering correlates well with the number of grains/m^2 in spring and winter barley (Bingham et al., 2008a,b). Early applications of N fertiliser to barley before stem extension are likely to stimulate tillering and provide a plant available supply of N to sustain tillers during the tiller death phase which begins at around the same time that the stem starts extending. A substantial proportion of tillers can die during stem extension, so maintaining tillers during the tiller death phase is likely be important for maximising ear number. The 'Medium' N timing treatment applied one third N at tillering, one third N at GS30 and delayed one third of the N until GS31. Delaying some N until GS31 may explain why this treatment achieved the greatest yield response, which was slightly greater than applying all N before GS31. Data obtained from the HM14 experiment showed that early application of N increases light interception at both GS37 and GS57 (Appendix Tables 7.43 and 7.44). There was no significant impact of N timing on shoots/m^{2,} at GS31, although there was an indication that early application of N increased tiller number. However, a smaller number of tillers appeared to be lost under the Medium N timing than early timing treatment (Appendix Table 7.47). It would be worthwhile investigating whether splitting the N applications into a greater number of smaller doses could be used to further enhance final ear number by maximising tillering and minimising tiller death.

The 'Autumn' N timing treatment in which 30 kg N/ha was applied in the seed bed with the seed, followed by 'Early' N timed treatments did not increase yield compared with the RB209 N treatment. It is possible that this was because all of the experimental sites were ploughed which would have stimulated some N mineralisation in the autumn resulting in an adequate supply of N for autumn crop growth. Crop observations revealed little or no difference in crop growth between the N treatments before winter. If the crop did not take up the autumn N before winter then there would have been a risk that this N would have been lost to nitrate leaching over-winter. This would have been a higher risk on the shallow chalky soils of the N Yorkshire experiments. The total N applied for the autumn N treatment was identical to the other N timing treatments, so if any fertiliser N was leached over-winter, then this would have reduced the overall N supply that the Autumn N timing treatment supplied to the crop. Many barley crops are established following minimal cultivations and often with chopped straw, both of which reduce the amount of available N for crop uptake. Further research should investigate whether autumn N is advantageous in these conditions.

There was no evidence that varieties responded differently to N timing. It may be hypothesised that 6-row barley is less sink limited than 2-row barley (due to its greater capacity to maximise grains/m^2 by producing more grains per ear), and therefore would have been expected to respond less positively to early N. The reason that 6-row conventional and hybrid varieties did respond equally positively to early N as 2-row varieties maybe because 6-row conventional varieties have been found to produce fewer ears/m^2 and hybrid varieties are sown at lower seeds rates. Both of these factors are likely to have counteracted the 6-row varieties capacity to produce many grains/m^2 by producing more grains per ear.

Early N was shown to increase crop height by up to ten centimetres in the experiments where funding was available to measure crop height. However, there was no clear evidence that this increased height resulted in a significant increase in lodging risk. This was partly because not all of the experiments lodged. A model of barley lodging has shown that height increases would be expected to increase the risk of lodging (Berry et al., 2006). At this stage it would be prudent for growers to assume that earlier N is likely to increase the risk of lodging and therefore growers should ensure a more robust PGR strategy to mitigate against this risk. An assessment of disease levels in the HM14 experiment revealed that the early and medium N treatments had a higher area of flag leaf affected by Net Blotch and Brown Rust. Therefore, growers should also ensure an adequate fungicide programme is used to mitigate against this risk.

The effect of early N to reduce grain N concentration by almost 0.1% on average, will be helpful for many malting barley growers because it will enable them to realise more yield potential from new varieties by applying a modest amount of additional N (of 15-25 kg N/ha) without increasing the risk of exceeding the grain N specified by the end market. There was also no evidence to support early application of N having a detrimental effect on specific weight.

5.3 N recommendations for winter barley

N Rate

- Research has shown that the economically optimal rate of N fertiliser increases with yield.
- Where previous experience of growing winter barley indicates that yields above the UK average winter barley yield of 6.5 t/ha can be realistically expected, the recommended rate should be increased by 10 kg N/ha for each 0.5 t/ha additional yield, up to a maximum yield of 12 t/ha. *NB the experimental yield threshold of 7 t/ha above or below which N should be adjusted has been adjusted to 6.5 t/ha to represent typical farm yields.*
- Similarly for crops with an expected yield of less than 6.5 t/ha, the recommended rate should be reduced by 10 kg N/ha for each 0.5 t/ha reduction in expected yield.
- Growers and agronomists must be confident about achieving higher than normal expected yields to justify increasing N rates.
- At the optimum N rate for yield the apparent N fertiliser recovery rate averaged 65% and there were no significant differences between varieties.

N timing

- There is no requirement for seedbed nitrogen.
- Where the total nitrogen rate is less than 100 kg N/ha, apply this amount as a single dressing by early stem extension (GS30–31).
- Where the total nitrogen rate is between 100 and 200 kg N/ha, split the dressing with half during late tillering in mid-February/early March and half at GS30–31.
- Where the total nitrogen rate is above 200 kg N/ha, apply three splits with 40% during late tillering in mid-February/early March, 40% at GS30 and 20% at GS31/32.
- These recommendations assume appropriate measures are taken to control lodging (e.g. choice of variety, use of plant growth regulator). Reduce the recommendation by 25 kg N/ha if the lodging risk is high.

5.4 Further research requirements

- Identify crop traits that breeders should select for in order to achieve High Yield and Low N Optima (HYLO) varieties
- Develop a method of predicting grain N concentration based on factors such as N supply, yield potential and environment/site factors.
- Investigate whether splitting the N applications into a greater number of smaller doses could be used to further enhance final ear number by maximising tillering and minimising tiller death.
- Investigate the optimum N timing for N rates of 200 kg N/ha and above.
- Evaluate autumn N treatment on barley established using minimal tillage.
- Quantify the increase in lodging risk that results from applying N earlier and how this can be best mitigated through the use of PGRs.

6. Acknowledgements

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8. Appendix

Table 7.1 Application timings and N rate for N timing experiments at RM14

Treatment	Rate (kg/ha) (14/10/13)	Rate (kg/ha) GS 25-29 (8/3/14)	Rate (kg/ha) GS30 (11/4/14)	Rate (kg/ha) GS31 (2/5/14)	Total
RB209	0	40	0	150	190
Medium	0	60	70	60	190
Early	0	120	70	0	190
Autumn	30	90	70	0	190

Table 7.2 Application timings and N rate for N timing experiments at HM14

Treatment	Rate (kg/ha) (17/10/13)	Rate (kg/ha) GS 25-29 (8/3/14)	Rate (kg/ha) GS30 (11/4/14)	Rate (kg/ha) GS31 (2/5/14)	Total
RB209	0	40	0	170	210
Medium	0	70	70	70	210
Early	0	130	80	0	210
Autumn	30	100	80	0	210

Table 7.3 Application timings and N rate for N timing experiments at SAG14.

Treatment	Rate (kg/ha) (11/10/13)	Rate (kg/ha) GS 23-25	Rate (kg/ha) GS 30	Rate (kg/ha) GS 33	Total
V Late	25	0	135	45	180
Late	25	36	90	54	180
Medium	25	54	90	36	180
Early	25	72	108	0	180

Table 7.4 Application timings and N rate for N timing experiments at RM15.

Treatment	Rate (kg/ha) (30/10/14)	Rate (kg/ha) GS 25-29 (27/2/15)	Rate (kg/ha) GS30 (26/03/15)	Rate (kg/ha) GS31 (13/4/15)	Total
RB209	0	40	0	150	190
Medium	0	60	70	60	190
Early	0	120	70	0	190
Autumn	30	90	70	0	190

Table 7.5 Application timings and N rate for N timing experiments at HM15.

Treatment	Rate (kg/ha) (2/10/14)	Rate (kg/ha) GS 25-29 (5/3/15)	Rate (kg/ha) GS30 (26/3/15)	Rate (kg/ha) GS31 (16/4/15)	Total
RB209	0	40	0	170	210
Medium	0	70	70	70	210
Early	0	130	80	0	210
Late	30	100	80	0	210

Table 7.6 Application timings and N rate for N timing experiments at SAG15.

Treatment	Rate (kg/ha) (29/9/14)	Rate (kg/ha) GS 23-35	Rate (kg/ha) GS 30	Rate (kg/ha) GS 33	Total
V Late	25	0	135	45	180
Late	25	36	90	54	180
Medium	25	54	90	36	180
Early	25	72	108	0	180

Table 7.7 Application timings and N rate for N timing experiments at RM16.

Treatment	Rate (kg/ha) (6/10/15)	Rate (kg/ha) GS 25-29 (23/2/16)	Rate (kg/ha) GS30 (16/03/16)	Rate (kg/ha) GS31 (19/4/16)	Total
RB209	0	40	0	130	170
Medium	0	60	60	50	170
Early	0	110	60	0	170
Autumn	30	80	60	0	170

Table 7.8 Application timings and N rate for N timing experiments at HM16

Treatment	Rate (kg/ha) (30/9/15)	Rate (kg/ha) GS 25-29 (3/3/16)	Rate (kg/ha) GS30 (14/4/16)	Rate (kg/ha) GS31 (27/4/16)	Total
RB209	0	40	0	170	210
Medium	0	70	70	70	210
Early	0	130	80	0	210
Late	30	100	80	0	210

Table 7.9 Application timings and rate for N timing experiments at SAG16.

Treatment	Rate (kg/ha) (1/10/15)	Rate (kg/ha) GS 23-35 (7/3/16)	Rate (kg/ha) GS 30 (5/4/16)	Rate (kg/ha) GS 33 (28/4/16)	Total
V Late	25	0	135	45	180
Late	25	36	90	54	180
Medium	25	54	90	36	180
Early	25	72	108	0	180

Table 7.10 Yield (t/ha) and Nopt (kg/ha) for the HM14 N rate trial.

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Yield at Nopt
Cassia	2.99	6.08	7.40	8.43	7.60	6.81	6.55	164	8.03
Meridian	2.69	5.28	6.74	8.24	8.95	8.84	6.79	286	8.74
Venture	2.43	5.66	7.26	7.07	6.42	5.88	5.74	152	7.27
Volume	2.69	5.59	6.93	7.97	7.77	7.66	6.44	194	7.80
Halcyon	2.68	5.22	6.35	6.86	6.37	5.90	5.56	139	6.68
Maris Otter	2.61	4.95	5.91	6.09	5.47	4.64	4.95	158	6.05
Grand Total	2.68	5.46	6.76	7.44	7.14	6.67	6.01	182	7.00
	P	SED	LSD						
N rate	<.001	0.14	0.307						
Variety	<.001	0.09	0.181						
N rate x Variety	<.001	0.23	0.491						

Table 7.11 Grain N% for the HM14 N rate trial

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Grain N% at Nopt
Cassia	1.36	1.34	1.50	1.86	2.07	2.19	1.72	164	1.69
Meridian	1.23	1.25	1.48	1.88	2.15	2.25	1.71	286	2.16
Venture	1.29	1.20	1.53	1.76	2.11	2.36	1.71	152	1.58
Volume	1.32	1.25	1.48	1.87	2.12	2.26	1.72	194	1.84
Halcyon	1.34	1.23	1.47	1.88	2.19	2.31	1.74	139	1.57
Maris Otter	1.32	1.26	1.50	1.85	2.20	2.24	1.73	158	1.65
Grand Total	1.31	1.25	1.49	1.85	2.14	2.27	1.72	182	1.75
	P	SED	LSD						
N rate	<.001	0.04	0.088						
Variety	0.453	0.02	0.031						
N rate x Variety	<.001	0.05	0.108						

Table 7.12 Yield (t/ha) and Nopt (kg/ha) for the RM14 N rate trial.

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Yield at Nopt
Cassia	3.20	5.41	6.47	6.92	7.12	7.21	6.05	157	6.90
Meridian	4.66	7.26	8.34	8.62	8.32	7.31	7.42	157	8.26
Venture	3.72	5.83	6.60	6.83	6.56	6.92	6.03	157	6.91
Volume	4.72	7.59	8.18	8.26	8.02	7.73	7.36	157	8.29
Halcyon	3.30	5.18	6.16	7.10	7.01	6.50	5.87	157	6.72
Maris Otter	2.94	4.24	5.36	6.14	5.93	5.58	5.03	157	5.88
Grand Total	3.75	5.92	6.85	7.31	7.11	6.82	6.28	157	7.16
	P	SED	LSD						
N rate	<.001	0.52	1.156						
Variety	<.001	0.21	0.416						
N rate x Variety	0.255	0.70	1.423						

Table 7.13 Grain N% for the RM14 N rate trial

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Grain N% at Nopt
Cassia	1.17	1.35	1.66	2.20	2.38	2.54	1.88	157	1.92
Meridian	1.10	1.34	1.65	2.13	2.25	2.44	1.82	157	1.88
Venture	1.16	1.33	1.65	2.09	2.47	2.45	1.86	157	1.89
Volume	1.20	1.44	1.63	2.17	2.45	2.58	1.91	157	1.91
Halcyon	1.25	1.43	1.71	2.25	2.46	2.65	1.96	157	1.97
Maris Otter	1.20	1.45	1.73	2.14	2.40	2.84	1.96	157	1.90
Grand Total	1.18	1.39	1.67	2.16	2.40	2.58	1.90	157	1.91
	P	SED	LSD						
N rate	<.001	0.05	1.051						
Variety	0.003	0.04	0.081						
N rate x Variety	0.718	0.10	0.203						

Table 7.14 Yield (t/ha) and Nopt (kg/ha) for the SAG14 N rate trial.

	N rate (kg/ha)								
Variety	0	70	140	210	280	350	Grand Mean	Nopt	Yield at Nopt
Cassia	4.93	8.91	10.74	11.77	9.70	7.63	9.15	153	11.20
Meridian	4.76	9.02	11.40	11.95	12.28	12.52	10.06	235	12.34
Venture	5.35	9.12	10.91	11.36	8.86	11.86	9.75	193	11.04
Volume	4.36	9.09	11.28	11.86	10.79	10.37	9.51	181	11.67
Grand Total	4.79	9.04	11.11	11.73	10.41	10.59	9.63	191	11.56
	P	SED	LSD						
N rate	<.001	0.25	0.505						
Variety	<.001	0.20	0.412						
N rate x Variety	<.001	0.50	1.009						

Table 7.15 Grain N% for the N rate trial at SAG14.

	N rate (kg/ha)								
Variety	0	70	140	210	280	350	Grand Mean	Nopt	Grain N% at Nopt
Cassia	1.36	1.28	1.48	1.77	1.92	2.06	1.65	153	1.53
Meridian	1.40	1.36	1.48	1.65	1.88	1.99	1.63	235	1.74
Venture	1.42	1.33	1.51	1.71	1.93	2.07	1.66	193	1.66
Volume	1.38	1.38	1.62	1.85	1.98	2.07	1.71	181	1.75
Grand Total	1.18	1.39	1.67	2.16	2.40	2.58	1.90	191	1.67
	P	SED	LSD						
N rate	<.001	0.03	0.056						
Variety	0.004	0.02	0.046						
N rate x Variety	0.315	0.06	0.112						

Table 7.16 Yield (t/ha) and Nopt (kg/ha) for the HM15 N rate trial.

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Yield at Nopt
Cassia	4.73	6.91	8.23	9.07	9.19	9.14	7.88	209	9.09
Meridian	4.73	8.10	8.40	9.25	10.00	10.47	8.71	302	10.16
Venture	4.61	6.78	8.31	9.07	9.31	9.04	7.78	207	9.13
Volume	5.28	7.24	8.69	8.89	8.74	8.72	7.93	178	8.92
Pastoral	4.45	6.37	7.70	8.81	8.51	8.61	7.41	205	8.56
Maris Otter	3.72	5.50	6.74	7.37	7.06	6.41	6.13	165	7.13
Grand Total	4.58	6.82	8.01	8.74	8.80	8.71	7.63	211	9.00
	P	SED	LSD						
N rate	<.001	0.24	0.525						
Variety	<.001	0.15	0.301						
N rate x Variety	<.001	0.41	0.823						

Table 7.17 Grain N% for the HM15 N rate trial

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Grain N% at Nopt
Cassia	1.28	1.32	1.47	1.81	2.14	2.44	1.74	209	1.83
Meridian	1.26	1.27	1.43	1.81	2.17	2.38	1.74	302	2.24
Venture	1.23	1.26	1.50	1.81	2.09	2.44	1.72	207	1.81
Volume	1.23	1.26	1.51	1.82	2.19	2.46	1.75	178	1.73
Pastoral	1.32	1.37	1.65	2.06	2.40	2.66	1.91	205	2.07
Maris Otter	1.32	1.37	1.56	1.94	2.33	2.68	1.87	1.32	1.37
Grand Total	1.27	1.31	1.52	1.87	2.22	2.51	1.79	211	1.91
	P	SED	LSD						
N rate	<.001	0.03	0.057						
Variety	<.001	0.02	0.035						
N rate x Variety	0.006	0.05	0.094						

Table 7.18 Yield (t/ha) and Nopt (kg/ha) for the RM15 N rate trial.

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Yield at Nopt
Cassia	6.47	8.31	10.10	10.80	11.34	10.93	9.56	221	11.00
Meridian	6.68	8.77	10.52	11.36	11.74	12.29	10.17	265	11.91
Venture	6.60	8.80	10.71	11.28	11.49	11.84	10.13	240	11.56
Volume	7.73	9.86	11.44	12.56	12.30	12.98	11.33	235	12.56
Pastoral	5.83	8.07	9.46	10.48	10.72	11.01	8.84	242	10.77
Maris Otter	5.66	7.49	8.85	9.57	9.17	8.12	8.14	166	9.31
Grand Total	6.42	8.43	10.03	10.99	11.17	11.09	9.63	228	11.0
	P	SED	LSD						
N rate	<.001	0.31	0.682						
Variety	<.001	0.15	0.300						
N rate x Variety	<.001	0.45	0.917						

Table 7.19 Grain N% for the RM15 N rate trial

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Grain N% at Nopt
Cassia	1.28	1.32	1.47	1.81	2.14	2.44	1.74	221	1.96
Meridian	1.26	1.27	1.43	1.81	2.17	2.38	1.74	265	2.04
Venture	1.23	1.26	1.50	1.81	2.09	2.44	1.72	240	2.10
Volume	1.23	1.26	1.51	1.82	2.19	2.46	1.75	235	1.96
Pastoral	1.32	1.37	1.65	2.06	2.40	2.66	1.91	242	2.30
Maris Otter	1.32	1.37	1.56	1.94	2.33	2.68	1.87	166	1.88
Grand Total	1.27	1.31	1.52	1.87	2.22	2.51	1.79	228	2.04
	P	SED	LSD						
N rate	<.001	0.06	0.124						
Variety	<.001	0.05	0.090						
N rate x Variety	0.006	0.11	0.229						

Table 7.20 Yield (t/ha) and Nopt (kg/ha) for the HM16 N rate trial.

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Yield at Nopt
Cassia	2.53	5.05	6.45	7.38	8.00	8.22	6.27	221	7.12
Meridian	1.73	4.45	5.95	7.30	7.57	7.71	5.79	251	7.45
Venture	2.55	4.65	5.62	6.06	6.61	6.44	5.32	194	6.22
Volume	2.45	4.86	6.18	6.96	7.30	7.33	5.85	216	7.07
Pastoral	2.21	4.58	5.62	6.17	6.37	6.59	5.26	198	6.26
Maris Otter	1.69	3.48	4.42	5.25	5.26	5.23	4.22	187	5.04
Grand Total	2.19	4.51	5.71	6.52	6.85	6.92	5.45	211	7
	P	SED	LSD						
N rate	<.001	0.18	0.394						
Variety	<.001	0.08	0.162						
N rate x Variety	0.059	0.25	0.514						

Table 7.21 Grain N% for the HM16 N rate trial

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Grain N% at Nopt
Cassia	1.46	1.31	1.44	1.78	2.03	2.19	1.70	221	1.86
Meridian	1.47	1.29	1.45	1.73	1.97	2.29	1.70	251	1.91
Venture	1.40	1.25	1.37	1.69	1.92	2.11	1.62	194	1.64
Volume	1.46	1.26	1.40	1.76	2.05	2.29	1.70	216	1.81
Pastoral	1.51	1.35	1.55	1.89	2.13	2.34	1.80	198	1.87
Maris Otter	1.54	1.39	1.54	1.88	2.22	2.34	1.82	187	1.83
Grand Total	1.47	1.31	1.46	1.79	2.05	2.26	1.72	211	2.04
	P	SED	LSD						
N rate	<.001	0.03	0.076						
Variety	<.001	0.02	0.039						
N rate x Variety	0.295	0.06	0.112						

Table 7.22 Yield (t/ha) and Nopt (kg/ha) for the RM16 N rate trial.

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Yield at Nopt
Cassia	6.59	8.75	10.55	10.40	9.16	8.97	9.07	113	10.10
Meridian	6.34	8.89	10.23	10.09	8.55	8.79	8.82	110	9.90
Venture	6.32	8.63	8.89	7.42	7.93	5.78	7.50	83	8.76
Volume	6.56	9.31	9.91	10.39	9.49	9.75	9.23	122	10.04
Pastoral	6.11	8.25	8.97	8.17	6.84	7.85	7.67	94	8.49
Maris Otter	4.81	6.86	7.51	5.72	5.11	4.60	5.77	79	7.01
Grand Total	6.12	8.46	9.34	8.70	7.85	7.62	8.01	100	9.00
	P	SED	LSD						
N rate	<.001	0.35	0.780						
Variety	<.001	0.20	0.39						
N rate x Variety	<.001	0.56	1.127						

Table 7.23 Grain N% for the RM16 N rate trial

	N rate (kg/ha)								
Variety	0	60	120	200	280	360	Grand Mean	Nopt	Grain N% at Nopt
Cassia	1.31	1.48	1.64	2.00	2.08	2.33	1.72	113	1.65
Meridian	1.32	1.45	1.70	2.00	2.16	2.36	1.71	110	1.66
Venture	1.25	1.39	1.65	1.95	2.17	2.12	1.71	83	1.48
Volume	1.36	1.59	1.68	2.04	2.20	2.41	1.72	122	1.75
Pastoral	1.38	1.50	1.76	2.08	2.38	2.40	1.74	94	1.63
Maris Otter	1.49	1.59	1.83	2.26	2.50	2.37	1.73	79	1.64
Grand Total	1.31	1.25	1.49	1.85	2.14	2.27	1.72	100	1.64
	P	SED	LSD						
N rate	<.001	0.06	0.130						
Variety	<.001	0.05	0.104						
N rate x Variety	0.972	0.13	0.259						

Table 7.24 Straw biomass (t/ha) for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	4.20	4.72	4.82	5.08	4.70
Meridian	4.41	5.19	6.02	5.50	5.26
Venture	3.93	4.38	4.55	4.20	4.26
Volume	3.49	4.29	4.91	4.92	4.44
Grand Total	4.06	4.67	5.07	4.87	4.67
	P	SED	LSD		
Timing	0.013	0.13	0.261		
Variety	<.001	0.13	0.261		
Timing x Variety	0.109	0.26	0.522		

Table 7.25 Straw biomass (t/ha) for the RM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	5.70	5.53	6.40	5.87	5.88
Meridian	5.14	5.05	5.91	4.63	5.18
Venture	5.90	5.39	5.42	5.38	5.52
Volume	5.08	5.74	6.26	6.13	5.80
Grand Total	5.46	5.43	6.00	5.50	5.60
	P	SED	LSD		
Timing	0.431	0.37	0.901		
Variety	0.160	0.33	0.672		
Timing x Variety	0.658	0.67	1.379		

Table 7.26 Total N uptake (kg N/ha) for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	144	146	146	131	142
Meridian	152	140	155	131	146
Venture	137	132	133	115	129
Volume	141	135	132	120	132
Grand Total	145	150	153	137	146
	P	SED	LSD		
Timing	0.138	7	17.7		
Variety	<.001	3	6.5		
Timing x Variety	0.709	9	19.5		

Table 7.27 Total N uptake (kg N/ha) for the RM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	214	202	211	222	212
Meridian	202	185	222	205	203
Venture	199	214	201	209	206
Volume	203	214	187	203	202
Grand Total	204	204	205	210	206
	P	SED	LSD		
Timing	0.951	11	27.5		
Variety	0.713	10	20.0		
Timing x Variety	0.622	20	41.4		

Table 7.28 Lodging Index at harvest for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	40.3	35.6	36.4	31.1	35.8
Meridian	33.9	33.9	29.4	27.5	31.2
Venture	41.7	38.1	40.0	30.6	37.6
Volume	39.7	42.5	40.3	26.1	37.2
Grand Total	38.9	37.5	36.5	28.8	35.4
	P	SED	LSD		
Timing	0.064	3.1	7.63		
Variety	0.006	1.8	3.69		
Timing x Variety	0.350	4.4	9.20		

Table 7.29 Lodging Index at harvest for the RM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	7.22	5.00	5.56	6.67	6.11
Meridian	6.67	6.67	3.89	6.11	5.83
Venture	5.56	5.83	5.00	2.22	4.65
Volume	2.22	4.44	6.39	3.33	4.10
Grand Total	5.42	5.49	5.21	4.58	5.17
	P	SED	LSD		
Timing	0.955	1.80	4.403		
Variety	0.620	1.74	3.598		
Timing x Variety	0.900	3.52	7.187		

Table 7.30 Straw biomass (t/ha) for the HM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	4.28	5.06	4.08	5.02	4.57
Meridian	4.02	4.38	4.43	4.65	4.37
Venture	4.61	4.11	4.01	5.16	3.59
Volume	3.29	3.35	3.85	3.89	4.47
Grand Total	4.05	4.13	4.09	4.68	4.24
	P	SED	LSD		
Timing	0.28	0.37	0.903		
Variety	0.016	0.32	0.671		
Timing x Variety	0.781	0.67	1.378		

Table 7.31 Straw biomass (t/ha) for the RM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	10.47	7.77	7.89	7.06	8.30
Meridian	6.60	7.38	7.55	6.86	7.10
Venture	7.02	7.99	7.96	7.01	7.50
Volume	6.79	7.77	7.55	6.83	7.23
Grand Total	7.72	7.73	7.74	6.94	7.53
	P	SED	LSD		
Timing	0.894	1.26	3.075		
Variety	0.327	0.69	1.423		
Timing x Variety	0.599	1.73	3.641		

Table 7.32 Total N uptake (kg N/ha) for the HM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	209	231	184	219	208
Meridian	188	205	184	184	189
Venture	215	181	185	189	194
Volume	178	178	191	173	180
Grand Total	198	196	186	189	192
	P	SED	LSD		
Timing	0.746	18	42.8		
Variety	0.025	9	19.6		
Timing x Variety	0.657	24	50.3		

Table 7.33 Total N uptake (kg N/ha) for the RM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	287	261	262	241	263
Meridian	234	244	254	229	241
Venture	252	261	260	233	251
Volume	258	236	258	233	246
Grand Total	258	251	259	234	250
	P	SED	LSD		
Timing	0.018	6	14.2		
Variety	0.019	67	13.8		
Timing x Variety	0.361	13	26.5		

Table 7.34 Lodging Index at harvest for the HM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	0.83	4.17	5.50	0.83	2.83
Meridian	6.67	5.00	1.67	11.67	6.25
Venture	0.33	1.67	1.67	0.50	1.04
Volume	3.61	3.06	2.50	5.83	3.75
Grand Total	2.86	3.47	2.83	4.71	3.47
	P	SED	LSD		
Timing	0.578	1.47	3.591		
Variety	0.014	1.47	3.040		
Timing x Variety	0.136	2.94	6.014		

Table 7.35 Lodging Index at harvest for the RM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	4.44	4.44	5.00	4.44	4.58
Meridian	5.00	4.44	4.44	4.44	4.58
Venture	5.56	5.00	4.44	5.00	5.00
Volume	5.00	4.44	5.56	4.44	4.86
Grand Total	5.00	4.58	4.86	4.58	4.76
	P	SED	LSD		
Timing	0.901	0.68	1.665		
Variety	0.576	0.36	0.740		
Timing x Variety	0.778	0.92	1.942		

Table 7.36 Straw biomass (t/ha) for the HM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	4.11	4.50	4.83	5.05	4.62
Meridian	4.26	5.49	4.89	5.07	4.93
Venture	3.39	4.19	4.45	4.02	4.07
Volume	3.63	4.69	4.41	4.71	4.32
Grand Total	3.89	4.72	4.67	4.71	4.50
	P	SED	LSD		
Timing	0.004	0.16	0.390		
Variety	<0.001	0.15	0.310		
Timing x Variety	0.353	0.31	0.630		

Table 7.37 Straw biomass (t/ha) for the RM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	5.45	6.10	5.41	5.26	5.55
Meridian	4.73	5.36	5.42	5.73	5.31
Venture	4.45	5.49	5.23	5.00	5.04
Volume	4.91	6.09	5.20	5.36	5.39
Grand Total	4.88	5.76	5.31	5.34	5.32
	P	SED	LSD		
Timing	0.188	0.34	0.830		
Variety	0.494	0.33	0.686		
Timing x Variety	0.933	0.67	1.367		

Table 7.38 Total N uptake (kg N/ha) for the HM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	156	149	147	144	149
Meridian	151	170	146	138	151
Venture	133	129	126	113	124
Volume	146	151	141	132	144
Grand Total	148	150	140	132	142
	P	SED	LSD		
Timing	0.010	4	8.7		
Variety	<.001	4	8.4		
Timing x Variety	0.416	8	16.1		

Table 7.39 Total N uptake (kg N/ha) for the RM15 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	191	213	196	171	193
Meridian	181	206	200	195	196
Venture	168	203	177	161	177
Volume	183	221	200	189	198
Grand Total	181	211	194	179	191
	P	SED	LSD		
Timing	0.014	7	17.6		
Variety	0.079	8	17.3		
Timing x Variety	0.92	16	33.1		

Table 7.40 Brackling (%) at harvest for the HM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	85.0	90.0	81.7	90.0	86.7
Meridian	86.7	88.3	86.7	90.0	87.9
Venture	96.5	97.0	96.0	97.0	96.6
Volume	91.0	96.0	90.0	82.5	90.6
Grand Total	89.2	92.8	88.5	90.5	90.3
	P	SED	LSD		
Timing	0.082	1.3	3.29		
Variety	0.013	2.9	6.05		
Timing x Variety	0.748	5.2	10.77		

Table 7.41 Lodging Index at harvest for the RM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	6.1	5.0	0.6	2.2	3.5
Meridian	2.8	6.9	0.6	0.0	2.6
Venture	6.7	12.8	5.6	2.2	6.8
Volume	1.7	5.6	1.7	1.1	2.5
Grand Total	4.3	7.6	2.1	1.4	3.8
	P	SED	LSD		
Timing	0.018	1.4	3.50		
Variety	0.033	1.6	3.20		
Timing x Variety	0.76	3.0	6.21		

Table 7.42 Height (cm) at GS85 for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	84.3	95.0	97	96	93.1
Meridian	114.0	127.7	128.7	132.3	125.7
Venture	93.3	95.7	103.0	96.3	97.1
Volume	101.0	114.0	118.3	118.0	112.9
Grand Total	98.1	108.2	111.8	110.7	107.2
	P	SED	LSD		
Timing	<.001	0.6	1.50		
Variety	<.001	1.3	2.63		
Timing x Variety	0.015	2.9	4.70		

Table 7.43 Light Interception at GS37 for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	86.6	97.9	99.1	98.6	95.6
Meridian	80.4	96.4	98.3	97.4	93.1
Venture	89.5	96.2	97.2	97.4	95.5
Volume	86.0	96.6	98.9	97.3	94.7
Grand Total	85.6	96.8	98.8	97.7	94.1
	P	SED	LSD		
Timing	0.009	2.7	6.63		
Variety	0.194	1.2	2.52		
Timing x Variety	0.354	3.4	7.36		

Table 7.44 Light Interception at GS57 for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	91.0	97.8	99.0	98.7	96.6
Meridian	89.3	97.3	98.4	97.6	96.6
Venture	90.4	98.1	99.1	98.3	96.5
Volume	91.0	97.8	98.2	98.5	96.3
Grand Total	90.4	97.7	98.7	98.3	96.3
	P	SED	LSD		
Timing	<.001	0.6	1.43		
Variety	0.05	0.4	0.76		
Timing x Variety	0.828	0.9	1.80		

Table 7.45 Green Leaf Area (%) of the shoots at GS87 for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	94.4	90.0	94	86.1	90.9
Meridian	84.4	75.0	83.3	66.7	79.6
Venture	87.8	84.4	76.4	77.2	81.4
Volume	89.4	89.1	90.3	76.7	86.5
Grand Total	91.3	84.5	85.9	76.7	84.6
	P	SED	LSD		
Timing	0.003	2.1	5.09		
Variety	<.001	2.6	5.38		
Timing x Variety	0.105	5.0	10.15		

Table 7.46 Green Leaf Area (%) of the flag leaf at GS87 for the HM14 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	92.6	81.8	82.8	76.7	83.4
Meridian	88.1	72.2	72.2	63.9	74.1
Venture	87.2	71.7	65.0	68.3	73.1
Volume	81.2	75.1	73.7	66.1	74.0
Grand Total	87.3	75.2	73.4	68.8	76.2
	P	SED	LSD		
Timing	0.003	2.7	6.69		
Variety	0.008	3.1	6.40		
Timing x Variety	0.813	6.0	12.31		

Table 7.47 GAI, shoots/m^2, dry weight (t/ha) for the HM14 N timing trial.

		22/04/2014 (GS 31)			14/05/2014 (GS 41-59)					10/06/2014 (GS 71-73)				
N Timing	Variety	GAI	Shoots/ m2	Total DW t/ha	GAI	Shoots /m2	Live Shoots/m 2	Dead Shoots/ m2	Total DW t/ha	GAI	Shoots/ m2	Live Shoots/m2	Dead Shoots/m2	Total DW t/ha
RB209	Volume	1.50	702	1.43	4.03	786	765	21	4.98	5.16	700	617	83	11.3
Medium	Volume	2.00	905	1.64	6.03	804	657	147	6.94	5.65	628	513	115	11.7
Early	Volume	2.95	1095	2.27	6.81	835	661	173	7.45	5.30	631	560	172	13.1
Autumn	Volume	2.64	964	2.17	6.21	1052	773	280	7.2	4.85	569	395	174	11.5
RB209	Cassia	1.86	1083	1.79	4.52	1179	1117	61	5.66	6.52	1391	1329	62	11.0
Medium	Cassia	2.11	932	1.84	6.04	1065	975	90	7.08	6.01	890	823	67	11.8
Early	Cassia	3.01	1335	2.24	6.90	1166	1027	138	7.33	6.01	963	869	95	12.0
Autumn	Cassia	3.14	1167	2.55	6.56	1190	1005	185	7.33	6.35	1088	968	120	13.2
N Timing	P Value	0.011	0.086	0.086	0.045	0.348	0.702	0.077	0.136	0.899	0.089	0.004	0.604	0.219
	SED	0.296	111.4	0.234	0.71	97.2	110.4	57.7	0.825	0.397	96.7	55.7	61.16	0.634
	LSD	0.725	272.6	0.5726	1.738	237.9	270.1	141.2	2.018	0.97	236.6	136.3	149.66	1.551
Variety	P Value	0.157	0.049	0.049	0.411	<0.001	<0.001	0.25	0.519	0.013	<.001	<.001	0.01	0.88
	SED	0.163	91.7	0.125	0.274	50.7	55.2	29.6	0.309	0.308	71.6	62.5	15.08	0.728
	LSD	0.376	211.4	0.2874	0.632	116.9	127.3	68.1	7.12	0.71	165.1	144.2	34.77	1.679
N Timing x Variety	P Value	0.75	0.616	0.616	0.916	0.379	0.825	0.471	0.827	0.541	0.22	0.19	0.637	0.598
	SED	0.36	171	0.29	0.81	121	135	71	0.93	0.59	140	105	65	1.21
	LSD	0.817	366.7	0.639	1.816	263.9	296.4	155.9	2.100	1.263	330.1	226.0	151.3	2.618

Table 7.48 Height (cm) at GS65 for the HM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	96.3	101.2	103.2	99.2	100.0
Meridian	109.9	118.4	122.1	119.2	117.4
Venture	93.3	96.3	98.6	93.8	95.5
Volume	110.2	114.9	117.9	116.9	115.0
Grand Total	102.4	107.7	110.5	107.3	107.0
	P	SED	LSD		
Timing	0.022	1.8	4.37		
Variety	<.001	0.7	1.47		
Timing x Variety	0.013	2.2	4.72		

Table 7.49 Height (cm) at GS65 for the RM16 N timing trial.

	Timing				
Variety	RB209	Medium	Early	Autumn	Grand Mean
Cassia	90.5	104.1	98.6	98.9	98.0
Meridian	94.1	105.4	98.6	96.7	98.7
Venture	92.4	102.5	102.6	98.1	98.9
Volume	106.7	118.3	115.6	115.8	114.1
Grand Total	95.9	107.6	103.9	102.4	102.4
	P	SED	LSD		
Timing	0.007	2.0	5.00		
Variety	<0.001	1.7	3.55		
Timing x Variety	0.832	3.6	7.42		

Table 7.50 Height (cm) at GS65 for the SAG16 N timing trial.

	Timing				
Variety	V.Late	Late	Medium	Early	Grand Mean
Cassia	70.0	71.7	78.3	75.0	73.8
Meridian	100.0	100.0	106.7	108.3	103.8
Venture	66.7	73.3	78.3	76.7	73.8
Volume	88.3	91.7	95.0	93.3	92.1
Grand Total	81.3	84.2	89.6	88.3	85.8
	P	SED	LSD		
Timing	0.011	2.6	5.28		
Variety	<.001	2.6	5.28		
Timing x Variety	0.989	5.2	10.57		

Table 7.51 Ears/m^2 at GS65 for the SAG16 N timing trial.

	Timing				
Variety	V.Late	Late	Medium	Early	Grand Mean
Cassia	657	661	660	680	665
Meridian	478	489	492	579	502
Venture	659	623	558	645	621
Volume	483	427	438	465	453
Grand Total	569	542	537	592	560
	P	SED	LSD		
Timing	0.177	27	55.8		
Variety	<.001	27	55.8		
Timing x Variety	0.739	55	111.7		