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VARIATION IN THE RESPONSE OF BARLEY CULTIVARS TO NITROGEN FERTILIZER

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ABSTRACT

Field experiments were conducted in South Australia in 2 years (1991 and 1993) to compare the response to nitrogen (N) fertilizer among 78 cultivars of 2-row barley (*Hordeum vulgare*) differing in height and yield potential. The aim of the study was to quantify the genotypic variation of responsiveness in grain yield and grain protein concentration (GPC) and to assess the practicability of screening for N responses in the field. There was a difference in the responses to N between the 2 years and the correlation between responsiveness of the cultivars in the 2 years was small. The grain yield responses and GPC responses to N within each year were not correlated, suggesting it may be possible to select for yield and GPC responsiveness independently. Despite the variability between seasons, principal component analysis indicated that short cultivars were more responsive in both years. Late-flowering cultivars tended to have lower yields, but in terms of the response to N, late ear emergence contributed to a higher yield response. At a site where symptoms of boron toxicity were evident, sensitivity to boron toxicity also contributed to yield responsiveness to N. The study indicated that there is considerable genotypic variations in responses to N and that it is possible to screen a large number of cultivars for response to N but such screening needs to be conducted over a large number of sites and years because of the inherent variability of the target environment.

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تغییرات واکنش ارقام مختلف جو نسبت به کود نیتروژنه

قدرت اله فتحی ،جی. ک. مک دونالد،آر. سی. ام. لانس و ال. سی. جایلز

به ترتیب دانشجوی سابق دکترا (اکنـون اسـتاد یـار مجتمـع عـالی آموزشـی و پژوهشـی کشـاورزی رامین، دانشگاه شهید چمران اهواز، ایران)و استادان بخش علوم گیاهی دانشـگاه آدلایـد و دانشـگاه فلیندرز، استرالیا.

چکیده

برای مقایسه واکنش ۷۸ رقم جو دو ردیفه که از نظر ارتفاع و میزان عملکرد با هـم متفـاوت بودند، یک رشته آزمایش های مزرعه ای در طی دو سـال (سـال هـای ۱۹۹۱، ۱۹۹۳) در جنـوب استرالیا انجام شد. هدف از آزمایش تعیین تغییرات ژنوتیپی در واکنش گیاه از نظر میزان محصـول و میزان پروتئـین دانه ودست یابی به یک روش عملی برای جدا سازی ارقام جـو در شـرایط مزرعـه از نظر واکنش نسبت به نیتروژن بود. نتایج آزمایش ها نشان داد که از نظرواکنش نسبت بـه نیـتروژن، بین دو سال زراعی تفاوت وجود داشته است و همبستگی بین واکنش ارقام در دو سال ضعیف بود. بین عملکرد و پروتئـین دانه از نظر واکنش نسـبت بـه نیـتروژن در هیچیـک از سـال هـای آزمایشـی همبستگی دیده نشد. این موضوع بیانگر این است که واکنش محصول و پروتئـین نسبت به نیـتروژن را می توان جداگانه بررسی کرد. با وجود تغییرات بین سـال هـای زراعـی، تحلیـل مؤلفـه اجـزاء اصلی نشان داد که ارقام پاکوتاه واکنش بیشتری نسبت به نیتروژن داشتند. ارقام با گلدهـی دیرتـر، عملکرد کمتری داشتند، ولی از نظر واکنش نسبت بـه نیـتروژن ارقـامی کـه دیرتـر بـه خوشـه رفتـه بودند، عملکرد بیشتری داشتند. در محلی که علائـم مسمومیت بور وجود داشت، حساسیت نسبت

به مسمومیت بور نیز در واکنش عملکرد نسبت به نیتروژن موثر بود. نتایج این بررسی نشـان دادکـه تغییرات ژنوتیپی قابل توجهی در واکنش نسبت به نیتروژن وجود دارد و بدین ترتیب می توان تعـداد زیادی از ارقام جو را از نظر واکنش نسبت به نیتروژن جـدا سـازی کـرد، ولـی بـه خـاطر تغییرات توارثی و شرایط محیطی بـرای چنیـن جـدا سـازی، انجـام آزمـایش هـای بیشـتری در مکـان هـا و زمان های مختلف ضروری به نظر می رسد.

INTRODUCTION

Two-row, malting barley is an important crop in southern Australia where it is often grown as a second cereal crop in a rotation. Many barley growers do not apply nitrogen (N) fertilizer or only apply small amounts at sowing, because of the risk of increasing the grain protein concentration (GPC) to levels that would jeopardize malting quality (>11.8%). However, by applying inadequate amounts of N fertilizer, the crops may become N deficient which could limit their yield. Although the GPC from such crops may be suitable for malting quality barley, in many cases the reduced income from the lower yield is not compensated by the premium paid for malting grade barley.

In Australia, a considerable amount of work has been conducted on responses to N fertilizer, particularly in wheat. These often show highly variable responses between sites and seasons that make the reliable prediction of the optimum rate of N fertilizer difficult. One possible way of increasing the efficiency of N fertilizer use is to develop cultivars which will give large grain yield responses but which will not have high responses in GPC when N fertilizer is applied. In barley, varietal differences in grain yield response to applied N have been demonstrated in the field under a wide range of conditions (2, 3, 6, 12, 17). Characters such as height, maturity and resistance to biotic stresses are likely to contribute to yield responsiveness in a complex manner. By using a diverse array of genotypes which cover a range of these characteristics and analyzing the data using principal component analysis, the inter-relationships between different agronomic characters and their overall contribution to yield and GPC responses can be examined. The purpose of this experiment was to examine the importance of some of these characteristics in determining the responsiveness of barley to N fertilizer.

MATERIALS AND METHODS

Experiment 1

This experiment was conducted at Northfield, South Australia in 1991. The soil at the site is an alkaline clay (Palexererts, black earth, pH ($CaCl_2$) = 7.8, soil nitrate-N=18.1 µg g^{-1}) and the previous year's crop was wheat. Seventy eight cultivars of 2-row barley were grown at two levels of nitrogen, 0 and 50 kg N ha^{-1}. The experimental design was a split plot, randomized complete block with 3 replicates; main plots were levels of N and subplots were cultivars. Sowing was delayed until 25 July 1991 due to heavy rainfall in June (Table 1). This sowing time is later than the optimum time but is not uncommon for barley crops grown in southern Australia. The seed was sown at 55 kg ha^{-1} in 4-row plots, 0.6 m wide and 4.2 m long. Nitrogen was applied in a single application as urea (46% N) immediately before sowing at a depth of approximately 5 cm. At sowing, a basal dressing of 20 kg P ha^{-1} as triple superphosphate was drilled with the seed. The following data was collected during the season:

(i) Tiller number per plant was counted in the field at 5 locations within each plot on September 23. Five plants in each location (25 samples/plot) were sampled and the average was calculated.

(ii) Plant height was measured at 10 positions within each plot after ear emergence had occurred in all cultivars. Height was measured from ground level to the top of the head using a meter ruler.

(iii) As an estimate of the area of the flag leaf, flag leaf length was measured with a ruler at the end of ear emergence, 10 leaves in each plot. Only green tissue was measured.

(iv) Symptoms of boron toxicity became evident in some cultivars during the experiment. Therefore, the plots were scored for toxicity symptoms on October 21. A visual scale of 0 to 9 was used. A score of 0 indicated no symptoms and a score of 9 indicated symptoms covering most of the leaves (10).

(v) The time of ear emergence, growth stage 59 Zadoks *et al.* (19) for cultivar was recorded when 50% of the plants on the plot had completed ear emergence. Data are expressed as the number of days after October 1.

(vi) Visual symptoms of N deficiency (leaf chlorosis and poor tillering) were scored using a 1 to 5 scale, with 1 meaning the leaves were not chlorotic and plants showed vigorous growth and 5 indicating the leaves were very chlorotic and there was little tillering. Scoring was conducted at the end of ear emergence and is referred to as a chlorotic score in the tables.

(vii) Foliar disease, mainly barley scald (*Rhynchosporium secalis*) infected some of the varieties during the latter half of the experiment. This was assessed after ear emergence using an empirical score from 1 to 10 with high scores indicating lack of disease and generally good growth. The score is referred to as general growth score.

(viii) Temperature differential, the difference between the canopy and air temperatures (9) was measured on October 29, after all cultivars had flowered. Measurements were made with an infrared thermometer, Model 510B (Everest Interscience Inc., CA, USA), with a 4° field of vision held at a declination angle of 30°, resulting in a spot size of about 0.25 m^2. A large positive temperature differential indicated the canopy temperature was greater than the air temperature.

At maturity (November 15), plots were harvested with a small harvester. A sample of grain was taken from each plot and GPC was determined on a 0.5 g sample of grain by the Kjeldahl method.

Experiment 2

The second experiment was carried out at Charlick Experiment Station, South Australia in 1993. The soil at this site is an alkaline, solonized brown soil (Xerochrepts, pH ($CaCl_2$)=7.3, soil nitrate-N=21.6 µg g^{-1}). The same 78 cultivars of barley used in experiment 1 were grown at two levels of N. Due to heavy rainfall in June and July of 1992 it was not possible to sow barley crops at optimum time, therefore, the experiment 2 was conducted in 1993. The experimental design was a split plot, randomized complete block with 3 replicates; main plots were cultivars and subplots were N treatments. The aim of different experimental design to that used at Northfield 1991 was to improve the ability to recognize different responses of individual cultivars to N. The cultivar seeds were sown on 22 July 1993 in plots of 8 rows, 1.2 m wide and 4.2 m long. Because of the larger plot size and the different equipment used to sow the crop and apply the N fertilizer, there were small differences in the sowing and fertilizer rates used. The seed was sown at a rate of 62 kg ha^{-1} and N was applied as urea at two stages: with the seed at sowing at a rate of 20 kg N ha^{-1} and broadcast at a rate of 25 kg N ha^{-1}, 8 weeks after sowing. There was very high rainfall over winter (June-August) in 1993 at Northfield, therefore, the second experiment was conducted at Charlick Experiment Station which was not very far from Northfield site.

Dry matter production at ear emergence was estimated by taking a quadrat sample (2 rows × 0.5 m) at 2 locations in each plot from 3 replicates. Samples were cut at ground level and the 2 samples from each plot were mixed before being oven-dried at 80° C for 2 days and weighed. A subsample from each sample was ground to pass through a 2-mm sieve and the N concentration measured using the Kjeldahl method on a 0.5 g sample. Time of ear emergence, plant height, general growth score and flag leaf length were determined by the same methods described for experiment 1. Boron toxicity was not evident in this experiment, so cultivars were not scored for the damage. Flour GPC was determined by near infrared reflectance (NIR) (Technicon Infralyzer 400R) after being calibrated against the Kjeldahl method.

Statistical Analysis

An initial analysis of variance was performed to verify genetic variation in the traits measured and to examine the effect of N on these traits. Due to the large number of cultivars and variables measured, there were many sources of variation in data which could have overlapping effects on each other. A principal component analysis (PCA) based on the covariance of the agronomic measurements, except grain yields and grain protein concentration was used to analyze the data further (11). PCA is a data reduction technique used to identify a small set of variables which accounts for a large proportion of the variation in the original data. Each of the principal components (PCs) is a weighed combination of the parameters measured and allows the interrelationships between components to be examined. The PCA was conducted on standardized variables $[(x_i-x)/SD_x]$ because of the wide range in the values of the different data sets. The data were analyzed using the Genstat 5 statistical program (7).

RESULTS

Weather

Total annual and seasonal rainfall at Northfield in 1991 was higher than at Charlick in 1993, due largely to the very high rainfall over winter (June- August) (Table 1). Rainfall declined sharply at the end of the season in 1991, whereas in 1993 significant falls of rain were received late into grainfilling, which may have helped to extend the grainfilling period.

Table 1. The total monthly rainfall received at Northfield in 1991 and Charlick in 1993 and the seasonal (April to October) and annual totals.

	Monthly rainfall (mm)	
Month	Northfield, 1991	Charlick, 1993
January	15.4	18.2
February	0.0	9.3
March	9.7	13.0
April	32.2	0.0
May	11.2	23.8
June	103.5	31.1
July	76.2	79.8
August	64.4	49.4
September	69.2	80.6
October	69.2	26.8
November	46.8	64.0
December	0.1	64.0
April-October	426	324
Total	**498**	**456**

Differences between Sites

Grain yield was higher and GPC lower at Charlick in 1993 compared with Northfield in 1991 (Table 2). Plant height and flag leaf length at Charlick were lower than at Northfield, suggesting vegetative growth was less. Flowering at Charlick was, on average, 10 days earlier than at Northfield.

Table 2. The effect of nitrogen on the growth, yield and grain protein concentration of barley at Northfield in 1991 and Charlick in 1993. Values are the averages over 78 cultivars.

	Northfield, 1991		Charlick, 1993	
	0 kg N ha^{-1}	50 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}
Grain yield (t ha^{-1})	2.10	2.50†	2.60	3.40†
GPC (%)	11.70	14.80†	8.00	8.60†
Ear emergence (days after 1 October)	23.10	21.50†	12.10	11.80†
Height (cm)	63.00	73.00†	57.00	62.00†
Tiller number per plant	4.60	7.00ns		
Flag leaf length (cm)	7.10	9.10†	3.60	4.90†
Boron score	3.80	3.60†		
Chlorosis score	2.00	3.00†		
General growth score	4.00	7.00ns	4.00	7.00†
Dry matter at ear emergence (g m^{-2})			400.00	577.00§
Shoot N concentration at ear emergence (%)			1.17	0.05†
Total shoot N (g m^{-2})			4.70	6.10†

† = $P<0.01$, § = $P<0.001$, ns = not significant.

Nitrogen fertilizer significantly increased the vegetative growth (e.g., greater plant height and flag leaf length) of plant at both sites (Table 2) but more so at Northfield. Both grain yield and GPC were significantly affected by the addition of N at Northfield and Charlick but the responses in the two years were different. At Northfield, the average yield response was lower and the GPC response was larger than the respective responses at Charlick (Table 2). At both sites, the main effects of nitrogen and cultivar were highly significant for most of the variables measured. The significant nitrogen cultivar interaction at Northfield occurred with plant height, flag leaf length, GPC and date of ear emergence whereas at Charlick significant interactions occurred for yield, GPC, date of ear emergence, dry matter at ear emergence, N concentration and N content at ear emergence. The grain yield responses of the cultivars to N at the 2 sites were not correlated ($r = 0.11$, $n = 75$).

Yield-GPC Relationships

There was a significant negative relationship between mean grain yield and GPC for the 78 cultivars at the 2 sites (Fig. 1, a and d). However, there was no significant correlation at either site between the absolute response of grain yield and GPC (Fig.1, b and e) or between the relative response in grain yield and relative GPC responses (Fig. 1, c and f). The yield, GPC and grain N yield data for a selected range of cultivars that have been or currently are grown in southern Australia are shown in Tables 3 and 4. The results from Charlick (Table 4) illustrate the range of responses that can occur at a more responsive site. The yield and GPC responses of Weeah, a tall cultivar, were low and below the site average. Triumph and Skiff, which are short cultivars, both showed larger responses in grain yield to added N but the GPC of Skiff did not increase while that of Triumph increased significantly. The grain yield of Clipper, a tall cultivar that was widely grown, preminum malting barley in southern Australia in the 1980s, did not respond to added N, but there was a significant increase in GPC. Galleon, a feed barley, showed a moderate increase in yield but a large increase in GPC. The grain N yield increased in most cultivars and although there were differences in the yield and GPC responses to N. These results largely reflect the differences in the yield responses between these cultivars.

The low and negative yield responses to N at Northfield (Table 3) makes direct comparisons with the Charlick data difficult. However, when combined with the Charlick data, it is apparent that there are some cultivars such as Weeah and Clipper which show poor responses to N over a range of conditions while there are cultivars such as Forrest, Skiff and Shannon which show large responses under favorable conditions but respond much less under drier seasonal conditions. GPCs were high when N was added and there was little difference in the responses between cultivars. The cultivars Dampier, O'Conner and Stirling had a lower GPC than the other cultivars at 0 kg N ha^{-1} and O'Connor also had a relatively low GPC when N was added.

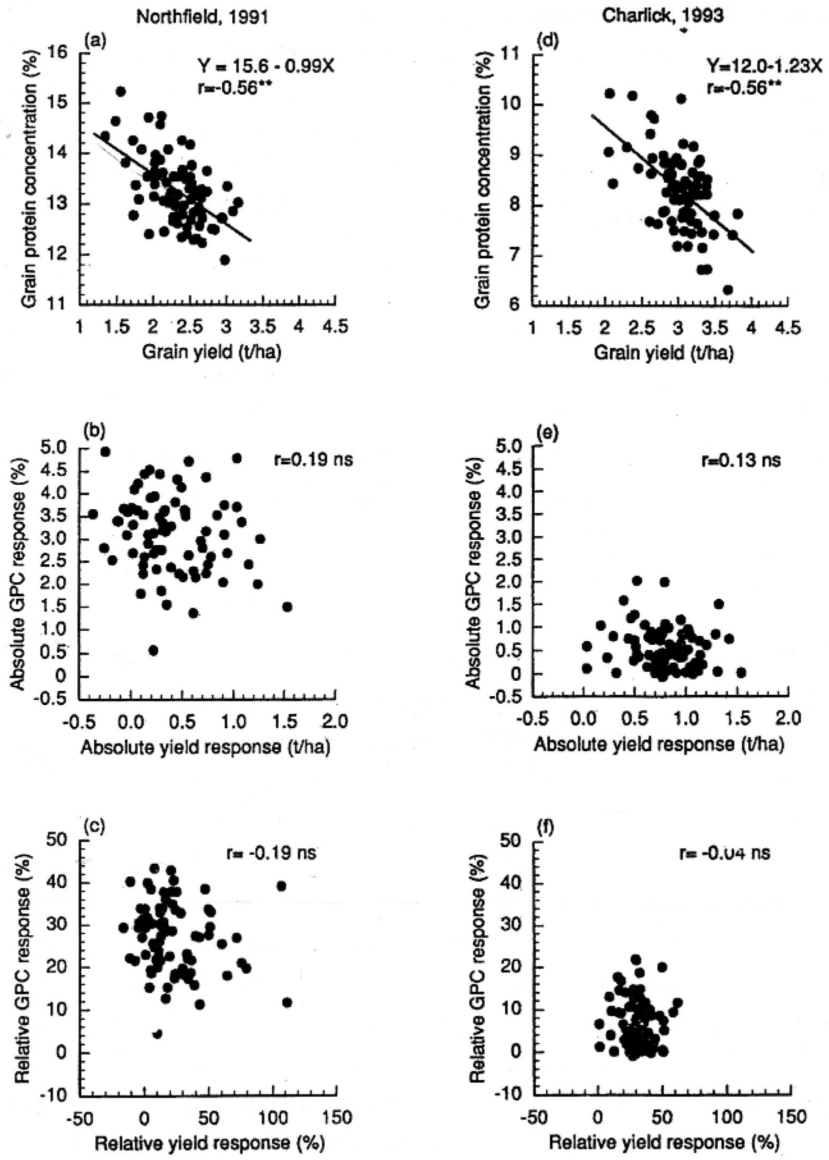

Fig. 1. The relationship between grain yield and grain protein concentration (GPC) in mean (a), absolute (b) and relative response (c) at Northfield and Charlick (d, e and f) for 78 barley cultivars.

Table 3. Grain yield, grain protein concentration and grain N yield at two levels of N for selected cultivars at Northfield in 1991.

Main production region and cultivar	Grain yield ($t\ ha^{-1}$)		Grain protein concentration (%)		Grain N yield ($kg\ ha^{-1}$)	
	0 kg N ha^{-1}	50 kg N ha^{-1}	0 kg N ha^{-1}	50 kg N ha^{-1}	0 kg N ha^{-1}	50 kg N ha^{-1}
Victoria						
Lara	1.89	2.17	11.8	16.1	51	54
Parwan	2.40	2.71	11.6	14.8	50	56
Weeah	1.92	2.15	11.6	15.5	40	36
South Australia						
Clipper	2.32	2.28	11.4	14.5	42	43
Galleon	1.93	3.17	11.1	13.5	54	60
Schooner	1.99	3.02	11.2	14.9	46	68
Skiff	2.28	2.71	12.8	15.6	59	45
Western Australia						
Dampier	2.14	2.64	10.2	14.4	4.6	4.4
Forrest	2.37	2.19	11.8	14.3	45.0	44.0
O'Connor	2.58	3.10	10.7	13.1	53.0	40.0
Stirling	1.89	2.42	10.7	14.2	47.0	48.0
Tasmania						
Franklin	2.89	3.44	11.7	14.3	65.0	69.0
Shannon	2.61	2.73	11.6	13.8	53.0	46.0
Triumph	2.14	2.84	12.1	14.9	44.0	50.0
Site mean	**2.12**	**2.53**	**11.7**	**14.8**	**44.0**	**47.0**

Table 4. Grain yield, grain protein concentration and grain N yield at two levels of N for selected cultivars at Charlick in 1993.

Main production region and cultivar	Grain yield ($t\ ha^{-1}$)		Grain protein concentration (%)		Grain N yield ($kg\ ha^{-1}$)	
	0 kg N ha^{-1}	45 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}
Victoria						
Lara	3.16	4.19	5.9	6.8	29.0	45.0
Parwan	2.80	3.85	7.1	7.2	32.0	44.0
Weeah	2.47	2.78	8.6	8.7	34.0	38.0
South Australia						
Clipper	2.28	2.30	8.9	9.5	32.0	35.0
Galleon	2.81	3.27	8.2	9.4	3.7	4.8
Schooner	2.60	3.52	7.9	8.4	33.0	47.0
Skiff	3.03	4.58	7.8	7.9	38.0	57.0
Western Australia						
Dampier	2.75	3.52	8.2	8.6	36.0	49.0
Forrest	2.26	3.05	9.6	9.9	35.0	48.0
O'Connor	2.60	3.22	7.3	8.1	30.0	41.0
Stirling	2.64	3.42	8.8	8.8	37.0	48.0
Tasmania						
Franklin	2.60	3.66	7.2	7.2	30.0	42.0
Shannon	2.45	3.22	8.0	8.5	31.0	44.0
Triumph	2.36	3.49	8.1	8.8	30.0	42.0
Site mean	**2.61**	**3.41**	**8.0**	**8.6**	**33.0**	**46.0**

Correlations with Grain Yield and GPC

The simple correlation coefficients between the measured parameters and grain yield at the 2 rates of N are shown in Tables 5 and 6. At Northfield (Table 5), yield at both levels of N was negatively correlated with the date of ear emergence and GPC predominantly, and positively correlated with plant height. Tiller number was important at 0 kg N ha^{-1} only, while at 50 kg N ha^{-1} yield was negatively correlated with the canopy temperature differential. In contrast, at Charlick (Table 6) there was a negative correlation between plant height and GPC with grain yield at both N rates and date of ear emergence was not significantly correlated with yield.

Table 5. Simple correlation coefficients between measured attributes and grain yield and grain protein concentration at two rates of N at Northfield in 1991.

	Grain yield		Grain protein concentration	
	0 kg N ha^{-1}	50 kg N ha^{-1}	0 kg N ha^{-1}	50 kg N ha^{-1}
Grain protein concentration	-0.62†	-0.50†		
Date of ear emergence	-0.57†	-0.42†	0.57†	0.42†
Tiller number	0.44†	0.03	-0.39†	-0.12
Plant height	0.35†	0.26§	-0.17	-0.27†
Flag leaf length	-0.21	-0.11	0.28†	0.02
Chlorosis score	-0.13	-0.07	-0.18	-0.08
General growth score	0.09	0.11	0.21	-0.23§
Boron score	0.05	0.12	-0.22	0.16
Temperature differential	-0.14	-0.34†	-0.18	0.08

† = P<0.01, § = P<0.05.

The characters that were correlated with yield also were correlated with GPC, but in an opposite direction. Grain protein concentration at Northfield was significantly correlated with ear emergence date at both N rates and tiller number and flag leaf length were important at 0 kg N ha^{-1}, while at 50 kg N ha^{-1} both plant height and general score were negatively correlated with GPC. At Charlick, higher GPC was associated with ear emergence and, at 0 kg N ha^{-1}, with greater growth and total shoot N.

Table 6. Simple correlation coefficients between measured attributes and grain yield and grain protein concentration at two rates of N at Charlick in 1993.

	Grain yield		Grain protein concentration	
	0 kg N ha^{-1}	45 kg N ha^{-1}	0 kg N ha^{-1}	45 kg N ha^{-1}
Grain protein concentration	-0.45†	-0.55†		
Date of ear emergence	0.07	0.15	-0.57†	-0.53†
Plant height	-0.26§	-0.42†	0.05	0.09
Flag leaf length	0.08	-0.05	0.22	-0.27†
General growth score	-0.01	0.03	0.18	-0.08
Dry matter at anthesis	0.15	-0.05	0.32†	0.16
Shoot N concentration	0.10	0.20	-0.06	-0.21
Total shoot N	-0.16	-0.09	0.27	0.01

† = P<0.01, § = P<0.05.

Principal Component Analysis, Northfield 1991

Principal component analysis at 0 kg N ha^{-1}. The cummulative variation of the first 3 principal components (PCs) accounted for 72.4% of the total observed variation [Table 7(i)]. PC_1 which accounted for 41.2% of total variation showed that date of ear emergence, flag leaf length, plant height and temperature differential were more important than the other attributes, although date of ear emergence and flag leaf length were the major components. The value of PC_1 was high when ear emergence was late, flag leaves were long, the canopy temperature differential was high and plant was shorter.

PC_2, which accounted for 17.6% of total variation indicated that temperature differential, symptoms of boron toxicity, flag leaf length and the degree of chlorosis were more important than the other variables. A large temperature differential, long flag leaf greater symptoms of boron toxicity and degree of chlorossis contributed to a high PC_2. The third principal component, which accounted for 13.6% of total variation, showed flag leaf length and temperature differential to be important. PC_2 was greater with a long flag leaf and low temperature differential.

Table 7. Eigenvectors of eight principal components from principal component analysis of agronomic characteristics of barley cultivars grown with 0 or 50 kg N ha^{-1} at Northfield, 1991

Variable	Principal component							
	1	2	3	4	5	6	7	8
				(i) 0 kg N ha^{-1}				
Date of ear emergence	0.733	-0.136	0.317	0.091	0.518	-0.075	0.243	0.053
Tiller number	-0.246	0.011	0.004	-0.097	0.146	-0.384	0.162	0.858
Plant height	-0.389	-0.119	-0.036	-0.564	0.485	-0.051	0.391	-0.352
Temperature differential	0.382	0.587	-0.641	-0.291	-0.002	-0.057	0.101	0.028
Flag leaf length	0.730	0.458	0.675	-0.492	-0.263	-0.059	-0.118	-0.003
Boron toxicity	-0.267	0.515	0.112	0.292	0.539	0.478	-0.188	0.106
Chlorosis score	-0.168	0.376	0.111	0.488	-0.015	-0.615	0.304	-0.329
General growth score	0.019	-0.070	-0.087	-0.118	0,338	-0.481	-0.781	-0.132
Eigenvalues	**96.5**	**41.2**	**31.8**	**28.3**	**16.9**	**9.9**	**6.3**	**3.7**
Percent of variance	**41.2**	**17.6**	**13.6**	**12.0**	**7.2**	**4.2**	**2.7**	**1.6**
Cumulative variance (%)	**41.2**	**58.8**	**72.4**	**84.3**	**91.5**	**95.7**	**98.4**	**100.0**
				(ii) 50 kg N ha^{-1}				
Date of ear emergence	0.709	0.169	0.066	0.365	0.082	-0.280	0.049	0.494
Tiller number	-0.148	0.089	0.140	-0.146	0.128	-0.899	-0.216	-0.239
Plant height	-0.334	-0.255	-0.159	-0.376	0.271	-0.037	-0.049	0.761
Temperature differential	0.308	0.166	-0.545	-0.677	0.123	0.023	0.024	-0.004
Flag leaf length	-0.071	0.671	0.598	-0.078	0.341	0.239	0.052	-0.076
Boron toxicity	-0.329	0.157	-0.507	0.459	0.625	-0.022	0.085	0.023
Chlorosis growth score	-0.386	0.538	-0.192	0.151	-0.613	-0.099	-0.065	0.335
General growth score	-0.086	-0.025	-0.049	-0.079	-0.080	-0207	0.966	-0.015
Eigenvalues	**90.1**	**32.0**	**27.7**	**23.8**	**17.4**	**9.1**	**7.2**	**4.9**
Percent of variance	**42.5**	**15.1**	**13.0**	**11.2**	**8.2**	**4.3**	**3.4**	**2.3**
Cumulative variance (%)	**42.5**	**57.6**	**70.6**	**81.8**	**90.0**	**94.3**	**97.7**	**100.0**

Principal component analysis at 50 kg N ha^{-1}. The variables that were important at 0 kg N ha^{-1} also tended to be important at 50 kg N ha^{-1} PC_1, which accounted for 42.5% of the variation, showed date of ear emergence to be the most important variable, while chlorosis, plant height, boron toxicity and temperature differential were relatively less important [Table $7_{(ii)}$]. Time of ear emergenece showed a positive contribution to the value of PC_1, while high boron scores reduced the value. In PC_2, which accounted for 15.1% of variation, flag leaf length and chlorosis were the most important variables. Both of these variables contributed positively to PC_2. PC_3, which accounted for 13.0% of variation, showing that flag leaf length, temperature differential and boron toxicity were the most important variables.

Principal Component Analysis, Charlick 1993

Principal component analysis at 0 kg N ha^{-1}. Cumulative variation of the first 3 PCs at 0 kg N ha^{-1} was 82.4% [Table 8 $_{(i)}$]. PC_1, which accounted for 42.1% of total variation, showed that date of ear emergence and shoot total N at ear emergence to be the most important parameters, although ear emergence date was also important. Late ear emergence date and low total N at ear emergence contributed to a high PC_1.

Height and shoot N concentration at ear emergence contributed most to PC_2, although there was also a contribution from the time of ear emergence. Tallness and lower shoot N concentration at ear emergence and early ear emergence increased PC_2. The third PC, which accounted for only 18.7% of total variation, showed shoot N concentration, height and total N in shoot at ear emergence to be the major variables [Table $8_{(i)}$].

Principal component analysis at 45 kg N ha^{-1}. The importance of ear emergence time and total N at ear emergence were again evident at the higher N rate. PC_1, which accounted for 40.6% of the total variation, showed the date of ear emergence, shoot total N and dry matter production at ear emergence to be the most important factors, while the most important variables in PC_2 were plant height, shoot N content and dry matter at ear emergence [Table $8_{(ii)}$]. In addition, both time of ear emergence and flag leaf length were negatively correlated to PC_1 and positively to PC_2.

Table 8. Eigenvectors of seven principal components from principal component analysis of agronomic characteristics of barley cultivars grown with 0 kg N ha^{-1} or 45 kg N ha^{-1} Charlick, 1993.

Variable	Principal component 1	2	3	4	5	6	7
				(i) 0 kg N ha^{-1}			
Date of flowering	0.822	-0.327	-0.162	0.037	0.376	-0.219	-0.000
Dry matter at anthesis	-0237	0.256	-0.118	-0.091	0.605	-0.159	-0.682
Shoot N conc. at anthesis	-0.185	-0.518	-0.723	-0.006	-0.278	0.135	-0.282
Shoot total N at anthesis	-0.327	0.027	-0.412	-0.078	0.496	-0.123	0.675
Plant height	0.212	0.653	-0.465	0.380	-0.297	-0.282	0.003
General growth score	0.225	0.275	-0.169	0.014	0.196	0.898	0.017
Flag leaf length	0.177	0.238	-0.150	-0.916	-0.205	-0.087	0.013
Eigenvalues	**97.8**	**50.1**	**43.4**	**18.9**	**14.8**	**7.1**	**0.2**
Percent of variance	**42.1**	**21.6**	**18.7**	**8.1**	**6.4**	**3.1**	**0.1**
Cumulative variance (%)	**42.1**	**63.7**	**82.4**	**90.1**	**96.9**	**99.9**	**100.0**
				(ii) 45 kg N ha^{-1}			
Date of flowering	0.623	0.306	-0.559	0.208	-0.378	-0.138	-0.005
Dry matter at anthesis	-0.344	0.347	0.201	0.498	-0.302	0.003	-0.618
Shoot N conc. at anthesis	-0.302	0.212	-0.615	-0.398	0.385	-0.035	-0.421
Shoot total N at anthesis	-0.509	0.460	-0.206	0.208	-0.044	-0.033	0.663
Plant height	0.142	0.595	0.433	-0.597	-0.167	-0.232	-0.004
General growth score	0.160	0.276	0.032	-0.049	0.068	0.943	0.009
Flag leaf length	0.312	0.314	0.192	0.386	0.764	-0.186	0.003
Eigenvalues	**112.6**	**64.0**	**46.8**	**25.2**	**20.9**	**7.7**	**0.3**
Percent of variance	**40.6**	**23.1**	**16.9**	**9.1**	**7.5**	**2.8**	**0.1**
Cumulative variance (%)	**40.6**	**63.7**	**80.6**	**89.6**	**97.1**	**99.9**	**100.0**

DISCUSSION

In each year, significant genotypic differences in grain yield and GPC responses to N were measured. However, there was a large year effect on the responses to N among the cultivars and over the two experiments, there was no significant correlation between the yield response of cultivars. Yields at Northfield were lower than at Charlick and did not respond as much to N despite a greater vegetative growth (e.g., greater plant height and flag leaf length) and a larger response in vegetative growth to N; in some cultivars, grain yields declined with added N. The disparity in the responses in vegetative growth and yield may not be unrelated because under rainfed conditions there will often be an optimum amount of dry matter production for grain yield which depends in part on the availability of soil moisture near anthesis and during grain filling (4). Vigorous vegetative growth followed by relatively dry conditions around ear emergence and during grain filling can limit the response to applied N. At Northfield, low rainfall during November 1991 coupled with a later time of ear emergence (Tables 1, 2) may have reduced grain growth; the occurrence of boron toxicity may have adversely affected yield as well. These differences in response to N in the field emphasizes the over-riding influence that seasonal conditions may have on genotypic variation in N response and the difficulty it imposes on selection for N responsiveness. The poor correlation in the yields of cultivars between the two sites suggests that for the barley growing areas of South Australia a number of responsive cultivars suited to the range of environments where barley is grown may be needed. For example, in areas where the chance of boron toxicity is high, breeding for greater boron tolerance may also increase the chance of improved grain yield responsivenss to N.

Despite the difference in reponsiveness between sites, the results for a number of the cultivars agree with some previous reports on their responsiveness. For example, Parwan had a low GPC at Charlick and Schooner showed high responses in GPC in both years (Table 3), responses which are consistent with those reported for these cultivars by Wheeler *et* *al.* (17). These workers also reported that O'Connor yielded well at 0 Kg N ha^{-1}, but showed relatively little yield response to N, which is also consistent with the results of the present experiments. It appears, therefore, that there are genotypic differences in responses in yield and GPC which can be exploited in developing cultivars responsive to N.

There was a significant negative relationship beween mean grain yield and mean GPC across the 78 cultivars (Fig. 1, a and d), although there was a considerable scatter around the general trend line. In contrast to the negative relationship between yield and GPC, there was no correlation between the responses in grain yield and GPC to applied N, either in absolute or relative terms (Fig. 1, b, c, e and f). These data suggest that grain yield and GPC responses were essentially independent variables and that it may be possible to select for GPC responses specifically without substantially altering yield potential. This agrees with data presented by Wheeler *et al.* (17) who showed that variation in response of yield and GPC to N were independent. Previously, Piper and Rasmusson (16), using populations derived from crosses between high and low protein lines, suggested that it may be possible to select for low protein barley, but the results from the present experiments indicate that this idea may be extended to selecting cultivars that show high yield responses and low protein responses. However, the large differences between sites noted previously need to be taken into consideration and further work is needed on the consistency of responses to N among cultivars, the most appropriate sites for selection and the most efficient methods for screening. The observation that were more significant nitrogen × cultivar interactions at Charlick suggests that sites and/or seasons that are conductive to positive yield responses to N are the most suitable for examining genotypic variations in N responsiveness.

The experiments demonstrated plant height to be an important character for N responsiveness. Although seasonal and edaphic conditions were different between the two experiments, responsiveness to N was inversely related to height in both years. In these two experiments, lodging was not a problem, so the results suggest that there is some other factor associated with height which contribute to responsiveness. Improvements in yield associated with reductions in height and improved partitioning of dry matter have been well documented in wheat (14) and this has also contributed to improve N use efficiency (5). Reduced height has also helped to improve the yield of barley (18) although the results are not totally clear-cut because data of Ali *et al.* (1) suggest that the contribution of reduced height to yield may be relatively small in some cases. There are few results that show what effect a reduction in height has had on N use efficiency of barley. Nedel *et al.* (15) found no difference in the response to N between standard height and semidwarf isotypes of barley, but they conceded that the poor yields of the semidwarf may be due to the fact that they were derived from induced mutants and there had been little further genetic improvement of the lines. Apart from genetic differences, height is also reduced with N deficiency, so the negative effect that height had on yield response may indicate that cultivars better able to grow at low levels of soil available N (and hence are taller) may, as a consequence, be less responsive to applied N. In addition to N responsiveness, plant height was related to yield, although not in a consistent manner. At Northfield, where there was a large response in vegetative growth to N, yield was positively correlated with height (Table 5). However, at the more responsive site at Charlick, yield and height were inversely related (Table 6). The importance of plant height to yield responsiveness in barley still requires further study and its importance relative to stem strength *per se* needs to be evaluated.

The importance of the time of ear emergence to yield and yield response to N were equivocal. At Northfield, late ear emergence was associated with lower yields at both levels of N. This is inconsistent with the trends observed in wheat improvement in Australia where there has been a gradual reduction in the time from sowing to flowering over time (14). However, in terms of the response to N, late ear emergence was associated with a higher yield response. This seems somewhat paradoxical, given the generally accepted importance of early flowering in Mediterranean environments (14). The pattern of development in cereals can be greatly affected by the level of N nutrition as well as by cultivar (13) and the correlation between later ear emergence and yield responsiveness may be associated with changes in the timing of other developmental events that influence ear or spikelet numbers. The importance of maturity to N responsiveness which was observed in two years with quite different yield responses suggests that this area needs further investigation.

At northfield, PCA suggested that cultivars which showed more severe symptoms of boron toxicity at 0 Kg N ha^{-1} tended to be more responsive to N. Gupta (8) considers that N nutrition can be important in affecting boron uptake by plants. He cites several examples where, under high levels of boron, addition of N decreased boron uptake and concentrations in plants. At Northfield, adding N significantly reduced the symptoms of boron toxicity suggesting that adding N may have alleviated boron toxicity. The effect may be in the most sensitive cultivars, which may be an explanation of the positive contribution of boron score to N responsiveness.

CONCLUSION

These experiments have shown that it is possible to screen a large number of cultivars at two N rates in the field to help identify desirable cultivars. However, it also showed that there is a large influence of the environment on the responsiveness of barley cultivar to N, which means that such screening needs to be conducted over a number of sites and years. Much of the variation in yield and in the responses to N fartilizer was related to the time of ear emergence and the height of the crop. The importance of interactions with other nutritional problems to N responsiveness was seen at Northfield where boron toxicity influenced barley response to N.

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