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Responsiveness of Wheat Cultivars to Nitrogen Fertilizer

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Abstract: Genotypic differences in responses to nitrogen (N) fertilizer of 6 cultivar of wheat (Atrak, Falat, Fong, Star, Showa, Atila) grown at 6 different rates of N (0, 50, 100, 150, 200 and 250 kg N ha^{-1}) were examined. Measurements of vegetative growth, N content, grain yield (GY), grain protein concentration (GPC) and yield components were taken to identify traits that may contribute to high yield responsiveness. The optimum rates of N for dry matter production at ear emergance (DM_{ee}) were greater than 80 kg N ha^{-1} for all cultivar and often growth increased up to 105 kg N ha^{-1}. Optimum rates of N for grain yield (Nopt) were lower and ranged, on average, from 50 kg N ha^{-1} for Clipper to 96 kg N ha^{-1} for Showa. The initial response to N varied from 13-14 kg kg^{-1} N in Showa, Fong and Star, to 36 kg kg^{-1} N in Atila. The N_{opt} for Atila was 71 kg N ha^{-1} and it tended to show the greatest yield response to N. It produced 19 kernels/g DM_{ee}, compared with 15-17 kernels/g DM_{ee} in the other cultivars. Unlike most other cultivars, Atila's yield was consistently and positively correlated with ears m^2, Falat was the only cultivar to show a similar relationship. However, the average kernel weight of Atlia was up to 5 mg lower than that of Atrak, Fong and Star and varied more than these cultivars between sites, suggesting that consistent grain size may be a problem in this cultivar. Atrak and Star had lower Nopt (51 kg ha^{-1}) and a less variable kernel weight. There were no signs of differences in GPC of the 6 cultivars used at 3 N-responsive sites. Adding N increased GPC up to the highest rate of N and the responses were generally linear. Average N rates of between 38 kg N ha^{-1} (Star) and 58 kg N ha^{-1} (Atila) were sufficient to raise GPC above 11.8%. The experiments showed that the N rates for optimum yields varied considerably among cultivars, but applying rates to achieve maximum yields may cause GPC to exceed the maximum value.

Key words: N fertilizer, growth, grain yield, grain protein, wheat

INTRODUCTION

There has been an increase in the use of Nitrogen (N) fertilizer in the production of wheat cultivars across southern regions of Iran as farmers try to increase their profitability by improving crop yields. Increasing N rates does not necessarily, however, improve Grain Yield (GY) and quality unless tailored to crop requirements for a variety of conditions (David, 1997). Inappropriate N management may result in lodging and loss of N through leaching, denitrification and N volatilization. Wheat crops are frequently subjected to N deficiency, due to low rates of N fertilizer application, organic farming practices (Sabine and Marie, 2001), or a delay between the optimal time for N application, corresponding to a period when the crop has a high N requirement and the date on which the N fertilizer is applied by the farmer (Meynard *et al*., 1988; Kirda *et al*., 2001).

The N deficiency may last until harvest if no extra N fertilizer for one to several weeks after the beginning to the deficiency. Grain number, the principal determinant of yield (Alcoz *et al*., 1993; Corbels *et al*., 1998), is reduced in crops subjected to N deficiency before anthesis (Abbate *et al*., 1995; Jeuffory and Bouchard, 1999). If nutrition conditions vary, then grain number is strongly correlated to spike dry matter and N content at anthesis (Ellen and Spiertz, 1980; Fischer, 1993). At anthesis, the proportion of aerial spike dry matter is lower in plant receiving low rates of N fertilizer than in plants receiving high rates (Limaux *et al*., 1999). However, aviation in this responses to N do exist between cultivars, but the expression of these differences may depend on the environmental conditions under which the cultivars are grown.

Under appropriate conditions it is possible to increase grain yield and grain protein concentration (GPC) within the devisable range (Ehdaie and Waines, 2001; Kirda *et al.,* 2001). Alcoz *et al*. (1993) found that GPC increased with added N (0-200 kg N ha^{-1}) and that there were different responses between cultivars. The work of Alcoz *et al.* (1993) was conducted under irrigated conditions where large responses are favoured and the likelihood of adverse effects of high rates of N on grain set and grain filling are less than under dryland conditions. However, the extensive array of field experiments conducted with wheat across southern Iran indicates that cultivars for yield and GPC response.

To manage N efficiency in wheat cultivars, the importance of genotype to the yield and GPC responses needs to be examined. Therefore, experiments were conducted to characterize the grain yield and GPC response in wheat cultivars with different yield potentials and quality attributes to a wide range of N rates. Data on vegetative and grain yield and GPC were collected to quantify the response of wheat to N fertilizer and to examine the interaction between cultivars and N rate on plant growth, grain yield and GPC.

MATERIALS AND METHODS

Sites: Experiments were conducted two years (2001 and 2002) in south Iran at 4 sites in the medium annual rainfall zone (300-350 mm) of the cereal belt at the Bahbahan Research Center and Shushter in 2001 and at Ramin Agricultural Research and Education Center, Mollasani and Bahbahan Research Center in 2002 in Khuzestan province. Characteristics of the 2 sites are grown in Table 1.

Treatments and experimental design: Experiments were conducted in the field using a split-plot design with 4 replicates. Six wheat cultivars (Atrak, Falat, Fong, Star, Showa, Atila) were grown at 8 rates of added N (kg N ha^{-1}: 0,15, 30, 45, 60, 75, 90, 105). The cultivars are bread wheat, except for showa, which is classified as durum wheat. These 6 cultivars have been or are currently grown in south Iran. In south Iran, Fong is classified as an early cultivar, Atrak, Falat, Showa and Atila as mid-late season. The main plots were wheat cultivars while levels of N (46%N) in two time 6 weeks after sowing and stem elongation. A basal dressing of superphosphate (50 kg P ha^{-1}) was drilled with the seed at sowing. Weeds were controlled by the use of herbicides and were not considered to be a factor in the yield responses.

Establishment of the experiment: Each cultivar was sown in rows 20 cm apart. Plot sizes were 10 rows wide by 12 m long. Plots were sown on 6 and 8 December in 2001 and 2002, respectively. Before sowing in both years, germination tests were conducted on 5 g of seed and sowing rates were adjusted to 145 seed m^2. Seeds were sown 25-35 mm deep.

Measurements

Dry matter: At 2 sites, Bahbahan and Mollasani, in 2002 plots was sampled at about 10 weeks after sowing to assess early crop growth. Measurements were based on a quadrate size of 2 rows by 0.5 m at 2 locations per plot.

Table 1: Characteristics of the sites in 2001 and 2002

	Bahbahan 2001	Shushter 2001	Bahbahan 2002	Mollasani 2002
Rainfall (mm)				
November-March	345	264	345	275
Mean temperature (°C)				
November-March	21.5	22.6	19.5	20.5
Previous Crops				
Year 2	Wheat	Wheat	Barley	Wheat
Year 1	Repe seed	Barley	Wheat	Wheat
Soil type				
	Silty clay	Silty	Silty clay	Silty clay
Soil pH ($CaCl_2$)				
0-30 cm	7.5	5.8	7.6	7.1
30-60 cm	7.6	6.1	7.9	7.5
Soil nitrate N at sowing (μg g)				
0-30 cm	15.2	16.8	20.1	17.8
30-60 cm	16.5	19.8	22.5	22.6

Samples were taken at tillering (Zadoks *et al.*, 1974) at Bahbahan in 2002 and at stem elongation at Mollasani in 2002. At the sites a sample was taken at ear emergence. Dry matter production at ear emergence (DM_{ce}) was estimated from a single, randomly selected quadrate (0.30 m^2) from each plot. The samples were oven-dried at 80°C for 48 h and dry matter determined.

Above-ground dry matter at maturity was measure following the same sampling technique used at ear emergence. Ear number was counted or each sample and the grain threshed from the ears, Individual kernel weight was estimated from a sample of 100 grains from each quadrate sample and the number of kernels/m^2 was derived from the quadrate grain yield and the mean kernel weight. Nitrogen concentration in the grain and straw was measured after digestion by the kjeldahl method and the N concentration of the grain was multiplied by 6.25 to give GPC. Nitrogen Harvest Index (NHI) was calculated as the ratio of grain N content to total N content. Grain yield was estimated at the end of the experiment after harvesting 8 rows using a small plot harvester.

Nitrogen analysis. Dried material was ground to pass through a 1 mm sieve and 1 g was used for analysis. The sample and a catalyst tablet containing selenium and potassium sulfate were digested with 15 mL of concentrated sulfuric acid at 390°C. The digest was diluted with 50 mL of water and the amount of N in the digest determined by steam distillation and titration with 0.1 mol HCl L using a kjeltec Autoanalyser.

Statistical analyses: All data were analyzed by analysis of variance using SPSS. Data form the 4 sites were analyzed in a combined analysis of variance, after checking for homogeneity of variance, to examine the interactions between site, N and cultivar. The responses to N at each site were examined using linear and quadratic contrasts. For grain yield and dry matter production, the quadratic effect was significant and curves were fitted to the data. From these curves, 4 parameters were calculated to characterize a cultivars's response to N: (I) yield with zero applied N (Yo); (ii) slope at N= 0, to estimate the initial responsiveness; (iii) N required to achieve the maximum yield (N_{opt}) and (IV) the maximum yield level (yield at N_{opt}; Y_{max}). The relative importance of the different yield components to yield was assessed using simple correlations.

RESULTS

Seasonal weather: Seasonal rainfall, particular spring rainfall, was lower and temperatures higher in 2001 compared with 2002 (Table 1). Winter rainfall at all sites was 32-53 mm above average, suggesting responses to N before anthesis was unlikely to have been limited by availability of moisture.

General results: The analysis of variance over the 4 sites indicated that there were major effects of site, cultivar and N rate on dry matter production, yield and GPC. The highest mean site yield was 3.35 t ha^{-1} at Bahbahan in 2002 and the lowest at Mollasani in 2002 and Shushtar in 2001 (Table 2). Average GPC ranged from 11.1% (Bahbahan 2002) to 14% (Shushter 2001). There was a significant interaction between cultivars and N rate for grain yield and a significant site×cultivar×N rate interaction for DM_{ee}, GPC and ears m^{-2} which was caused mainly by the low response to N at Shushter (Fig. 1).

Average responses to N at each site: Applied N significantly increased DM_{ee} at all sites, although overall growth and the response to N were much less at Shushter than at the other sites (Fig. 1). Significant grain yield responses to N occurred at 3 sites, Bahbahan 2001, 2002 and Mollasani 2002 but not at Shushter (Fig. 1). At these 3 N-responsive sites, the quadratic component of the main effect of N was significant. Lower yield was obtained at Shushter than at Bahbahan 2001 even though greater vegetative growth occurred. The discussions on N responses that follow will concentrate on the 3 responsive sites (Bahbanhan 2001 and 2002, Mollasani 2002). Where there is no significant interaction with site, data are presented as the average response over the 3 responsive sites.

Cultivar responses to N

Early growth: Growth after 10 weeks (DM_{10}) was greater at Mollasani than at Bahbahan in 2002, but at both sites there was a large dry matter response to N, although significant responses sometimes occurred only after 15 or 30 kg N ha^{-1} were applied (Fig. 2). On average, Fong produce most dry matter and responded to N up to the highest rate.

Table 2: Average values for dry matter production at ear emergence (DM_{ee}) grain yield (GY), grain protein concentration (GPC) and yield components at 4 sites in 2001 and 2002

Site	DM_{ee} (g m^{-2})	GY (t ha^{-1})	GPC (%)	Ears No. m^{-2}	Kernels No. m^{-2}X10^{-3}	Kernel wight(mg)
Bahbahan 2001	458	2.89	12.5	437	6.59	38.1
Shushter 2001	377	2.59	14.0	460	5.87	39.1
Bahbahan 2002	675	3.35	11.1	521	11.9	36.8
Mollasani 2002	556	2.47	12.4	463	7.85	38.4
LSD (p = 0.05)	56	0.35	0.8	45	0.85	1.6

Table 3: Average values for grain yield, ear number, kernel number, kernel weight and grain protein concentration for 6 wheat cultivars grown at 4 sites in 2001 and 2002

Site	Atrak	Falat	Fong	Star	Showa	Atila	LSD (p = 0.05)
Grain yield (t ha^{-1})							
Bahbahan 2001	2.86	2.95	2.83	2.74	2.96	2.84	Ns
Shushter 2001	2.68	2.64	2.44	2.51	2.53	2.66	ns
Bahbahan 2002	3.20	3.16	2.85	3.53	3.52	3.56	0.40
Mollasani 2002	1.97	2.58	1.76	2.63	2.74	3.02	0.82
Ear number m^{-2}							
Bahbahan 2001	467	427	481	377	450	423	ns
Shushter 2001	488	465	410	470	457	471	ns
Bahbahan 2002	515	496	476	510	556	567	ns
Mollasani 2002	415	421	374	497	520	56 2	41
Kernel number m^{-2}							
Bahbahan 2001	6.16	6.61	6.83	5.70	6.31	7.50	ns
Shushter 2001	5.86	5.95	5.52	5.61	5.84	6.34	ns
Bahbahan 2002	11.40	10.92	11.16	12.32	13.17	12.20	ns
Mollasani 2002	7.06	8.21	6.01	8.02	7.94	9.85	ns
Kernel weight (mg)							
Bahbahan 2001	39.8	37.3	38.4	38.5	38.9	37.4	0.6
Shushter 2001	42.5	42.0	40.4	41.0	40.1	40.1	0.8
Bahbahan 2002	39.4	33.8	38.7	37.2	37.4	33.9	1.6
Mollasani 2002	41.8	38.6	36.8	41.4	38.8	39.3	ns
Grain protein concentration (%)							
Bahbahan 2001	12.5	12.4	12.6	12.6	12.3	12.8	ns
Shushter 2001	15.9	15.7	15.8	16.1	15.7	15.7	ns
Bahbahan 2002	10.8	11.8	10.6	10.9	10.9	11.1	ns
Mollasani 2002	12.2	12.3	13.6	13.2	13.5	11.2	ns

Dry matter at ear emergence: Additions of N increased DM_{ee}, although the responses varied considerably between site (Fig. 1) and cultivars. The optimum rate N was in excess of 80 kg N ha^{-1} in all cultivars and often DM_{ee} increased up to the highest rate of N applied.

Grain yield: Yield declined at the highest N rates. Optimum rates of N (averaged over the 3 sites) were Atrak and Star, 15 kg N ha^{-1}; Fong, 59 kg N ha^{-1}; Atila, 71 kg N ha^{-1}; Falat, 78 kg N ha^{-1}; and Showa, 96 kg N ha^{-1} (Fig. 3). The initial yield responses to N were: Showa, 13.3 kg kg N^{-1}; Star, 14.1 kg kg N^{-1}; Fong, 14.8 kg kg N^{-1}; Falat, 21.9 kg kg N^{-1}; Atrak, 25.3 kg kg N^{-1} and Atila, 36.1 g kg^{-1} N. Showa had a high predicted N_{opt} but its initial response was low, whereas the low-yielding cultivar Fong had a low N_{opt} as well as a poor initial response to N. The greatest Y_{max} (3.52 t ha^{-1}) was predicted for Atila and

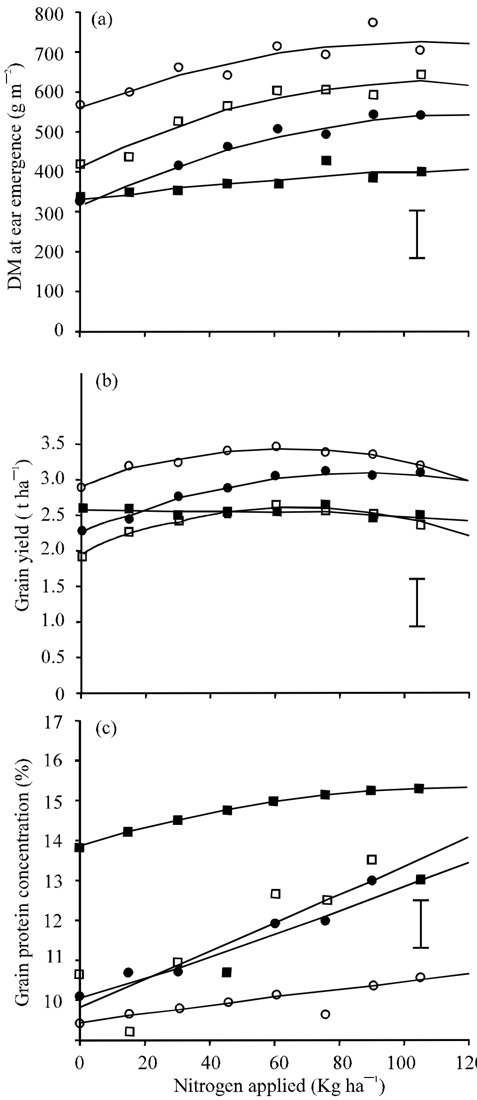

Fig. 1: Effect of the rate of N on (a) dry matter production at ear emergence, (b) grain yield and (c) grain protein concentration at 4 sites, Bahbahan (●) and Shushter (■) in 2001 and Bahbahan (○) and Mollasani (□) in 2002. LSD (p = 0.05) values from the analysis of variance over the 4 sites are shown

the lowest for fong (2.62 t ha^{-1}). Differences in the responsiveness of the 6 cultivars can also be assessed from the relative increase in yield between Y_0 and Y_{max}; these were: Atrak, 29%: Falat, 36%; Fong, 20%; Star, 13%; Showa, 24% and Atila, 57%.

The large responses in dry matter production observed after 10 weeks did not benefit yield in most cases. In Falat and Atila, grain yield was positively correlated with dry matter production at 10 weeks after sowing (Table 4), while with Fong at Bahbahan 2002 there was a negative correlation. Improved early growth due to addition of N was not significantly correlated with yield in the remaining cultivars.

At Bahbahan 2001, there was a positive relationship between DM_{ee} and grain yield within each cultivar but at the other sites DM_{ee} and yield were not correlated (Table 4). Dry matter production at Bahbahan 2001 was lower than at the other sites (Table 2) and the positive correlation with yield may reflect the poorer productivity of the crops at this site.

Grain protein concentration: There was no significant difference in the average GPC of the 6 cultivars among the 3 responsive sites (Table 3). Adding N increased the GPC up to the highest rate, although there were small differences between cultivars in the initial response to N (Fig. 3). This response was significantly linear for all cultivars except Falat and Showa. In these 2 cultivars GPC did not increase significantly until either 45 or 60 kg N ha^{-1} had been applied. A similar response was apparent in Atila, but because of the greater variability in the data, there was no significant improvement by describing the data using a polynomial equation. The responsiveness in GPC to N among the remaining cultivars was Fong>Star>Atrak>Atila, which was the inverse of the ranking of the grain yield response among these 4 cultivars. GPC did not exceed 11.9% until between 38 kg N ha^{-1} (Star) and 58 kg N ha^{-1} (Atila) was added to the crop (Fig. 3). Except for Atrak, in which N_{opt} coincided with the N rate at 11.9% GPC, these rates were well below the N_{opt} for the cultivar. The rates ranged from 47% of N_{opt} in Shown to 82% in Atila, but were generally within the range of 70-80% of N_{opt}. There were no significant differences in the NHI between genotypes and NHI declined at the highest rates of applied N at all sites largely to the effect of N on grain yield (data not Shown).

Yield components

Ear number: Ear number responded significantly and positively to added N up to the highest rate of N at 3 responsive sites (Bahbahan 2001 and 2002, Mollasani 2002). For Atila and Falat in particular, there was a significant correlation between grain yield and ears m^2 (Table 4). At Bahbahan 2001, when the average number of ears m^2 was lower than at the other 2 responsive sites (Table 2), the yield of most cultivars was significantly correlated with ears m^2 and the application of N stimulated growth through greater tillering and ear production.

Kernel number: There were no significant differences between cultivars, in the number of kernels/m^2 (Table 3). Adding N increased kernel number, but generally the

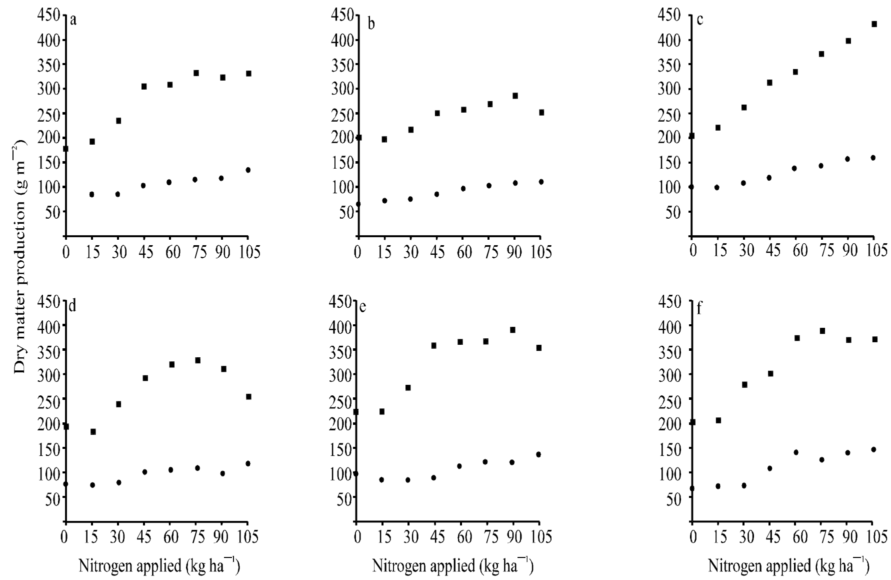

Fig. 2: Effect of the rate of N on dry matter production 10 weeks after sowing in 6 cultivars of wheat at Bahbahan (●) and Mollasani (■) in 2002. (a) Atrak, (b) Falat, (c) Fong, (d) Star, (e) Showa, (f) Atila

Table 4: Simple correlation coefficients between plot grain yield, yield components and grain protein concentration (GPC)

Cultivar	DM_{10}	DM_{ee}	E No. m^{-2}	K No. m^{-2}	KW	GPC
Bahbahan 2001						
Atrak	0.33	0.74*	0.61	0.69	-0.52	0.61
Falat	0.76*	0.91**	0.71*	0.79*	-0.30	0.51
Fong	-0.73*	0.75*	0.25	0.13	-0.58	0.27
Star	0.43	0.84**	0.74*	0.62	-0.90**	0.82*
Showa	0.52	0.88**	0.82*	0.51	-0.64	0.88**
Atila	0.82*	0.78*	0.94**	0.90**	-0.86**	0.65
Bahbahan 2002						
Atrak	0.27	0.21	0.47	-0.29	-0.06	0.17
Falat	0.81*	0.66	0.77*	0.06	-0.68	0.58
Fong	-0.71*	-0.51	-0.48	-0.32	0.61	-0.56
Star	-0.17	0.53	0.31	0.33	-0.02	0.32
Showa	0.41	0.51	0.78*	0.63	-0.23	0.39
Atila	0.79*	0.33	0.91**	0.70*	-0.56	-0.15
Mollasani 2002						
Atrak	0.40	0.42	0.19	0.57	-0.02	0.29
Falat	0.74*	0.41	-0.18	0.63	-0.70*	0.32
Fong	0.41	0.20	-0.01	0.48	-0.36	0.34
Star	-0.09	-0.29	-0.15	0.53	0.54	-0.68
Showa	0.63	0.64	0.22	0.34	-0.61	0.39
Atila	0.84*	0.77**	0.96**	0.72*	-0.67	-0.01

* $p<0.05$, ** $p<0.01$, DM_{10} = Dry Matter at 10 weeks, DM_{ee} = Dry Matter at ear emergence, ENO = Ear Number, KNO = Kernel Number, KW = Kernel Weight

Table 5: Intercept and slope (±SE) of the regression between kernel weight (mg) and N rate (kg ha^{-1}) at 3 sites responsive to N fertilizer

Cultivar	Intercept (mg)	Slope (mg kg^{-1} Nm^2)	R^2	Signif.
Bahbahan 2001				
Atrak	41.4	-0.033±0.019	0.55	*
Falat	40.1	-0.056±0.012	0.78	**
Fong	40.6	-0.044±0.012	0.69	*
Star	40.5	-0.039±0.013	0.59	
Showa	39.9	-0.020±0.009	0.42	ns
Atila	39.6	-0.043±0.009	0.82	**
Bahbahan 2002				
Atrak	41.2	-0.038±0.018	0.44	ns
Falat	36.4	-0.083±0.013	0.75	**
Fong	41.3	-0.051±0.017	0.61	*
Star	39.7	-0.043±0.006	0.90	**
Showa	38.8	-0.021±0.007	0.57	*
Atila	36.9	-0.060±0.008	0.89	**
Mollasani 2002				
Atrak	42.8	-0.015±0.026	0.05	ns
Falat	39.4	-0.017±0.018	0.11	ns
Fong	43.6	-0.088±0.036	0.50	ns
Star	43.4	-0.089±0.036	0.52	*
Showa	43.2	-0.035±0.028	0.21	ns
Atila	41.3	-0.038±0.013	0.59	*

* $p<0.05$, ** $p<0.01$, ns, not significant

increases were only about 200-400/m^2. Of the 6 cultivars examined, only the yield of Atila was correlated with kernels/m^2 at each responsive site (Table 4). On average, the ratio between kernels/m^2 and DMee was highest in Atila (19.2) and there was little difference between the other cultivars.

Kernel weight: Kernel weight generally declined as the N rate increased at all sites (Table 5) and it was lowest at the higher yielding sites (Table 2). The kernel weight to Showa and Atrak tended to be less affected by N rate than the other cultivars (Table 5). At Bahbahan in 2001, the decline in kernel weight in Falat tended to be greater than that of the other cultivars and at Bahbahan in 2002, the kernel weight of Falat and Atila was sensitive to N rate. Where the linear relationship between kernel weight and N rate was not significant, significant reductions in kernel weight did not occur until rates of N>45 kg N ha^{-1},

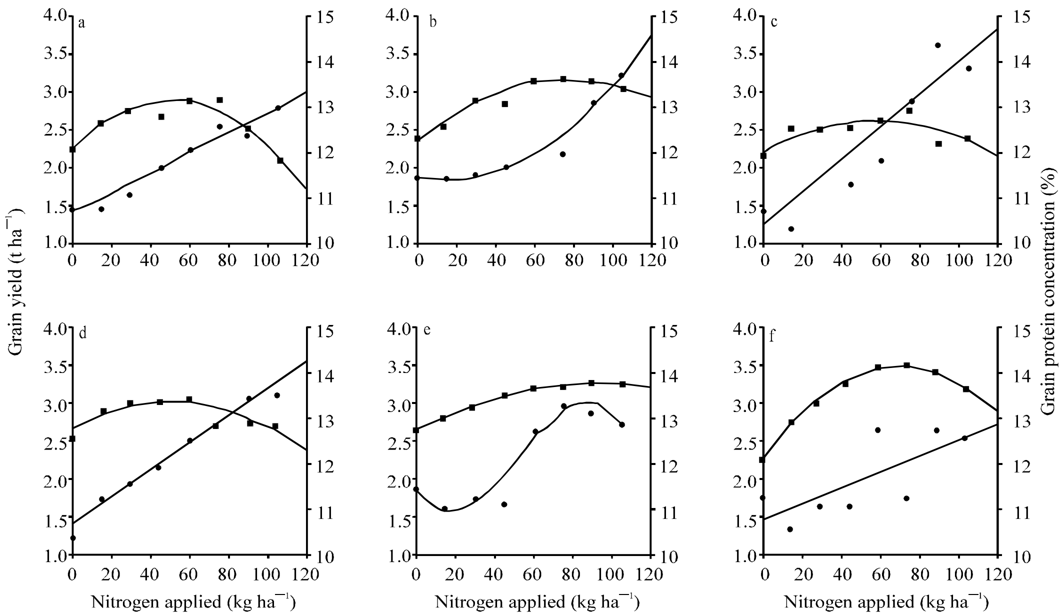

Fig. 3: Responses of grain yield (■) and grain protein concentration (●) to N in 6 wheat cultivars: (a) Atrak, (b) Falat, (c) Fong, (d) Star, (e) Showa, (f) Atila. The values are the average of the 3 responsive sites, Bahbahan 2001 and 2002 and Mollasani 2002. The equations relating grain yield (Y) and GPC (P) to N rate are:

Atrak: $Y = 2.25+0.025\ N-0.0025\ N^2$ ($r^2 = 0.824$, $p<0.01$)

$P = 10.63+0.0225\ N$ ($r^2 = 0.938$, $p<0.01$)

Falat: $Y = 2.33+0.0218\ N-0.00014N^2$ ($r^2 = 0.862$, $p<0.01$)

$P = 11.47-0.0103\ N+0.00028N^2$ ($r^2 = 0.929$, $p<0.01$)

Fong: $Y = 2.19+0.0148\ N-0.00013N^2$ ($r^2 = 0.484$, $p<0.01$)

$Y = 10.32+0.036\ N-0.00012N^2$ ($r^2 = 0.770$, $p<0.01$)

Star: $Y = 2.68+0.0141\ N-0.00014N^2$ ($r^2 = 0.420$, $p<0.01$)

$Y = 10.61+0.031\ N$ ($r^2 = 0.970$, $p<0.01$)

Showa: $Y = 2.63+0.0134\ N-0.00071N^2$ ($r^2 = 0.960$, $p<0.01$)

$Y = 11.48+0.068\ N-0.0022N^2-0.0001N^3$ ($r^2 = 0.830$, $p<0.01$)

Atila: $Y = 2.33+0.0361\ N-0.0002N^2$ ($r^2 = 0.960$, $p<0.01$)

$Y = 10.75+0.017\ N$ ($r^2 = 0.460$, $p<0.01$)

were applied. Reductions in kernel weight from applying 45 kg N ha^{-1} ranged from 0.3 mg in Showa (Bahbahan 2002) to 3.6 mg in Star (Mollasani, 2002), with most reductions being 1.5-2.0 mg (Table 5).

DISCUSSION

Selecting for responsiveness, or at least identifying genotypes that are more likely to show good responses to N, would improve the chances of achieving economic responses to N in wheat. The complex interaction between climate, soil fertility and genotype in determining grain yield and GPC means that developing cultivars of wheat which are responsive to N and which have appropriate quality characteristics.

Grain yield: In this experiments, seasonal and site conditions had an over-riding effect on yield responses to N and on the ability to discriminate between cultivars. Of the 4 sites chosen for these experiments, a significant response in grain yield to N was obtained at 3 and the site optimum N rate varied from about 45 kg N ha^{-1} up to about 90 kg N ha^{-1}. The cultivar×N interactions were most evident at Bahbahan 2001 and 2002, which were the 2 sites with the highest productivity (Table 2). These differences in responses to N fertilizer are typical of experiments in southern Iran (Siadat 2000, Fathi 2001), but site selection assumes considerable importance in studies of this type. Genotypic differences and significant cultivar×N interactions were found with grain yield rather than GPC, although closer examination in the GPC responses to N. Nevertheless, differences between cultivars are more strongly expressed in yield than in GPC and therefore it is preferable to select sites where there is a high probability of achieving a significant yield response. Vegetative growth, measured by DM_{10} and

DM_{ee}, had higher optimum rates of N than those measured for grain yield. In both seasons, winter rainfall was high and above average, which was conductive to responses to N. However, these increases in dry matter production were only correlated with grain yield in Falat and Atila (Table 4); for Fong at Bahbahan 2002 DM_{10} was negatively correlated with yield (Table 4). Large increases in dry matter production early in the growing season may not increase yields of winter cereals, or may even decrease yields in some cases if it results in depletion of soil moisture or increased lodging (Fischer, 1979). It seams that dry matter production was not a major limitation to yield in these experiments, except at Bahbahan 2001, but the data suggest that partitioning of the dry matter to the developing ear was an important factor in the yield differences between cultivars.

Atila showed highest response to N although DM_{ee} and ear numbers were not significantly different from most of the other cultivars. The ratio of kernel number to dry matter at anthesis (DM_a or DM_{ee}) is a measure of the efficiency of production of fertile reproductive sites and it will be influenced by the source-sink relationship before anthesis. Fischer (1979) and Anderson and Smith (1990) that short wheat produced 10-13 kernels/g DM_{ee} and tall wheat 7-8 kernel/g DM_a. A similar result was found among the 6 wheat cultivars. Atila produced more kernels/g DM_{ee} (19.2) than the other, tall cultivars (14.5-17.4). Andreson and Smith (1990) concluded that the yield advantage of a semi-dwarf wheat was related to both greater kernel number per unit area and a greater kernel size (Fig. 3a and b). However, the yield advantage of Atila was related to kernels/m^2.

Kernels weight: The average kernel weight of Atila and Falat was significantly lower than of the other cultivars at 2 of the 3 responsive sites (Table 3). As well, the variation in mean kernel weight between sites for Star and Showa. Across the 4 sites, the mean kernel weight of Atila ranged by 6.3 mg and Falat by 8.2 mg, whereas the range in kernel weight of the other cultivars was about 3-4 mg. At Bahbahan 2001 and 2002 the reduction in kernel weight with added N for Falat and Atila tended to be slightly greater than that of other cultivars, although not significantly (Table 5). Lower kernel weight of Atila and Falat may be due to the greater sensitivity of these cultivars to environmental conditions relative to that of the other cultivars examined. The smaller and more variable weight of the kernels in Atila and Falat cannot be simply explained by differences in kernels/m^2 because there was no relationship between the kernels/m^2 produced by individual cultivars and their kernel weight. The reduction in kernel weight between wheat cultivars may be due to differences in the development of post-anthesis water deficits. Post-anthesis drought reduces kernel weight in wheat (Bidinger *et al.*, 1977). Pot experiments with these cultivars have shown that Atila produces less root dry matter than the other cultivars (G. Fathi unpublished data). This may prevent the cultviar from exploiting subsoil reserves of moisture, making it more susceptible to post-anthesis water deficits. However, even grown in pots in the glasshouse, the kernel weight of Atila was sensitive to post-anthesis water deficits, particularly when grown at high rates of N.

Cultivar responses to applied nitrogen: The cultivar responses to applied N are based on average responses from a limited number of sites, although a number of the observations are consistent with field experiences with these cultivars. Arak was low yielding, had a relatively low N_{opt} and suffered a relatively large yield loss when supra-optimal N rates were applied. However, Atrak tended to have a high mean kernel weight and was able to maintain its kernel weight over a range of sites and N rates. Atrak, there fore, seems suited to relatively low fertility conditions and consistently gives a relatively large grain size.

Star, a widely grown cultivar in South Iran, yielded higher than Atrak on average and also had relatively low N_{opt}. However, the GPC Star tended to be more responsive to N than most other cultivars and of all the cultivars it required the least amount of N to exceed 11.8% GPC. Also, its kernel weight was slightly more sensitive to N than Atrak at one site. Therefore, although Star has the potential to yield well, the greater sensitivity of GPC and, to a lesser extent, kernel weight, suggests that its variation in some aspects of quality may be greater than Atrak.

Showa showed yield responses to N that were different to Atrak and Star. It yielded well when no N was applied had a high N_{opt}, maintained a relatively low GPC and high kernel weight over different N rates. Showa also had a low initial increase in GPC with the addition of N. These characteristics suggest that N management may be less critical in Showa than in some other cultivars, such as Atila. The Falat yield response to N suggests that variation in applied N may not substantially alter yield and the high N_{opt} means that there is a lower risk of inducing the yield reductions at high N rates seen in Atrak and Star. Atila was the most responsive cultivar but the yield of Atila when no N was applied tended to be low, due to reduced tillering and ear production. Stimulating early vegetative growth in Atila seems more critical to enhanced yields than in some of the other cultivars. Kernel weight of Atila tended to be lower and more variable than in the other cultivars which may be related, in part, to its tillering habit: tiller production in Atila was very responsive to N and under high levels of fertility it generally produced more tillers/m^2 and ears/m^2 than the other cultivars. Also, for the amount of dry matter produced, it set a large number of kernels/m^2.

Consequently, there may be increased levels of intra plants competition for assimilates during grain filling, especially when post-anthesis growth is curtailed by moisture or heat stress which may result in low and variable kernel weights. Therefore, Atila should be grown under higher levels of fertility than Star and in areas where the risk of post-anthesis water deficits in relatively low.

CONCLUSIONS

Considerable variation in the yield response to N was found among the 6 cultivars used but the variation in GPC responses was generally lower. These experiments also suggest that it may be feasible to select cultivars with different levels of responsiveness if some care is taken with the selection of sites and the use of N rates. Because of the curvilinear response to N and the variation in the value of N_{opt}, it recommend that a minimum of 3 levels of N be used, rather than just 2 which is commonly used in macre element screening in South Iran. Genotypic differences in responsiveness in yield responsiveness.

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