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RESEARCH ARTICLE

Effects of nitrogen rates on grain yield and nitrogen agronomic efficiency of durum wheat genotypes under different environments

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Keywords
Biomass yield; genotypic variability; grain yield; landraces; semi-dwarf genotypes.

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Abstract

Durum wheat is an important staple food crop in Tunisia and other Mediterranean countries and is grown in various climatic conditions. Production and yield are however severely limited not only by drought events but also by reduced levels of nitrogen fertilisation. A study was carried out at two locations in the sub-humid area of Tunisia: Mateur in 2009–10 and 2010–11 and Beja in 2011–12 and 2012–13 under rainfed conditions. Four durum wheat genotypes (landraces: Bidi, Azizi; improved: Om Rabia, Khiar) were evaluated for nitrogen agronomic efficiency and related agronomic traits under various nitrogen rates: 0, 50, 100, 150, 200 and 250 kg N ha^{-1}, with three replications. There was a significant interaction effect ($P \leq 0.001$) environments × genotypes × N treatments for grain yield (GY), biomass yield (BY), harvest index (HI), partial factor productivity of applied nitrogen (PFP_N) and nitrogen agronomic use efficiencies (NAE). GY was the most affected trait by nitrogen applied showing an increase of 94% under high N treatment (250 kg N ha^{-1}) compared to control plots without N treatments. A significant linear regression exists between GY (0 N) and GY for the different N rates ($r = 0.70$; $P < 0.001$). This effect was more pronounced for improved genotypes than landraces for all parameters excepting BY and NAE_{BY}. BY showed +11% increase in landraces than improved genotypes. PFP_N showed an average decrease of 65% under high-N fertilisation with 10% prevalence for improved genotypes. Landraces tend to promote vegetative growth while grain filling efficiency was higher for improved genotypes.

Introduction

Wheat derived end products constitute the main staple food in North Africa and for many Mediterranean areas (Latiri-Souki *et al.*, 1998). The total Tunisian wheat domestic consumption is around 2.85 million tons (USDA, 2011) which represent one of the world's highest per capita consumption of wheat estimated at 258 kg per capita per year. Durum wheat is one of the most important grain crops produced in the Mediterranean region and particularly in Tunisia where it accounts for 60% of national cereal production (Latiri *et al.*, 2010; Boukef *et al.*, 2013). During the past 50 years Tunisian nitrogen (N) fertilisers consumption increased by 5.14% annually on average till 2013 (Jarrahi *et al.*, 2013) leading to an average durum wheat yield increase of 33 kg ha^{-1} year^{-1} (Latiri *et al.*, 2010). Therefore, the study of crop responses to N and its agronomic efficiencies is fundamental in order to promote an environmentally friendly use of N fertiliser without hindering production levels (Arregui & Quemada, 2008). Improved wheat requires large amounts of fertilisers to reach maximum yield and high protein content. Nitrogen agronomic efficiency (NAE; grain or biomass yield increase per unit of applied N fertiliser) of improved wheat is not optimal since these genotypes were selected under non-limiting fertilisation conditions (Kichey *et al.*, 2007). Partial factor productivity of nitrogen (PFP_N; the ratio of the grain yield to the applied rate of N) and NAE are useful measures of nitrogen use efficiency (NUE; yield productivity per unit N taken up from soil) as they provide integrative indices that quantify total economic output relative to the use of all nutrient resources in the system (Wang *et al.*, 2007). Decline in partial productivity for N has been reported in cereal based systems leading to greater N cost to sustain yields. According to Cassman *et al.* (1996), PFP_N can be increased by increasing the levels of N or by increasing the efficiency of this nutrient uptake and utilisation for grain production. The relative importance of each yield component is affected by many factors, including genotype, environmental conditions and farmer practices (Brennan *et al.*, 2014; Ortiz-Monasterio *et al.*, 1997). This includes N availability for the plant assimilation as well as N remobilisation from leaves to grains during the filling stages. Pask *et al.* (2012) showed that N status has a major impact on the establishment of yield components. N remobilization efficiency from leaves (the proportion of N in leaves at anthesis which is not present at harvest) is estimated to be within a range of 75% (Kichey *et al.*, 2007). The genetic variability of wheat N uptake efficiency before anthesis determines the potential N that will be remobilised at maturity (Bancal, 2009). Grain yield (GY) variability at high N is closely related to both N uptake and utilisation efficiency (Worku *et al.*, 2007). Meanwhile, at low soil N levels, N utilisation efficiency prevailed (Moll *et al.*, 1982), reflecting the biomass and N partition in wheat tissue (Hirel *et al.*, 2011; Haegele *et al.*, 2013), and the ability to spike development (D'Andrea *et al.*, 2008; Ciampitti *et al.*, 2013).

Large genotypic variability has been reported for wheat NUE (Ortiz-Monasterio *et al.*, 1997; Ayadi *et al.*, 2014). Exploiting genotypic differences for N absorption and utilisation to improve NUE or to reach higher GY constitutes an important wheat breeder goal. Screening for genotypes with high N absorption under low fertiliser would constitute the first step of N efficient genotypes (Le Gouis *et al.*, 2000). Identifying genotypes which perform well under N limited conditions will be useful for minimising yield reductions in low-input production systems (Sylvester-Bradley & Kindred, 2009). In addition, the performing genotypes under N limited conditions are shown to be the most productive under high N input (Hirel *et al.*, 2007). The present experiment was designed and performed in order to assess genotypic variability among a set of improved and landraces durum wheat genotypes for agronomic efficiencies, PFP_N, HI, GY and BY under different N rates during four cropping seasons in two Tunisian sub-humid locations.

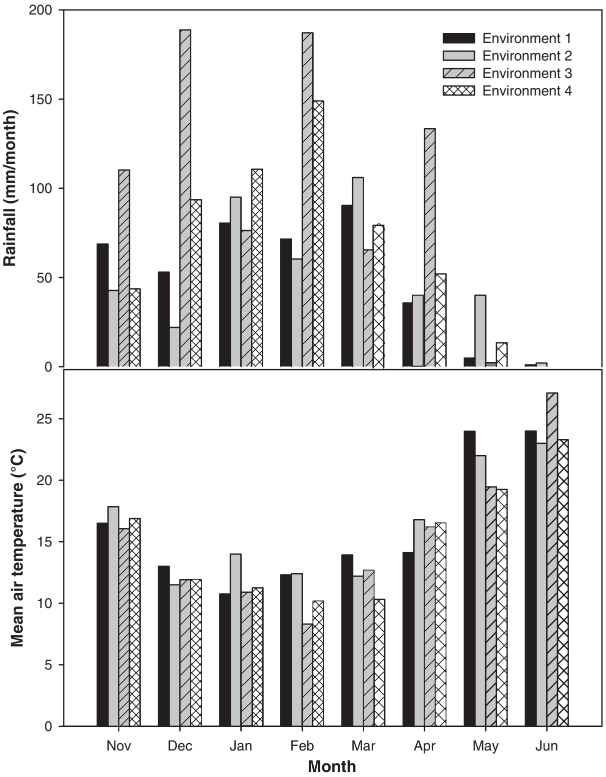

Figure 1 Monthly precipitations and mean air temperature of the experimental environment. Environment 1: Mateur 09–10; Environment 2: Mateur 10–11; Environment 3: Beja 11–12 and Environment 4: Beja 12–13.

Materials and methods

Plant material and experimental conditions

Four spring durum wheat genotypes (*Triticum turgidum* ssp. *durum*) constituted by two landraces (Bidi and Azizi) and two improved genotypes (Om Rabia and Khiar) were evaluated under rainfed conditions from 2009 to 2011 in Mateur (37°03′15.48″N, 9°37′14.73″E; denoted by environment 1 and 2 in 2009–10 and 2010–11, respectively) and from 2011 to 2013 in Beja (36°41′53.31″N, 9°08′38.13″E; denoted by environment 3 and 4 in 2011–12 and 2012–13, respectively). Mateur and Beja belong to the sub-humid climate and are characterised by a silt clay loam (vertisol) and clay (gleysol) soils, respectively (USDA, 2013). Temperature and rainfall during the study period are presented in Fig. 1. Rainfall above average were recorded, respectively, in environment 3 (Env 3) and 4 (Env 4) with 763 mm and 562 mm; while precipitations were below average for Env 1 (405 mm) and Env 2 (408 mm). Large precipitations occurred during November (110 mm) and December (188 mm) in Env 3 which is more than twice higher than the monthly mean (Fig. 1). This heavy and early rainfall, appeared to enhance the establishment of wheat plants which is known to have a positive effect on wheat growth (López-Bellido & López-Bellido, 2001). Monthly mean air temperatures were comparable to the average for all environments except Env 4 where temperatures were significantly cooler (17°C) than the mean temperatures during the period March to June which corresponds to heading to maturity stages.

N fertiliser was applied as granules of ammonium nitrate (33.5%N). Six N rates (0, 50, 100, 150, 200 and 250 kg N ha^{-1}) were designated as six treatments (N0, N50, N100, N150, N200 and N250). Nitrogen was applied at the same growth stage (GS) for the four genotypes: 30% at early tillering GS13, 40% at stem elongation GS16 and 30% at 2nd node GS32.

The experimental design was randomised complete-block with three replications, six N treatments, and four genotypes as the main plot factors. Each plot was constituted by 10 rows of 1 m long, spaced by 0.20 m. The genotypes within an experiment were sown by hand at the same seeding rate (300 seeds m^{-2}).

Weeds were controlled with Metosulam and 2,4-Dichlorophenoxyacetic acid herbicides (250 g L^{-1}). Leaf rust was controlled using Propiconazol and Cyproconazol at the recommended commercial rates.

Data collection and analysis

Total aerial biomass (BY, kg m^{-2}) and grain yield (GY, kg m^{-2}) were measured from the three central rows of each plot at maturity. Further, the harvest index (HI) was calculated as the ratio of grain yield to total shoot biomass.

Nitrogen agronomic efficiencies (NAE) estimates were based on the relative crop performance in treated plots as compared to plots without N fertilisation. NAE_{GY} was calculated as the increase in grain yield per unit of applied N; i.e., $NAE_{GY} = (GY_N - GY_0)$/Fertiliser N rate. NAE_{BY} was calculated as the increase in biomass at harvest per unit of applied N; i.e., $NAE_{BY} = (BY_N - BY_0)$/Fertiliser N rate, where GY_N (grain yield at plots with nitrogen applied) and BY_N are grain and biomass yields obtained at corresponding applied N Fertiliser rate; while GY_0 and BY_0 represent grain and biomass yields obtained in plots without N application. Partial factor productivity of applied N (PFP_N) was the grain yield per unit N applied; i.e., $PFP_N = GY$/Fertiliser N rate.

Statistical analysis

Analysis of variance (ANOVA) was performed using the general linear model (PROC GLM SAS) procedure to calculate the effect of environment, genotypes, N treatments and their interactions for all measured traits. Means were compared by least significant difference (LSD) test ($P < 0.05$), and a bivariate procedure was used to calculate the Pearson correlation coefficient. All the data were tested for homogeneity of error variances in each environment. Multiple linear regression analysis using PROC REG was used to analyse the relationship between GY and all other traits at different N rates. The models were built separately for landraces and improved genotypes. The regressions were used to detect relationships between GY at a given rates of N and GY at zero N applied. Data were analysed using the SAS version 9.1 (SAS Institute, 2009, Cary, NC, USA).

Results

Effect of environment, genotype and N treatments on grain and biomass yield

ANOVA showed significant ($P < 0.0001$) variations among the genotypes (G), N treatments (N), environments (E) and all interactions for all the tested agronomic traits (Table 1). Across all environments, GY was the highest in Env 3 (0.53 kg m^{-2}) and the lowest in Env 4 (0.39 kg m^{-2}). The BY was maximum in Env 3 (1.75 kg m^{-2}) and minimal in Env 4 (1.26 kg m^{-2}). GY and BY appeared to increase with N application rates. GY ranged from 0.29 kg m^{-2} without N supply to 0.57 kg m^{-2} under the highest N treatment (250 kg N ha^{-1}). BY ranged from 1.14 kg m^{-2} at 0 kg N ha^{-1} to 1.63 kg m^{-2} at 250 kg N ha^{-1} (Table 1).

There were differences in GY between the landraces and the high yielding durum wheat improved genotypes. On average, GY of the improved genotypes (Khiar and Om Rabia, 0.47 kg m^{-2}) was higher than for the landraces (Bidi and Azizi, 0.41 kg m^{-2}). Bidi produced the maximum BY (1.56 kg m^{-2}), which could be attributed to the plant height characteristics, followed by Azizi (1.49 kg m^{-2}) and Om Rabia (1.46 kg m^{-2}). Khiar produced the lowest BY (1.27 kg m^{-2}, Table 1). Maximum BY was recorded at 250 kg ha^{-1} for the landraces (1.75 kg m^{-2}) and improved genotypes (1.51 kg m^{-2}) (Fig. 2). The optimum N rate required to achieve the maximum GY is estimated to be 200 kg N ha^{-1}. So, N rates enhanced GY across variable growing conditions as depicted by the three way interactions. The quadratic equation described the interrelationship between N rate and GY and showed that the higher GY was observed for the improved genotypes. However, the high BY recorded in landraces could be attributed to a higher plant height and leaf area (instead of tillering ability) as observed in high yielding genotypes.

Table 1 Means of Biomass yield (BY), grain yield (GY), harvest index (HI), nitrogen agronomic efficiency for grain yield (NAE_{GY}), nitrogen agronomic efficiency for Biomass yield (NAE_{BY}) and partial factor productivity of nitrogen (PFP_N) of four genotypes grown under 6 N treatments in four environments

	BY ($kg\,m^{-2}$)	GY ($kg\,m^{-2}$)	HI (%)	NAE_{BY} ($kg\,kg^{-1}$ N)	NAE_{GY} ($kg\,kg^{-1}$ N)	PFP_N ($kg\,kg^{-1}$ N)
Environments (E)						
Env 1 (Mateur 09–10)	1.35	0.40	30.37	24.22	8.47	29.77
Env 2 (Mateur 10–11)	1.42	0.44	30.82	7.18	8.24	31.37
Env 3 (Beja 11–12)	1.75	0.53	31.01	35.21	12.22	38.37
Env 4 (Beja 12–13)	1.26	0.39	32.02	18.70	8.82	28.80
LSD	0.39	0.08	1.43	4.57	1.00	0.86
N treatments (N)						
0 N	1.14	0.29	26.35	–	–	–
50 N	1.30	0.33	26.44	31.27	7.72	66.68
100 N	1.40	0.41	29.77	25.45	10.55	41.31
150 N	1.57	0.50	32.70	28.37	13.97	33.60
200 N	1.61	0.55	35.24	23.38	13.24	27.97
250 N	1.63	0.57	35.82	19.48	11.16	22.91
LSD	0.305	0.08	1.05	4.27	1.03	0.90
Landraces						
Azizi	1.49	0.44	29.87	18.69	8.76	32.37
Bidi	1.56	0.39	25.43	10.57	6.84	28.54
Means	1.52	0.41	27.65	14.63	7.80	30.45
Improved						
Khiar	1.27	0.46	32.84	14.96	10.57	33.26
Om Rabia	1.46	0.48	36.08	30.61	11.58	34.15
Means	1.36	0.47	34.46	22.78	11.07	33.70
LSD	0.02	0.07	0.86	3.48	0.84	0.73

ANOVA	DF	BY ($kg\,m^{-2}$)	GY ($kg\,m^{-2}$)	HI (%)	NAE_{BY} ($kg\,kg^{-1}$ N)	NAE_{GY} ($kg\,kg^{-1}$ N)	PFP_N ($kg\,kg^{-1}$ N)
Environment (E)	**3**	3.32*	0.293**	35*	9796**	251**	1347**
Replication (r)	**2**	0.05ns	0.005ns	4ns	150ns	6ns	5ns
***r* (E)**	**6**	0.009	0.0004	12	126	6	4
Genotype (G)	**3**	1.11**	0.111**	1475**	3210**	314**	439**
Nitrogen (N)	**5**	1.83**	0.662**	845**	6029**	1260**	23 185**
E*G	**9**	0.24**	0.020**	152**	2410**	127**	109**
E*N	**15**	0.12**	0.012**	75**	1123**	47**	100**
G*N	**15**	0.05**	0.013**	102**	1118**	67**	49**
E*G*N	**45**	0.02 **	0.003**	36**	756**	26**	25**
Error	**184**	0.006	0.0005	6.91	112	6.57	5.005

r (E): error in replication within environment. The ANOVA is shown as the mean squares for the environment, genotype and nitrogen; ns: not significant, * Significant at $P < 0.05$ and ** Significant at $P < 0.01$.

Effect of environment, genotype and N treatments on harvest index and partial factor productivity of nitrogen

HI and PFP_N were affected by the environments, genotypes, N treatments and their respective interactions. N treatments affected positively HI and negatively PFP_N (Table 1). Increased HI and PFP_N by, respectively, 24% and 10% were noted in improved genotypes compared to landraces (Fig. 3). A significant reduction of 16% of PFP_N was found in Env 4 as compared to Env 1.

Effect of environment, genotype and N treatments on N agronomic efficiencies

NAE is significantly affected by genotypes and N rates ($P < 0.01$, Table 1). Improved genotypes showed higher NAE_{GY} (26%), NAE_{BY} (36%) and GY (13%) compared to landraces. N supply increased the NAE_{GY} up to a maximum then decreased for high N fertiliser rates (Fig. 4B). The maximum NAG_{GY} (16.49 $kg\,kg^{-1}$ N) was attained under 175 $kg\,N\,ha^{-1}$ for improved genotypes and under 150 $kg\,N\,ha^{-1}$ for landraces (11.6 $kg\,kg^{-1}$ N) (Fig. 4A). NAE_{BY} was higher for landraces (Table 1). Maximum NAE_{BY} was reached at 150 $kg\,N\,ha^{-1}$ for landraces (30.42 $kg\,kg^{-1}$ N) (Fig. 4B).

Relationship between grain yield and nitrogen agronomic efficiency

The averaged GY reached without N application ranged from 0.26 $kg\,m^{-2}$ to 0.35 $kg\,m^{-2}$ and from 0.25 $kg\,m^{-2}$ to 0.35 $kg\,m^{-2}$ for landraces and improved genotypes, respectively (Fig. 5). A positive relationship exists

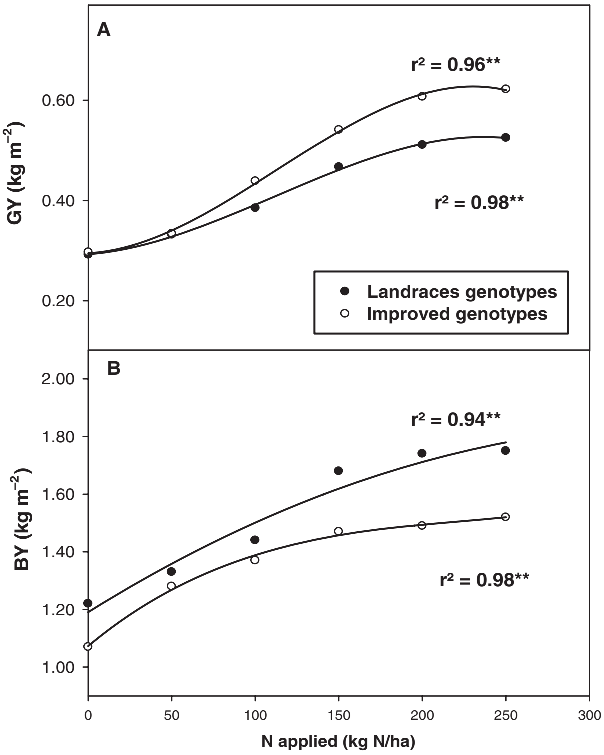

Figure 2 Response of grain yield (GY) (A) and biomass yield (BY) (B) to N application rate for landraces and improved durum wheat genotypes over four environments. Data are means across all environments. **: significant at $P<0.01$. r^2: Determination coefficients.

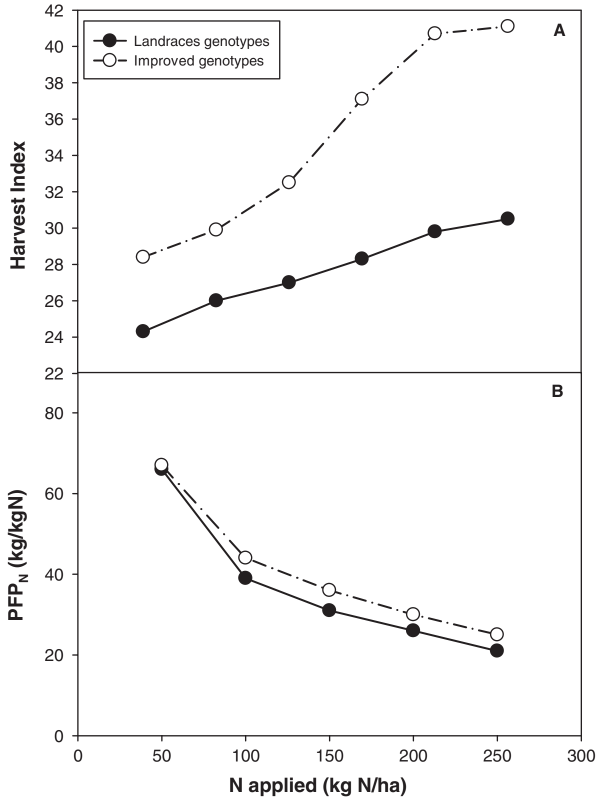

Figure 3 Response of harvest index (HI) (A) and partial factor productivity of nitrogen (PFP_N) (B) to N application rate for landraces and improved durum wheat genotypes over four environments. Data are means across all environments.

between GY and N fertiliser rate for all tested genotypes despite their origins and across all environments. In each case, there was a strong relationship ($r=0.83$ to $r=0.89$) among N treatments (50 to 250 kg N ha^{-1}) (Fig. 5).

A linear and positive relationship was found between GY and nitrogen agronomic efficiency (NAE_{GY}) in all growing conditions for improved genotypes ($r=0.70$) and the landraces ($r=0.66$) (Fig. 6).

Discussion

Yield traits and nitrogen agronomic efficiency affected by climate and soil conditions

The results showed that rainfall during the growing seasons is likely to be the most important factor affecting GY and NAE. The highest GY, BY and their efficiencies as NAE_{GY} (12.22 kg kg^{-1} N) and NAE_{BY} (35.21 kg kg^{-1} N) were observed in Env 3 characterised by the highest and most homogeneous rainfall distributed (Fig. 1). These results agree with those of López-Bellido & López-Bellido (2001) who reported that seasonal rainfall variations affected wheat yields within rainy years. Moreover, N efficiency is closely dependent on total rainfall and its distribution (Dobermann, 2005; Cossani *et al.*, 2011). In addition, PFP_N in Env 3 is 27% higher than in the other environments. This result conforms with those of Dobermann (2005) who reported that high yields and high PFP_N result from a combination of fertile soils, favourable climate and improved crop and soil management practices, including N fertiliser management.

Yield traits and nitrogen agronomic efficiency affected by N supply

GY, BY and HI showed significant increase under high N rates which constitutes a confirmation of many other studies (Guarda *et al.*, 2004; Chen *et al.*, 2015). The increased GY from 0.29 kg m^{-2} (0 N) to 0.57 kg m^{-2} (250 N) have been associated with increased total N uptake particularly below 200 N; while between 200 and 350 N no effect was observed (Sylvester-Bradley & Kindred, 2009; Hawkesford, 2012; Brennan *et al.*, 2014) as wheat tested genotypes reached probably their

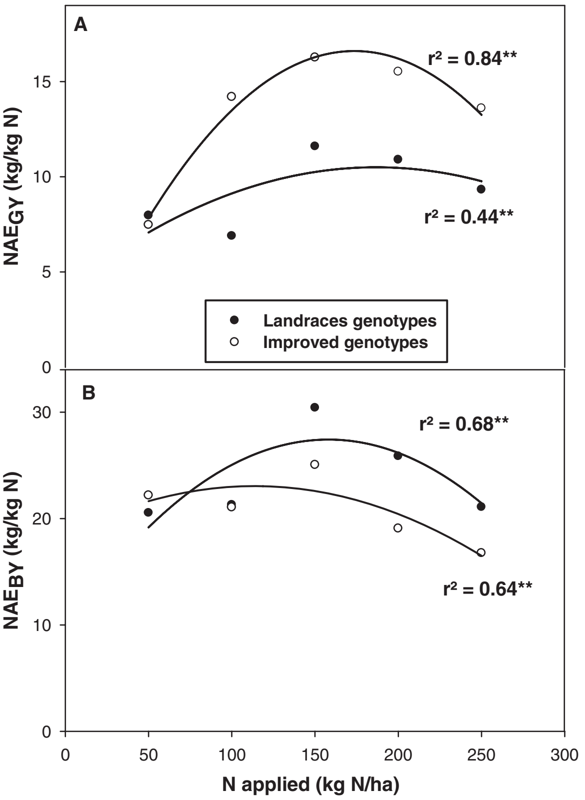

Figure 4 Response of nitrogen agronomic efficiency for grain yield (NAE_{GY}) (A) and nitrogen agronomic efficiency for biomass yield (NAE_{BY}) (B) to N application rate for landraces and improved durum wheat genotypes over four environments. Data are means across all environments. **: significant at $P < 0.01$. r^2: Determination coefficients.

yield potential. Maximum BY and HI were observed under 250 N. These results agree with those obtained on bread wheat (Hussain *et al.*, 2006). In fact, a positive relationship exists between N fertiliser rates, GY and HI which was due to a high biomass partitioning to grain production (Zarei *et al.*, 2013; Lu *et al.*, 2015).

Meanwhile, PFP_N decreased with the increase of N supply (Fig. 3B). The PFP_N normally ranges from 40 to 70 kg kg^{-1} N and higher values (>70 kg kg^{-1} N) have been observed only at low N fertiliser levels (Dobermann, 2005) or in efficiently managed cropping systems (Jin *et al.*, 2012; Liu *et al.*, 2015). The results of the present study showed that PFP_N values are in these ranges ($PFP_{50} = 66.68$ kg kg^{-1} N).

N fertiliser influenced NAE_{GY} and NAE_{BY} (Table 1). Lower crop N efficiency under high N input results mainly from re-use of total plant N tissue content for GY or BY associated with lower N uptake (Guarda *et al.*, 2004). Moreover, higher NAE_{BY} were observed under high N application levels (Craswell & Godwin, 1984).

Genetic variation in yield traits and nitrogen agronomic efficiency

Genetopic variability was observed for GY, BY, HI, NAE_{GY} and NAE_{BY} among tested durum wheat genotypes. GY genotypic variability has been largely reported in wheat and other cereals under various N supply (Foulkes *et al.*, 2009; Brancourt-Hulmel *et al.*, 2003; Gaju *et al.*, 2011; Cormier *et al.*, 2013; Hawkesford, 2014). GY was 13% higher in improved genotypes than landraces, which was associated mostly with a higher HI (+24%) but lower BY (+10%) (Table 1). Our results showed that without N supply, GY in improved and landraces are equivalent. However, starting from as low as 100 kg N, GY of improved genotypes outperform landraces (Fig. 2A) indicating that improved genotypes have a better response to N fertilisation and thus a higher NAE_{GY} (Fig. 4A). In fact, modern genotypes normally had higher GY than old genotypes under N fertilisation conditions (Brancourt-Hulmel *et al.*, 2003) and even in both N-poor and N-rich environments (Guarda *et al.*, 2004). On opposite, durum wheat landraces showed +11% higher BY than improved genotypes. Similar pattern has been reported in durum wheat (Álvaro *et al.*, 2008; Chamekh *et al.*, 2015) and was attributed to the absence of dwarf genes in landraces (Trethowan *et al.*, 2001). Cormier *et al.* (2013) reported that dwarfing genes are widely spread and used to control response to high-N supply. Introduction of dwarfing genes in modern genotypes leads to higher N accumulation, remobilization and utilisation efficiencies (Ortiz-Monasterio *et al.*, 1997; Gooding *et al.*, 2012). Besides, it was reported that the contribution of biomass and HI to increasing GY varied considerably among genotypes (Álvaro *et al.*, 2008). Biomass accumulation and partitioning under N fertilisation are crucial for improving wheat GY and NUE (Liu *et al.*, 2015). Improved genotypes showed the highest HI (34.46%) and GY (0.35 kg m^{-2}). HI has been proposed as selection criteria for cereal GY increase (Gooding *et al.*, 2012; Zarei *et al.*, 2013; Duan *et al.*, 2014; Hawkesford, 2014). Moreover, wheat genotypes with high HI values are known to have higher NUE (Raun & Schepers, 2008). The results showed that NAE_{GY} and NAE_{BY} showed opposite pattern in response to N fertilisation rates. NAE_{GY} maximum increase was obtained under 180 N for improved genotype (Fig. 4A) and ~150 N for landraces. Opposite pattern is observed for NAE_{BY} (Fig. 4B) with a maximum (30.42 kg kg^{-1} N) in landraces; while improved genotypes NAE_{BY} decreased since 150 kg N (Fig. 4B). The same NAE variability was reported previously for durum and bread wheat (López-Bellido *et al.*, 2008) as well as for barley (Angás *et al.*, 2006) in the Mediterranean region.

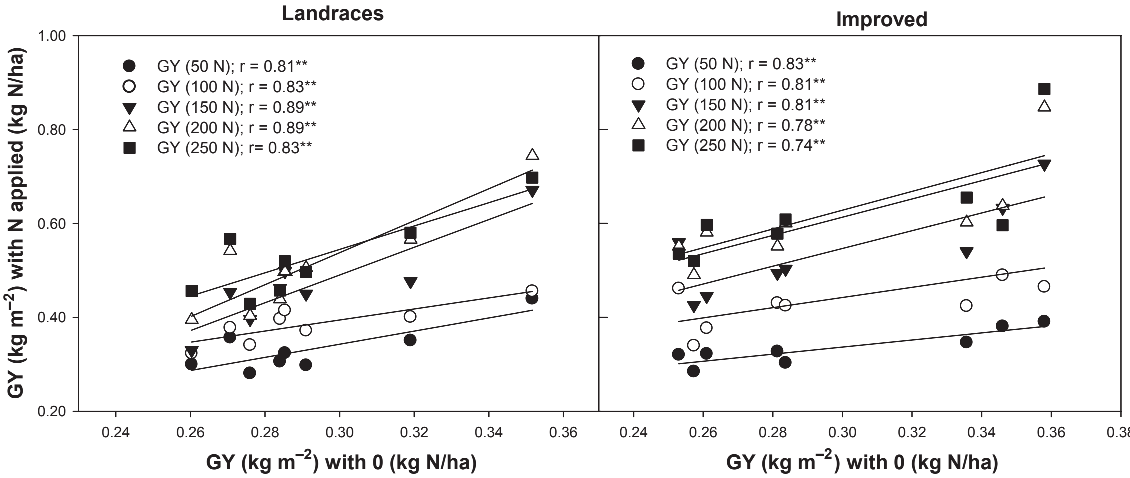

Figure 5 Relationship between grain yield (GY) with and without N fertiliser. Data are from four field trials conducted in two sites in Tunisia from 2009 to 2013. **: significant at $P < 0.01$. r^2: Pearson's correlation coefficient.

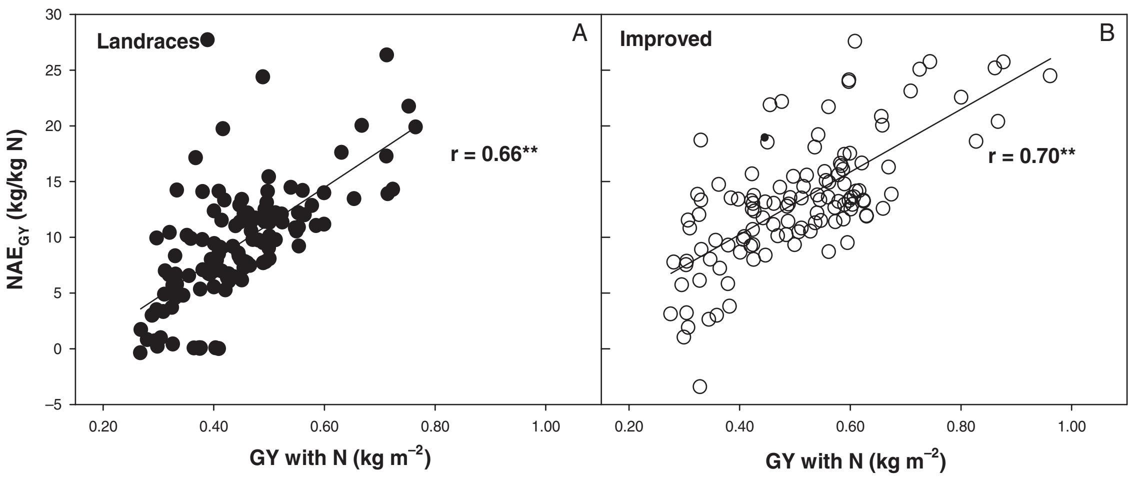

Figure 6 Relationship between agronomic N use efficiency (NAE_{GY}) and grain yield (GY) with N fertiliser for the landraces genotypes (A) and grain yield with N fertiliser for the improved genotypes (B). Data are from four field trials conducted in two sites in Tunisia from 2009 to 2013. **: significant at $P < 0.01$. r^2: Pearson's correlation coefficient.

Under N limited conditions, no difference was observed between wheat species; while under high N-input conditions, bread wheat displayed greater N accumulation capacity and a more efficient use of N for grain production (López-Bellido *et al.*, 2008). Genotypic differences in NAE_{BY} showed that old genotypes out-performed improved ones (Ortiz-Monasterio *et al.*, 1997). In general, very high values of NAE and PFP_N in maize, rice and wheat were associated with the use of lower N rates (Ladha *et al.*, 2005). Across all four environments, GY at the different N rates was shown to be highly related to GY under control conditions (GY_0) (Fig. 5). In fact, regression analysis revealed that GY_0 was the main explaining component for genotypic GY variability under N fertilisation rates. Thus, GY_0 could be considered as reliable indicator of GY at any N level (Peng *et al.*, 2010; Cossani *et al.*, 2011). Moreover, the correlation was highly significant between GY and NAE_{GY} only under N supply (Fig. 6). GY is correlated to BY, HI and to less extent to NAE_{BY}. Breeding for high yielding genotypes that are N efficient, can be achieved through the use of those parameters (Peng *et al.*, 2010; Zarei *et al.*, 2013).

Conclusion

There is limited information available on the NUE components of durum wheat genotypes grown under rainfed conditions in the southern countries of the southern Mediterranean Sea. The present study assesses the genotypic variability for GY and NAE in selected Tunisian wheat genotypes. The present investigation showed that Tunisian durum wheat improved genotypes and landraces have different responses to N fertilisation rates. For GY, improved genotypes are more adapted to N fertilisation. BY follows an opposite pattern, being higher and more responsive to N supply in landraces. Taken together, improving NUE and related crop responses can be undertaken using GY and HI. The efficient use of N in the soil–plant system can also result in genotypes producing high yield which is an important issue for food security.

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