



Response of two-row and six-row barley to fertiliser N under Irish conditions

R. Hackett[†]

Teagasc, Crops Research Centre, Oak Park, Carlow, Ireland

Abstract

A range of cultivar types, including two-row and six-row types as well as line and hybrid types, are used for winter barley production in Ireland. There is little information available on the fertiliser nitrogen (N) requirements or the N use efficiency of these different types, particularly under Irish conditions. The objectives of the work presented here were to compare the response to fertiliser N of a two-row line cultivar, a six-row line cultivar and a six-row hybrid cultivar in terms of grain yield and aspects of N use efficiency. Experiments were carried out over three growing seasons, in the period 2012–2014, on a light-textured soil comparing the response of the three cultivars of winter barley to fertiliser N application rates ranging from 0 to 260 kg N/ha. There was no evidence that cultivar type, regardless of whether it was a two-row or six-row line cultivar or a six-row hybrid cultivar, influenced the response to fertiliser N of winter barley. There were some indications that six-row cultivars were less efficient at recovering soil N but used accumulated N more efficiently than the two-row cultivar. This work provided no evidence to support adjustment of fertiliser N inputs to winter barley based on cultivar type.

Keywords

fertiliser N • N accumulation • six-row barley • two-row barley • yield

Introduction

There is renewed interest in the production of winter barley in recent years in Ireland and the area used to produce winter barley has increased accordingly (CSO, 2015). This can be attributed to a number of factors, including improved grain yields as a result of the introduction of new cultivars. Grain yield is also perceived as being more stable between seasons compared to other crops, particularly, winter wheat.

Barley can have two ear structures. In six-row barley, the three spikelets at each node on the rachis are fertile; whereas in two-row barley, only the central spikelet is fertile. In addition to an increase in the area of winter barley in Ireland, there is renewed interest in the cultivation of six-row types. Six-row barley has the potential to outyield two-row barley, particularly under high-input conditions, provided lodging can be prevented (Maidl *et al.*, 1996; Le Gouis *et al.*, 1999; Anon., 2015).

Apart from differentiation of barley cultivars based on ear structure, cultivars can be differentiated based on the breeding method used in their development. To date, the majority of cultivars of winter barley used in Ireland have been line cultivars. However, the commercial production of F1 hybrid barley is becoming more common (Longin *et al.*, 2012). Hybrid cultivars, which are currently all six-row types, have a number of potential advantages over line cultivars, including higher yield due to heterosis and greater yield stability across environments (Longin *et al.*, 2012; Mühleisen *et al.*, 2014).

Evaluating a range of line cultivars, hybrids and their parents across sites in a number of European countries, Mühleisen *et al.* (2013) indicated that hybrids displayed, on average, 11.3% mid-parent heterosis for yield and heterosis of 2.7% relative to the best line cultivar, indicating the potential of hybrid cultivars. The authors also indicated that hybrids may exhibit more stable yield than line cultivars when compared across environments. However, it is not clear how hybrid cultivars compare to line cultivars in terms of N requirements or N use efficiency.

Fertiliser N recommendations in Ireland for winter barley are determined using previous cropping history of the site and an indication of expected yield (Coulter and Lalor, 2008). Recommendations are largely based on data collected in the 1970s and 1980s (e.g., Conry, 1991), and it is not clear whether these recommendations are still valid for modern crops. In the current system, no direct account is taken of cultivar type when deciding on fertiliser N inputs.

Recent research on the response of winter barley to fertiliser N, particularly under Irish conditions, has been limited. In particular, there has been little work comparing the response of the different cultivar types to fertiliser N. Earlier work, both in Ireland and abroad, would indicate that there is often no difference in the response to N between two-row and six-row types. In a series of experiments over a number of years in the 1970s and 1980s in Ireland, Conry (1991) reported that a six-row cultivar responded in a similar way to a two-row cultivar to increasing

[†]Corresponding author: Richie Hackett

E-mail: Richie.Hackett@teagasc.ie

levels of fertiliser N. Under German conditions, Becker *et al.* (1984) found no difference between six-row and two-row cultivars in terms of response to N application rate, whereas Maidl *et al.* (1996) reported that a six-row cultivar reached maximum yield at a lower application rate of fertiliser N than a two-row cultivar. Charles *et al.* (2012) found no difference in the response of a two-row and six-row cultivar under Swiss conditions. There appear to be no recent comparisons of the response to fertiliser N of hybrid and line cultivars of winter barley under Irish conditions; therefore, it is not clear whether fertiliser N recommendations should vary based on cultivar type.

The objectives of the work presented here were to compare the response to fertiliser N of a two-row line cultivar, a six-row line cultivar and a six-row hybrid cultivar in terms of grain yield and aspects of N use efficiency.

Materials and methods

A field experiment was established with winter barley in each of three growing seasons, in the period 2012–2014, at the Teagasc, Crops Research Centre, Carlow, Ireland (52.86° N, 6.92° W, 54 m a.m.s.l.). The soil was of the Athy Complex, shallow component, which is a Eutric Cambisol with stony or gravelly coarse sandy loam texture and low moisture-holding capacity (Conry and Ryan, 1967). In each case, the site had been in tillage for at least 20 years, and the previous crop was a cereal.

A split-plot experimental design was used with four replications in the 2012 growing season and five replications in the remaining two seasons. Main plot factor was cultivar. Three cultivars were included: KWS Cassia, a two-row type; Leibniz, a six-row type; and Volume, a six-row hybrid type. The split-plot plot factor was N application rate (0, 100, 140, 180, 220 and 260 kg N/ha). N application rates were chosen to give a range of suboptimal and supra-optimal N application rates taking into account mean fertiliser N input to winter barley on commercial farms of 163 kg N/ha (Lalor *et al.*, 2010). Plot size was 12 m × 2.2 m.

Crops were sown in early October and received standard inputs of pesticides to control weeds, diseases and pests. Nutrients other than N were applied uniformly over the experimental area at rates equal to or higher than the standard recommendations for winter barley (Coulter and Lalor, 2008). Fertiliser N treatments were applied with a carefully calibrated mechanical spreader (Fiona Maskinfabrik A/S, Bogense, Denmark) as calcium ammonium nitrate. The total allocation of fertiliser N was applied in two applications. The first application comprising 33% of the total was applied in early March when the crop was at the late tillering stage, and the second, comprising 67% of the total, was applied in late

March/early April when the crop was at growth stage 30/31. At crop maturity, just prior to combine harvest, grab samples were taken from at least five random locations in each plot. Fifty ears were selected at random from these samples and were threshed to separate grain and straw, and both fractions were dried at 70°C for 48 h. Thousand-grain weight (TGW) was determined for each sample using an electronic grain counter (Contador; Pfeuffer, Kitzingen, Germany) and expressed at 85% dry matter (DM). The mean number of grains per ear was calculated by dividing the total number of grains in each sample by 50. Ear population (ears/m²) was estimated by dividing combine grain yields by the product of the number of grains per ear and mean grain weight (g).

Grain yield (adjusted to 85% DM) was determined using a small plot combine harvester. Grain protein content was determined, using representative samples taken during combine harvest, with a whole grain analyser (Infratec™ 1241 grain analyser; Foss Tecator AB, Hoganas, Sweden). Grain N uptake was determined as the product of grain yield and grain N concentration (calculated from grain protein content using a conversion factor of 6.25). Crop N uptake was calculated as the sum of grain N uptake and straw N uptake. The N concentration of the straw component, after milling through a 2 mm sieve, was determined using the Dumas combustion method (Leco FP428; Leco Corp., St. Joseph, MI, USA). Straw N uptake was calculated as the product of straw N concentration and straw DM yield.

Efficiency ratios of fertiliser N use for treatments receiving fertiliser N were calculated according to Lada *et al.* (2005).

$$\text{Recovery efficiency of N (RE}_N\text{)} = (U_F - U_0) / F_N$$

$$\text{Agronomic efficiency of N (AE}_N\text{)} = (Y_F - Y_0) / F_N$$

$$\text{Physiological efficiency of N (PE}_N\text{)} = (Y_F - Y_0) / (U_F - U_0)$$

where U_F and U_0 are total N accumulation (kg N/ha) and Y_F and Y_0 are the grain yield (kg DM/ha) in the fertilised and unfertilised treatments, respectively, and F_N is the application rate (kg N/ha) of fertiliser N.

Efficiency of N (fertiliser + soil-derived N) for all N application rates was calculated as follows:

$$\text{Nitrogen use efficiency (NUE)} = Y/U$$

where U is total N accumulation (kg N/ha) and Y is grain yield (kg DM/ha) for a given N application rate.

Combined analysis of variance over the three years was carried out for grain yield, protein N uptake and N efficiency ratio data. Cultivar, N application rate and year were included as fixed effects; replication and replication × cultivar were included as the random effects. When significant effects of year or cultivar were found, least-squares means were separated by independent pairwise *t*-tests. All mean comparisons were

adjusted as appropriate for multiplicity effects using Tukey adjustments for the *P*-values.

When significant effects of N application rate or its interactions with other treatment factors were detected, regression analysis, using N application rate as a quantitative factor, was carried out. Linear, quadratic and, in the case of protein content, cubic effects and their interactions with the other treatment factors were sequentially tested. Only significant effects were retained in the final model. The resulting linear, quadratic and cubic regression equations were of the following form:

$$Y = a + bx \text{ linear}$$

$$Y = a + bx + cx^2 \text{ quadratic}$$

$$Y = a + bx + cx^2 + dx^3 \text{ cubic}$$

where *Y* is the predicted grain yield (t/ha), N uptake (kg N/ha) or efficiency ratio; *x* is the N fertiliser application rate (kg N/ha); and the parameters *a* (intercept), *b* (linear coefficient), *c* (quadratic coefficient) and *d* (cubic coefficient) include all adjustments for the other factors.

All the analyses were carried out using the MIXED procedure of SAS 9.3, with $\alpha = 0.05$ (SAS Institute Inc., 2011). Correlation analysis was carried out to identify relationships between yield components (ear population, grains per ear or individual grain weight) and grain yield using the CORR procedure of SAS 9.3.

Results

A significant year effect was detected for many of the variables measured. Significant interactions between year and both N application rate and cultivar were also detected for many of the variables measured. However, as the main objective of the work was to determine differences in the effect of fertiliser N on the three different cultivar types, year effects are only presented where necessary to describe cultivar differences.

Yield and yield components

Grain yield increased in response to fertiliser N addition for all three cultivars in all three seasons (Figure 1). A significant interaction between cultivar and N application rate indicated differences between cultivars in their response to the different levels of N. However, this interaction was largely as a result of a higher yield obtained with the cultivar Volume in areas where 100 kg N/ha was applied, compared to both Cassia (0.3 t/ha higher) and Leibniz (0.5 t/ha higher); there was no significant difference among the cultivars at any other level of fertiliser N. When the responses to fertiliser N for each cultivar were modelled, the intercepts, as well as both the linear and quadratic coefficients, did not differ significantly between cultivars when averaged over seasons. When individual years were examined, there was also no difference between

cultivars in their response to N; similar linear and quadratic coefficients were obtained for the three cultivars within each season. Comparing between years, there were no significant differences between the mean yield of the three cultivars in 2012 or 2013, but in 2014, Cassia had a significantly higher yield than Leibniz (0.62 t/ha greater) but not relative to Volume. Ear population for Cassia was significantly higher than that of Leibniz and Volume, typically being 1.7–2.2 times higher (Figure 1). Ear population increased in response to fertiliser N, but the response was influenced by cultivar. There was a greater increase in ear population when 100 kg N/ha was applied to Cassia, than the corresponding increase for Leibniz or Volume. Ear population continued to increase with fertiliser N addition, although not for each 40 kg N/ha increment, for all three cultivars; however, these increases were lower for Volume and Leibniz when compared to Cassia. While a significant effect of year on the response in terms of ear population of the cultivars to N was detected, this was largely due to a lower response in the ear population for Cassia to fertiliser N application rates in excess of 100 kg N/ha in 2012 compared to the other two seasons. Correlation analysis indicated that, averaged over years, ear population was the yield component most closely correlated with yield ($r = 0.88$, 0.80 and 0.91 for Cassia, Leibniz and Volume, respectively, averaged over years; Table 1). When the correlation analysis was carried out with the unfertilised treatment excluded, *r* decreased to 0.55 , 0.64 and 0.55 for Cassia, Leibniz and Volume, respectively.

The number of grains per ear was significantly lower for Cassia than either Volume or Leibniz at all N application rates (Figure 1). Grains per ear increased significantly for all cultivars with the addition of 100 kg N/ha, but, averaged over seasons, further increases in fertiliser N caused only small changes in the number of grains per ear, particularly for both six-row types, in which there was no significant increase in grains per ear above 100 kg N/ha. While there was a significant effect of year on the response of grains per ear to fertiliser N application rate, this was largely due to a positive effect of increasing N application rate above 100 kg N/ha on grains per ear recorded for Cassia in 2012, which was not recorded for Cassia in either 2013 or 2014 or for either six-row cultivar in any season. Correlation analysis indicated a significant correlation between grains per ear and yield when unfertilised treatments were included (Table 1). When the unfertilised treatment was excluded, there was no significant correlation between grains per ear and yield for both six-row cultivars, as well as a weaker correlation, albeit significant, for Cassia compared to cases in which the unfertilised treatment was included ($r = 0.43$ versus 0.75).

Significant correlations between grains per square metre (the product of grains per ear and ear population) and yield were obtained for all three cultivars, both with and without

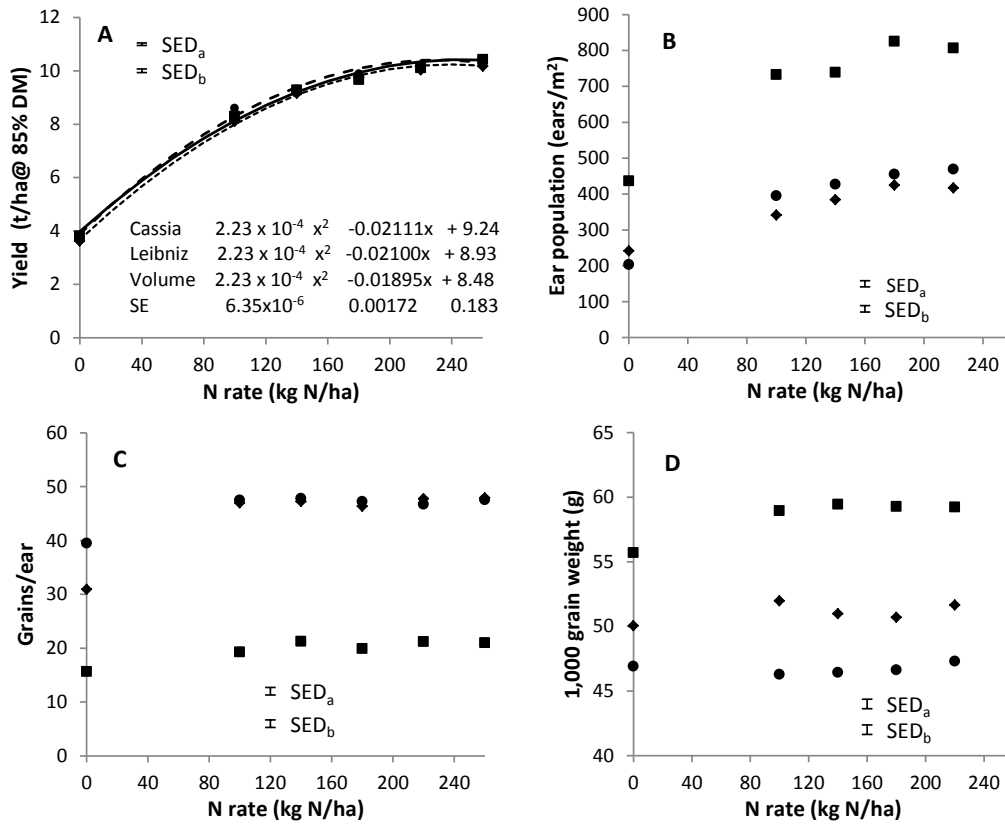


Figure 1. Effect of fertiliser N application rate on (A) grain yield, (B) ear populations, (C) grains per ear and (D) 1000 grain weight of Cassia (■), Leibniz (◆) and Volume (●) winter barley. Error bars are for comparisons within a cultivar (SED_a) and between cultivars (SED_b). Quadratic regression models relating grain yield to N application rate are also presented. SE = standard error. SED = standard error of difference.

Table 1. Pearson correlation coefficients (r) between components of grain yield and grain yield for three cultivars of winter barley over three seasons¹

	Ear population (ears/m ²)		Grains per ear		TGW ² (g)		Grain population (grains/m ²)	
	+	-	+	-	+	-	+	-
Cassia								
2012	0.89*	0.53*	0.88*	0.75*	0.68*	0.17	0.99*	0.96*
2013	0.91*	0.53*	0.81*	0.15	-0.11	-0.43*	0.99*	0.87*
2014	0.88*	0.61*	0.61*	0.28	0.57*	0.24	0.99*	0.93*
2012-2014	0.88*	0.55*	0.75*	0.43*	0.44*	0.28*	0.98*	0.92*
Leibniz								
2012	0.84*	0.68*	0.81*	0.14	0.38	0.12	0.98*	0.88*
2013	0.79*	0.38	0.90*	0.28	-0.45*	-0.46*	0.98*	0.84*
2014	0.93*	0.78*	0.30	-0.01	0.46*	0.08	0.98*	0.93*
2012-2014	0.80*	0.65*	0.60*	-0.14	0.16	0.16	0.93*	0.63*
Volume								
2012	0.95*	0.64*	0.75*	0.31	0.56*	0.29	0.99*	0.95*
2013	0.96*	0.76*	0.61*	-0.29	-0.70*	-0.54*	0.99*	0.87*
2014	0.93*	0.68*	0.51*	0.06	0.22	0.25	0.99*	0.92*
2012-2014	0.91*	0.56*	0.49*	-0.15	0.08	0.29*	0.94*	0.55*

¹Correlation analysis was carried out with (+) and without (-) the unfertilised treatment included. * = P < 0.05.

²TGW = 1,000 grain weight.

the unfertilised treatment included (Table 1). Averaged over seasons, the correlation was stronger for Cassia than for either six-row cultivar. The weaker correlation for both six-row cultivars compared to the two-row cultivar, averaged over seasons, was due to a greater increase in yield in response to increases in grains per square metre in 2013 and 2014 compared to 2012 for both six-row cultivars (data not shown). A similar response in grain yield to increasing grains per square metre was obtained for Cassia in all three seasons. There was no significant effect of fertiliser N on TGW in the case of the two six-row cultivars (Figure 1). There was a significant increase in TGW for Cassia as the fertiliser N application rate increased from 0 to 100 kg N/ha, but further increases in fertiliser N had no significant effect on TGW. These observations were reflected in the correlation analysis, which indicated that, averaged over seasons, there was no correlation between yield and grain weight in the case of the two six-row cultivars, while there was a significant positive correlation ($r=0.44$) between grain weight and yield for Cassia in cases where the unfertilised treatment was included but not when the unfertilised treatment was excluded (Table 1).

Crop N uptake and N use efficiency

Aboveground crop N uptake at harvest in areas where no fertiliser N was applied ranged between 52.9 and 60.2 kg N/ha (Figure 2). N uptake increased as fertiliser N application rate increased, an increase that was best described by a quadratic model. This indicated a decline in the rate of increase in N uptake as fertiliser N application rate increased, but the rate of decline was very limited. The rate of increase in N uptake in response to increases in fertiliser N was similar in all three

years. Cassia had significantly higher N uptake than either Leibniz or Volume and this difference was not influenced by the rate of N applied. However, the differences were relatively small; N uptake by Cassia was 7.5 and 8.5 kg N/ha higher than that of Volume and Leibniz, respectively, averaged over fertiliser N application rates. Differences between cultivars in terms of N uptake were not affected by either year or fertiliser N application rate.

Cultivar had a significant effect on protein content, with Cassia having significantly higher protein content than both the other cultivars and Volume having significantly lower protein content than Leibniz, when averaged over years and fertiliser N application rate (Figure 2). However, differences between cultivars were significantly influenced by the rate of fertiliser N applied. Where no fertiliser N was applied, the three cultivars differed significantly from each other in terms of protein content, with Cassia having the highest and Volume the lowest protein content. As the rate of fertiliser N application was increased, the protein content of Volume increased at a faster rate than that of both Cassia and Leibniz such that differences between protein content of Volume and that of the other two cultivars decreased with increasing N application rate. This was reflected in the linear coefficient of the cubic regression model for the protein response to fertiliser N being significantly higher for Volume than for either Cassia or Leibniz.

RE_{N} , the proportion of applied fertiliser N recovered in the aboveground biomass of the crop at harvest, ranged between 0.54 and 0.75 kg N/kg fertiliser N applied (Figure 3). RE_{N} was not influenced by cultivar, nor was there a significant interaction between cultivar and either N application rate

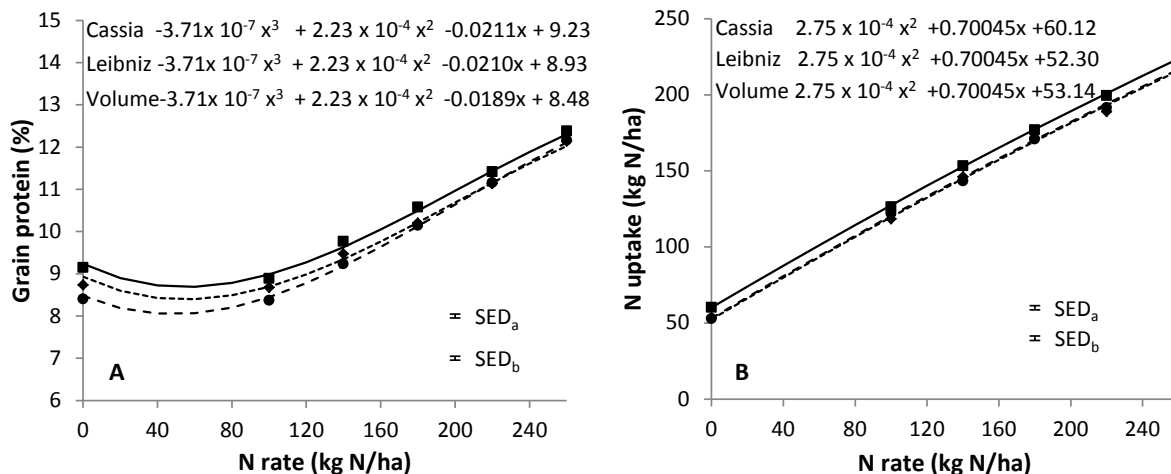


Figure 2. Effect of rate of fertiliser N application on (A) protein content and (B) above-ground N uptake at harvest of Cassia (■), Leibniz (◆) and Volume (●) winter barley. Data are mean of three seasons: 2012, 2013 and 2014. Error bars are for comparisons within a cultivar (SED_a) and between cultivars (SED_b). Cubic and quadratic regression models relating protein content and N uptake to N application rate are also presented. SED = standard error of difference.

or year. RE_N was influenced by fertiliser N application rate, but the effect was not consistent between seasons, with a curvilinear decline as fertiliser N increased observed in 2012 and 2013, while an increase in RE_N was observed in 2014 as the N application rate increased up to 180 kg N/ha, followed by a decline at higher N application rates (data not shown). AE_N , the amount of grain DM production/kg of fertiliser N applied, decreased from 51.6 to 27.5 kg DM/kg fertiliser N input as the fertiliser N application rate increased from 100 to 260 kg N/ha, averaged over years (Figure 3). However, the effect of increasing fertiliser N application rate on AE_N varied between cultivars. This was due to Volume having a significantly higher AE_N than either Cassia or Leibniz in areas where 100 kg N/ha was applied, a difference that did not occur at higher rates of fertiliser N application. Cassia and Leibniz did not differ significantly at any N application rate.

PE_N , the amount of grain DM production/kg of fertiliser N taken up, decreased from 77.9 to 43.7 kg DM/kg N as the fertiliser N increased from 100 to 260 kg N/ha (Figure 3). The PE_N of

all three cultivars responded similarly to increasing fertiliser N application rate.

NUE, the grain DM yield per unit of total N accumulated, including soil N, decreased as fertiliser N increased (Figure 3). However, cultivar had a significant effect on how NUE responded to fertiliser N application rate. In cases where no fertiliser N was applied, Volume had significantly higher NUE than both other cultivars and Leibniz had significantly higher NUE than Cassia. Volume maintained a significantly higher NUE than Cassia but not Leibniz, which did not differ significantly from Leibniz, as the fertiliser N increased from 100 to 180 kg N/ha, after which no significant differences existed among the cultivars.

Discussion

The lack of significant differences in yields between the three cultivars chosen to represent the cultivar types in this study is contrary to the findings of a more extensive comparison of

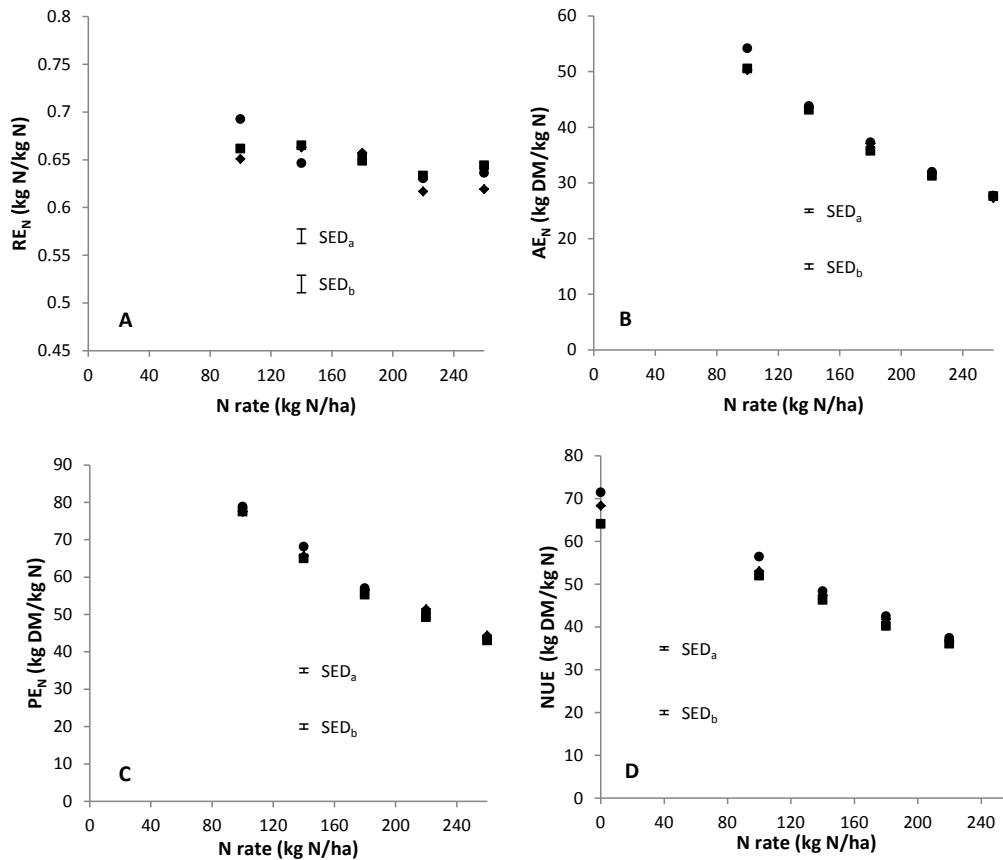


Figure 3. Effect of fertiliser N application rate on (A) recovery efficiency (RE_N), (B) agronomic efficiency (AE_N), (C) physiological efficiency (PE_N) and (D) nitrogen use efficiency (NUE) of Cassia (■), Leibniz (◆) and Volume (●) winter barley. Error bars are for comparisons within a cultivar (SED_a) and between cultivars (SED_b). SED = standard error of difference.

yield of the cultivars in question by Anon. (2015), who reported an average yield advantage compared to Cassia of 3% and 10% for Leibniz and Volume, respectively. It is also contrary to similar work comparing two-row and six-row cultivars in a number of other European studies, in which six-row cultivars outyielded two-row cultivars (Maidl *et al.*, 1996; Le Gouis *et al.*, 1999). There are no obvious reasons for this disparity. The experiments were carried out on a light soil with relatively low water-holding capacity, which could have prevented a cultivar with a higher yield potential from achieving that potential due to late-season moisture stress. However, there was abundant rainfall during the grain-filling period in 2012, which would have prevented any drought effects, but differences between cultivars were not detected in that season.

There was no evidence to suggest that the grain yield response to N varied between the cultivar types examined in this work. Obviously, this work examined only one of each cultivar type (two-row, six-row and six-row hybrid) and it has been reported that there can be considerable variation in the response to fertiliser N within a cultivar type (Arisnabarreta and Miralles, 2006). However, this work seems to indicate that there is no intrinsic difference between cultivar types, in terms of grain yield response to N, particularly where applied N rates are close to what is required to give maximum yield, and that any differences are likely to be cultivar specific rather than being due to the type of cultivar used. This appears to indicate that there is no need to differentiate between cultivar types in terms of the quantity of N applied within fertiliser recommendation systems. Any differences in N requirements of cultivar types can be accommodated by adjusting fertiliser N inputs in line with expected yields. There was not sufficient variation in yield levels in these experiments to determine whether the recommended adjustment in N application rate of 20 kg N/t (Coulter and Lalor, 2008) is sufficient for modern winter barley crops under Irish conditions. The higher yield obtained with the six-row hybrid cultivar compared to the other cultivars at the lowest rate of applied N might suggest that the hybrid cultivar would give better yields than conventional types, wherein N inputs are limited (e.g. low-input systems). The lower N uptake by both six-row cultivars, compared to the two-row cultivar for which no fertiliser N was applied, suggests that six-row cultivars may be less efficient at recovering soil N, than two-row cultivars. However, there was no difference between the cultivars in terms of recovery of applied fertiliser N. The reasons for the disparity between the cultivars in terms of soil N uptake and fertiliser N recovery are unclear. N accumulation was only measured at maturity, so no information on the course of N accumulation over the season was available. Consequently, it was not clear whether the differences between the cultivars had emerged before fertiliser N was applied in the spring or whether the differences only became apparent during the growing season,

after N application. Contrary to the results in this study, Le Gouis *et al.* (1999) reported greater recovery of soil N by six-row cultivars compared to two-row cultivars in one season but not in a second season. However, when fertiliser was applied, no difference in N recovery was detected between cultivar types, in agreement with the results of this study. A more robust study, including a number of sites with varying levels of soil N supply and a greater number of cultivars, is needed to determine more definitively the relative efficiency of cultivar types in terms of soil N recovery.

The fertiliser N recovery values recorded in this study were considerably lower than those recorded for both two-row and six-row winter barley by Maidl *et al.* (1996) but were within the range observed by Smith *et al.* (1988) under UK conditions and similar to those observed by Delogu *et al.* (1998) under Italian conditions.

The AE_n and PE_n values recorded in this study were considerably higher than those reported by Delogu *et al.* (1998), reflecting the greater response in grain yield, in comparison to the unfertilised treatment, to increases in fertiliser N application rate recorded in this study. At comparable N application rates, the NUE observed in this study was similar to that reported by Sylvester-Bradley and Kindred (2009) under UK conditions. Le Gouis *et al.* (1999) found no differences in NUE between two-row and six-row cultivars both with and without fertiliser N addition, although they used total above-ground biomass production to calculate NUE. In this study, wherein grain yield was used in the calculations, both the six-row cultivars had higher NUE than the two-row cultivar for which no fertiliser N was applied and the six-row hybrid variety maintained a higher NUE than the two-row cultivar at application rates up to 180 kg N/ha. However, the higher NUE was associated with lower protein content. Given that the majority of winter barley produced in Ireland is used for animal feed, cultivars with higher NUE are not necessarily beneficial as the barley will need greater supplementation with a protein source to provide sufficient protein levels for animal nutrition. It may be more appropriate to select cultivars with greater recovery efficiency of either soil N or applied fertiliser N or both.

As has been found previously for cereal crops, grain yield was well correlated with the number of grains per unit area and poorly correlated with grain size (Gallagher *et al.*, 1975; Blake *et al.*, 2006). Of the two components of grains per unit area, ear population was the component of yield most closely correlated with yield, particularly when only treatments receiving fertiliser N were considered. This indicates that the positive effects of increasing levels of fertiliser N on grain yield were principally due to increases in ear number. The positive effect of increased ear population on grain yield in winter barley has been described previously by a number of authors (Conry, 1984; Blake *et al.*, 2006).

Arisnabarreta and Miralles (2006) reported that yield generation was largely dependent on ear population in two-row barley and grains per ear in six-row barley. In this study, when the unfertilised treatment was excluded, ear population was the most closely correlated yield component with yield for both two-row and six-row cultivars and grains per ear was not correlated with yield for both six-row cultivars. The different findings in the two studies may be due to differences in levels of fertiliser N applied. Arisnabarreta and Miralles (2006) compared only two N application rates, a low N application rate of 40 kg/ha and a higher application rate of 150 kg N/ha. In this study, comparison of the unfertilised treatment with the lowest fertiliser N application rate, which may be more comparable to the aforementioned study, indicated that there was a greater increase in grains per ear and a lower increase in ear population for the six-row cultivars than for the two-row cultivar. This comparison would lead to similar conclusions regarding the relative importance of yield components in determining yield of two-row and six-row cultivars, as in the study of Arisnabarreta and Miralles (2006). However, in this study, when the higher fertiliser N application rates were included, ear population became the main driver of yield in the six-row cultivars.

In this work, N was applied to all three cultivars on the same dates. However, the fact that increasing ear number, as a result of increasing fertiliser N application rate, was not associated with reductions in either grains per ear or TGW could indicate that any alteration in the timing of N application that would lead to changes in tiller production or survival with consequent positive effects on ear population could lead to increases in yield, at a given level of fertiliser N. Maidl *et al.* (1996) reported that two-row cultivars needed more N before stem extension than six-row cultivars in order to maximise yield. Researchers in the UK reported that grain yield in winter barley could be increased by increasing the amount of N applied before the beginning of stem extension to 50% of the total amount (Allen-Stevens, 2015). This suggests that there is a need to examine the effect of different timings of fertiliser N on grain yield and its components in different cultivar types in an Irish context with a view to maximising the yield per unit input of fertiliser N.

Conclusions

This work found no evidence that cultivar type, whether a two-row or six-row line cultivar or six-row hybrid cultivar, influenced the response to fertiliser N of winter barley. Therefore, cultivar type is, in itself, not a good indicator of fertiliser N requirement under Irish conditions. There were some indications that six-row cultivars were less efficient at recovering soil N but used accumulated N more efficiently than the two-row cultivar.

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