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# *Per se* performance and combining ability of six wheat genotypes and their $F_1$ diallel crosses for NUE traits under contrasting-N conditions

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**Abstract:** Breeding wheat (*Triticum aestivum* L.) cultivars with improved adaptation to low-N fertilization has gained importance worldwide. This study aimed at investigating the *per se* performance of nitrogen use efficiency traits, the relative importance of general (GCA) and specific (SCA) combining ability in a set of wheat cultivars and promising lines and their $F_1$ diallel crosses. Parents (6) and $F_1$'s (15) were evaluated in in two seasons in two separate experiments using randomized complete block design with three replications; each experiment under one level of N ( 0 or 75 kg N/fed). Results across seasons showed that the rank of crosses in $F_1$ generation for most studied traits was changed from one environment (N-level) to another, indicating a significant G x N interaction. In general, means of NUE, and NUPE of the three parents L25 , L26 and L27 were higher in magnitude than those of the three other parents Gem 7, Gem 9 and Giza 168 under both high-N and low-N levels. Both GCA and SCA mean squares were significant, but the magnitude of GCA was higher than SCA, for all studied traits under the two levels of N, except GPC under low-N, suggesting the existence of a greater portion of additive than that of non–additive genetic variance in controlling the inheritance of these traits under the two levels of nitrogen. In general, the best general combiners in $F_1$'s for NUE and NUPE were L26 followed by L27 and L25 parents under both high-N and low-N. Under low–N conditions, the best SCA effects were shown the by $F_1$'s L25 x Gz168 for NUE and NUPE, L2 x Gem9 and L27 x Gem9 for NUPE and L25 x L 26, L25 x L27 and L27 x Gem9 for NUTE trait. Results indicate that under both N-levels, the best performing parents for grain yield and nitrogen use efficiency and their components are also the best general combiners and *vice versa*. But under high-N only, the mean performance of a given $F_1$ cross could be considered an indication of its SCA effects.

**Keywords:** *Triticum aestivum***,** NUE**,** N-uptake, N-utilization, N-harvest index, GCA, SCA

## I. INTRODUCTION

Increased interest is being shown worldwide in cultivars that are more efficient in utilizing soil resources and better fitted to water and nutrient limitations (El Bassam 1998; Good et al. 2004; Fageria and Baligar 2005; Lammerts van Bueren et al. 2008; Sylvester-Bradley and Kindred 2009). Among cereals, bread wheat (*Triticum aestivum* L.) is commonly identified as a species with higher requirements for nutrients, especially nitrogen. Thus, breeding wheat cultivars with improved adaptation to less favourable, but more optimized N fertilization regimes has gained importance.

In Egypt, like in other developing countries, such breeding strategies are also justified by limited-nitrogen supply that is major constraint limiting grain production. The efficiency of nitrogen use (NUE; defined here as the grain yield per unit of the soil N) and plant adaptation to less favorable nutrition regimes is complex with various mechanism involved (Sattelmacher *et al.* 1994; Hirel *et al*. 2007). Different characteristics, associated with both the uptake capacity (NUPE; defined here as a proportion of total N uptake to N availability in the soil) and efficiency of nitrogen utilization in grain mass formation (NUTE; defined here as the grain mass formed per unit of N absorbed), appear to be critical components of NUE (Moll *et al.* 1982 and Huggins and Pan 2003).

Although numerous reports on genotypic variation in components of N efficiency already suggest potential applications of this genetic knowledge for wheat improvements (Dhugga and Waines 1989; Ortiz-Monasterio *et al.* 1997; El Bassam 1998; Le Gouis *et al.* 2000; Gorny *et al.* 2006a; Laperche *et al.* 2006a; Kichey *et al.* 2007; Baresel *et al.* 2008 and Barraclough *et al.* 2010), relatively fewer attempts have been made to breed wheat for these traits (Van Ginkel *et al*. 2001; Brancourt-Hulmel *et al.* 2005 and Wolfe *et al*. 2008).

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Wheat breeders in Egypt have consistently targeted improved grain yield under high inputs of fertilizer, but nitrogen efficiency *per se* has never been a target. There is an extensive global literature on NUPE and NUTE in wheat. The small selection of papers cited here illustrates the points of agreement and conflict evident in the literature. Dhugga and Waines (1989) studied 12 varieties (3 tall) at 3 N-rates over 2 years in California, USA. There was genotypic variation in total-NUPE and grain-NUTE with total-NUPE being the dominant component of NUE (62–70%) at all N-rates. Ortiz-Monasterio *et al*. (1997) studied 10 varieties (2 tall) at 4 N-rates over 3 years in Mexico. NUE was found to track yield. There was genetic variation in total-NUPE and grain- NUTE between tall and short varieties and within short varieties. Total-NUPE contributed more to variation in NUE at low N, with equal contributions from NUPE and NUTE at medium N, and grain-NUTE contributed more at high N, the opposite of what Dhugga and Waines (1989) had found. There was a significant variety × N interaction for grain-NUTE, but not for total-NUPE. Le Gouis *et al.* (2000) studied20 varieties (2 tall) at 2 N-rates over 2 years in France. They found genetic variation in total-NUPE and total-NUTE. The contribution of total-NUPE to the variation in NUE was 64% at low-N and 30% at high-N (in agreement with Ortiz-Monasterio et al. 1997). There was significant G×N interaction for total-NUPE but not for total-NUTE. The literature on N-efficiency in Egypt varieties is sparse. This study aimed at investigating the *per se* performance of nitrogen use efficiency traits, the relative importance of GCA and SCA in a set of wheat cultivars and promising lines and their $F_1$ diallel crosses and the correlations between *per se* performance and combining ability effects under contrasting N environments.

## II. MATERIALS AND METHODS

This study was carried out at Giza Research Station of the Agricultural Research Center(ARC), Giza Egypt (30° 02'N latitude and 31° 13'E longitude with an altitude of 15.00 meters above sea level), in 2005/2006 season and at Noubarya Research Station of the ARC, Noubarya, Egypt (30°66'N latitude and 30°06'E longitude with an altitude of 15.00 meters above sea level), in 2006/2007, 2007/2008 and 2008/2009 seasons.

### 2.1. Materials

Six bread wheat genotypes (*Triticum aestivum* L.) were chosen for their divergence in tolerance to low-N, based on previous field screening carried out by Wheat Res. Dept., Field Crops Res. Inst., ARC, Egypt (Table 1).

**Table1.** *Designation, pedigree and tolerance to low N of the six promosing lines and Egyptian cultivars of wheat used for making diallel crosses of this study*

| Designation | Pedigree | Tolerance to low-N |
|---|---|---|
| Line 25(L25) | MYNA/VUL//TURACO/3/TURACO/4/Gem7. | Tolerant |
| Line 26(L26) | MUNIA/CHTO//AMSEL. | Tolerant |
| Line27(L27) | Compact-2/Sakha//Sakha61. | Tolerant |
| Gemeiza(Gem7) | CMH74A.630/SX//Seri82/3/Agent. | Sensitive |
| Gemeiza9(Gem9) | Ald "s"/HUC "s;;//CMH74A.630/SX. | Sensitive |
| Giza168(Gz168) | MRL/BUC//Seri. | Sensitive |

***Source:*** *Wheat Res. Dept., Field Crops Res. Inst., ARC. Egypt*

### 2.2. Making the F1 diallel crosses

In season 2005/2006, a half diallel of crosses involving the six parents (without reciprocals) was done at Giza Agric. Res. Stat., Agric. Res. Center, to obtain the $F_1$ seeds of 15 crosses. In season 2007/2008, the half diallel of crosses was again done to increase quantity of F1 seeds.

### 2.3. Field evaluation of 6 parents and 15 F1's

In the seasons 2007/2008, 2008/2009, parents (6) and $F_1$'s (15) were sown on 17th of November each season in the field of Noubarya Res. Stat., in two experiments under two levels of nitrogen fertilizer; each experiment under one level with three replications. The low level was without fertilization (LN) and the high level was 75 kg Nitrogen/ feddan (HN); this is the recommended level of Ministry of Agriculture. This level of nitrogen fertilizer (equals 168 kg Urea/fed) was added in two equal doses, the first dose was added just before the sowing irrigation and the second dose just before the second irrigation (21 days after irrigation). Each parent or $F_1$ was sown in two rows; each row was three meter long; spaces between rows were 30 cm and 10 cm between plants, and the plot size was 1.8 m. All other agricultural practices were done according to the recommendation of Ministry of Agriculture for growing wheat in Noubarya region.

Available soil nitrogen in 30 cm depth was analyzed immediately prior to sowing and N application at the laboratories of Water and Environment Unit, ARC, Egypt in the two seasons. Soil nitrogen was found to be 55 and 57 kg N/ fed in the seasons 2007/2008, 2008/2009, respectively. Available soil nitrogen after adding nitrogen fertilizer was therefore 55 and 130 kg N/fed in the first season and 57 and 132 kg N/fed in the second season for the two treatments, i.e. LN and HN, respectively. The available nitrogen to each plant (including soil and added N) was calculated for each environment to be 0.79, 1.85 g/plant in 2007/2008 season and 0.81 and 1.89 kg/fed in 2008/2009 season, with an average across the two seasons of 0.80 and 1.87 g/plant for the two environments LN and HN, respectively. All other agricultural practices were followed according to the recommendations of ARC, Egypt. The soil analysis of the experimental soil at Noubarya Research Station, as an average of the two growing seasons, indicated that the soil is sandy loam (67.86% sand, 7.00% silt and 25.14%), the pH is 8.93, the EC is 0.55 $dSm^{-1}$, the soluble cations in meq $l^{-1}$ are $Ca^{2+}$ (5.30), $K^{+}$ (0.70), $Na^{+}$ (0.31), $Mg^{2+}$ (2.60) and the soluble anions in meq $l^{-1}$ are $CO_3^{2-}$ (0.00), $HCO_3^{-}$ (2.10), $Cl^{-}$ (5.30) and $SO_3^{2-}$ (1.51).

### 2.4. Data Collection

Grain yield/ plant (GYPP) was measured as weight of the grains of each individual plant using an average of 10 plants each entry. At physiological maturity stage, five random guarded plants were removed from each plot by cutting at the soil surface. The plants were bulked as one sample per plot. They were separated into straws (including leaves, stems and spike residues) and grains. Samples were oven dried at 70°C to a constant weight and each part was weighed separately. Samples were ground in powder and nitrogen of straws (N straw) and grains ($N_g$) was determined using Kjeldahl procedure according to A.O.A.C. (1990). Total plant nitrogen ($N_t$) was calculated as follows: $N_t = N_g + N_{straw}$. The following traits were recorded: **1. Nitrogen use efficiency (NUE) g/g**= (GYPP / $N_s$). **2. Nitrogen uptake efficiency (NUPE)% =**100 ($N_t$ / $N_s$). **3. Nitrogen utilization efficiency (NUTE)** (g/g)= (GYPP/$N_t$). **4. Nitrogen harvest index (NHI%)=** 100($N_g$/ $N_t$). Where GYPP is grain yield/ plant in gram, $N_t$ is total nitrogen in the whole plant (grains and straw), $N_s$ is available nitrogen in the soil for each plant, and $N_g$ is grain nitrogen content. Nitrogen efficiency parameters were estimated according to Moll *et al.* (1982).

### 2.5. Statistical Analysis

Each environment (HN and LN) was analyzed separately across seasons as RCBD for the purpose of determining genetic parameters using GENSTAT 10th addition windows software. Least significant differences (LSD) values were calculated to test the significance of differences between means according to Steel *et al*. (1997).

### 2.6. Genetic Analysis of F1 Crosses

Diallel crosses in $F_1$ generation were analyzed to obtain general (GCA) and specific (SCA) combining ability variances and effects for studied traits according to Model I (fixed effect) Method 2. General (GCA) and specific (SCA) combining ability variances and effects were estimated according to Griffing (1956) model I (i,e the fixed model) method II. Estimates of both general ($\delta^2_g$) and specific ($\delta^2_s$) combining ability variances were calculated according to Griffing (1956) as shown in Singh and Chaudhary (1985).

Rank correlation coefficients calculated between *per se* performance of parents and their GCA effects in $F_1$'s; between *per se* performance of $F_1$ crosses and their SCA effects for studied traits under each environment across two seasons, using SPSS 17 computer software and the significance of the rank correlation coefficient was tested according to Steel *et al*., (1997). The correlation coefficient ($r_s$) was estimated for each pair of any two parameters as follows: $r_s = 1- (6\ \Sigma\ d_i^2)/(n^3-n)$ Where, $d_i$ is the difference between the ranks of the $i^{th}$ genotype for any two parameters, n is the number of pairs of data. The hypothesis Ho: $r_s = 0$ was tested by the r-test with (n-2) degrees of freedom.

## III. RESULTS AND DISCUSSION

### 3.1. Mean Performance

Means of each parent, F1 cross and F2 cross for studied traits under two nitrogen fertilizer rates (0 and 75 kg N /Fed) across two seasons are presented in Table (2). In general means of NUE, and NUPE of the three parents L25 , L26 and L27 were higher in magnitude than those of the three other parents Gem 7, Gem 9 and Giza 168 under both high-N and low-N levels. The first three parents (L25, L26 and L27) were therefore considered as low-N tolerant (N-efficient) genotypes and the latter ones (Gem 7, Gem 9 and Giza 168) as low-N sensitive (N-inefficient) parents.

The rank of crosses in F1 for most studied traits was changed from one environment (N-level) to another. The highest mean of NUE under low-N was obtained from L26 x L27 followed by L25 x L26 and L25 x L27 in F1 and L25 x L27 followed by L25 x L26 and L26 x Gz168 in F2 generation. These crosses were therefore considered tolerant (N-efficient) to low-N stress.

**Table2.** *Mean performance of all genotypes under high-and low- levels of nitrogen across two years for studied traits*

| **Genotypes** | **NUE(g/g)** | | | **NUPE(g/g)** | | |
|---|---|---|---|---|---|---|
| | **High N** | **Low N** | **Red%** | **High N** | **LowN** | **Red%** |
| **Parents** | | | | | | |
| L25 | 14.16 | 31.76 | -124.3** | 16.97 | 30.77 | -81.30** |
| L26 | 16.80 | 33.64 | -100.3** | 18.88 | 36.87 | -95.31** |
| L27 | 15.96 | 32.86 | -105.9** | 17.63 | 30.82 | -74.79** |
| Gem7 | 13.89 | 22.99 | -65.56** | 15.26 | 22.30 | -46.11** |
| Gem9 | 13.77 | 22.40 | -62.65** | 13.88 | 16.97 | -22.30** |
| Giza168 | 13.74 | 24.57 | -78.77** | 13.38 | 23.48 | -75.44** |
| **$F_1$ crosses** | | | | | | |
| L25 X L26 | 16.50 | 33.68 | -104.2** | 17.81 | 30.46 | -71.05** |
| L25 X L27 | 13.79 | 32.80 | -137.9** | 16.86 | 28.24 | -67.47** |
| L25X Gem 7 | 13.71 | 30.62 | -123.4** | 16.52 | 30.47 | -84.41** |
| L25 X Gem 9 | 14.32 | 25.06 | -74.98** | 16.40 | 30.37 | -85.26** |
| L25 X Gz 168 | 14.80 | 31.84 | -115.2** | 16.85 | 34.67 | -105.8** |
| L 26 X L 27 | 17.20 | 34.39 | -99.98** | 19.37 | 39.32 | -102.99** |
| L26 X Gem 7 | 15.76 | 28.35 | -79.86** | 19.47 | 31.36 | -61.07** |
| L 26 X Gem 9 | 16.47 | 26.26 | -59.46* | 16.78 | 33.92 | -102.08** |
| L 26 X Gz 168 | 17.94 | 27.59 | -53.75 | 15.81 | 30.65 | -93.85** |
| L 27 X Gem 7 | 18.35 | 30.19 | -64.54** | 13.84 | 25.00 | -80.62** |
| L 27 X Gem 9 | 15.89 | 25.68 | -61.59 | 12.92 | 36.03 | -178.80** |
| L27 X Gz168 | 16.36 | 29.65 | -81.29** | 16.16 | 24.11 | -49.19** |
| Gem 7 X Gem9 | 13.31 | 22.22 | -66.9** | 15.41 | 20.92 | -35.77** |
| Gem 7 X Gz 168 | 15.27 | 23.74 | -55.45** | 14.59 | 25.96 | -77.89** |
| Gem 9 X Gz 168 | 13.95 | 25.91 | -85.65** | 13.31 | 19.96 | -49.97** |
| L.S.D.$_{0.05}$(G) | 1.1 | 2.6 | | 0.98 | 3.2 | |
| (N) | | | 3.2 | | | 8.15 |
| (GN) | | | 2.0 | | | 2.5 |

| **Genotypes** | **NUTE(g/g)** | | | **NHI(%)** | | |
|---|---|---|---|---|---|---|
| | **High N** | **Low N** | **Red%** | **High N** | **LowN** | **Red%** |
| **Parents** | | | | | | |
| L25 | 0.84 | 1.03 | -23.25** | 54.87 | 52.07 | 5.11 |
| L26 | 0.89 | 0.91 | -2.31** | 57.17 | 56.51 | 1.14 |
| L27 | 0.91 | 1.07 | -18.31** | 55.75 | 55.49 | 0.47 |
| Gem7 | 0.92 | 1.03 | -12.43** | 55.52 | 56.46 | -1.68 |
| Gem9 | 1.03 | 1.32 | -27.92** | 56.25 | 59.15 | -5.15 |
| Giza168 | 1.04 | 1.06 | -2.15** | 57.04 | 55.98 | 1.87 |
| **$F_1$ crosses** | | | | | | |
| L25 X L26 | 0.93 | 1.11 | -19.20** | 53.14 | 55.66 | 0.28 |

| | | | | | | |
|---|---|---|---|---|---|---|
| L25 X L27 | 0.82 | 1.16 | -42.14** | 56.01 | 55.36 | -4.75 |
| L25X Gem 7 | 0.84 | 1.01 | -20.82** | 55.88 | 55.21 | 1.17 |
| L25 X Gem 9 | 0.88 | 0.83 | 5.30** | 57.92 | 59.87 | 1.19 |
| L25 X Gz 168 | 0.88 | 0.92 | -5.08** | 57.52 | 56.86 | -3.37 |
| L 26X L 27 | 0.89 | 0.88 | 1.41** | 54.61 | 57.62 | 1.15 |
| L26 X Gem 7 | 0.81 | 0.91 | -11.51** | 54.92 | 54.88 | -5.51 |
| L 26 X Gem 9 | 0.99 | 0.78 | 21.19** | 55.84 | 56.87 | 0.08 |
| L 26 X Gz 168 | 1.14 | 0.90 | 20.76** | 55.37 | 60.03 | -1.85 |
| L 27X Gem 7 | 1.33 | 1.22 | 8.00** | 57.27 | 56.79 | -8.42 |
| L 27 X Gem 9 | 1.23 | 0.71 | 42.15** | 56.57 | 57.95 | 0.85 |
| L27 X Gz168 | 1.02 | 1.23 | -21.31** | 54.83 | 59.79 | -2.43 |
| Gem 7 X Gem9 | 0.86 | 1.08 | -25.26** | 56.85 | 58.97 | -9.04** |
| Gem 7 X Gz 168 | 1.05 | 0.92 | 11.91** | 59.02 | 61.59 | -3.73* |
| Gem 9 X Gz 168 | 1.05 | 1.31 | -24.31** | 57.40 | 63.78 | -4.35* |
| L.S.D.$_{0.05}$(G) | 0.09 | 0.15 | | 0.76 | 1.75 | |
| (N) | | | 0.24 | | | 2.16 |
| (GN) | | | 0.15 | | | 3.87 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively*

On the contrary, the three crosses Gem 7 x Gem 9, Gem 7 x Gz168 and L27 x Gem 9 in F1 and F2 generations showed the lowest NUE under low-N, and therefore were considered sensitive (inefficient) to low-N stress.

It is worthy to note that the magnitude of N-induced alterations due to low-N stress in the majority of the N-efficiency components and other studied traits was distinctly dependent upon the genotype, as evident by the significant genotype x environment interactions. These results are consistent with observations previously reported in wheat (El Bassam , 1998, Le Gouis et al. 2000 and 2002 , Al-Naggar et al. 2012 ), barley ( Ceccarelli , 1994 and 1996 and Gorny and Sodkiewicz, 2001) and maize (Di Fonzo et al. 1982, Medici et al., 2004, Preseterl et al., 2008, Al-Naggar et al. 2008, 2009, 2010, 2011b, 2015 a, b, c ), corroborating that an evaluation of breeding materials under diverse fertilization regimes is necessary for choice of the most efficient parental forms and / or cross combinations, as suggested by Brancourt-Hulmel et al.(2005), Laperche et al. (2006a) , Dowson et al. (2008), Wolfe et al. (2008) and Al-Naggar et al. (2006, 2007b, 2009, 2010, 2011, 2012, 2015 a, b, c). The rank of parents for NUE was similar in the two N- environments, indicating less effect of interaction between parent and nitrogen level on nitrogen use efficiency.

The three tolerant parents showed the highest NUE under high-N and were therefore considered responsive parents. Moreover, L26 x L27and L25 x L27 in F1 and L26 x Gz168 in F2 generation had the highest NUE under high-N and are therefore considered responsive crosses.

### 3.2. Combining Ability Variances

Variances estimates for general (GCA) and specific (SCA) combining ability of the $F_1$ diallel crosses of wheat for combined data across two years under high and low levels of nitrogen are presented in Table (3 and 4). Mean squares due to genotypes were highly significant for all studied traits under the two levels of N. Mean squares due to GCA and SCA were also highly significant for all studied traits, except NHI for SCA under low-N, indicating that both additive and non-additive gene effects play an important role in the inheritance of most studied traits under different N application rates.

In the present study, the magnitude of GCA mean squares was higher than that of SCA, since the ratio of GCA/ SCA mean squares was higher than unity for all studied traits under the two levels of N, except GPC under low-N, where the ratio was below unity. Higher GCA/SCA ratio than unity, suggested the existence of a greater portion of additive and additive x additive than that of non–additive genetic variance in controlling the inheritance of these traits under the two levels of nitrogen.

**Table3.** *Mean squares due to general (GCA) and specific (SCA) combining ability and their interactions with years (Y) for studied traits in $F_1$' s under high N conditions across two years*

| SOV | df | MS | | | |
|---|---|---|---|---|---|
| | | NUE | NUPE | NUTE | NHI |
| Genotypes (G) | 20 | 14.06** | 22.94** | 0.11** | 10.87** |
| GCA | 5 | 33.28** | 64.84** | 0.15** | 16.95** |
| SCA | 15 | 7.65** | 8.98** | 0.10** | 8.84** |
| GCA x Y | 5 | 1.81* | 0.68 | 0.01** | 13.24** |
| SCA x Y | 15 | 1.24* | 2.81** | 2.28** | 13.97** |
| GCA/SCA | | 4.35 | 7.22 | 1.52 | 1.92 |
| GCA x Y/SCA x Y | | 1.46 | 0.24 | 0.01 | 0.95 |
| error | 80 | 0.51 | 0.36 | 0.003 | 1.70 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively*

**Table4.** Mean squares due to general (GCA) and specific (SCA) combining ability and their interactions with years (Y) for studied traits in $F_1$ diallel crosses under low N conditions across two years

| SOV | df | MS | | | |
|---|---|---|---|---|---|
| | | NUE | NUPE | NUTE | NHI |
| Genotypes (G) | 20 | 99.87** | 291.41** | 3.87** | 41.32** |
| GCA | 5 | 352.82** | 674.51** | 5.97** | 120.84** |
| SCA | 15 | 15.56** | 163.71** | 3.17** | 14.81 |
| GCA x Y | 5 | 7.39** | 9.40** | 4.71** | 27.0* |
| SCA x Y | 15 | 7.73** | 21.45** | 2.29** | 38.74** |
| GCA/SCA | | 22.67 | 4.12 | 1.88 | 8.15 |
| GCA x Y/SCA x Y | | 0.95 | 0.43 | 2.05 | 0.70 |
| error | 80 | 2.72 | 3.832 | 0.012 | 9.73 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively*

The greater importance of GCA relative to SCA variance as observed in this study was also reported by Larik *et al.* (1995) and Al-Naggar *et al.* (2006, 2007, 2012, 2014 and 2015 a, b, c) for (GYPP) and its components. Le Gouis *et al.* (2002) reported that in N-limited diallel F1 hybrids between modern French cultivars found markedly higher GCA/SCA ratios for grain yield, grain N yield and total above ground N than in those grown under high N nutrition. A similar preponderance of GCA effects for N uptake and NUTE was identified in $F_2$ and $F_3$ progenics of factorial hybrids between modern and exotic cultivars of barley grown under reduced N fertilization (Gorny and Ratajezak, 2008).

Results in Tables (3 and 4) indicate that mean squares due to SCA x year interaction were significant ($P \leq 0.01$) for the all studied traits under the two levels of N, except GPC and NHI under low N, indicating that non-additive variance was affected by years. Mean squares due to the GCA x year interaction were also significant ($P \leq 0.05$ or 0.01) for all studied traits under high and low N, except for NUPE under high-N and GPC under low-N, which were not significant, indicating that additive variance for most cases differs from one year to another. The mean squares due to SCA x year was higher than those due to GCA x year for all studied traits under both high and low- N, except for NHI and NUE under high–N, suggesting that SCA (non–additive) variance (in most cases) is more affected by year than GCA (additive) variance.

### 3.3. GCA Effects

Estimates of general combining ability (GCA) effects of parents for studied traits under the two levels of nitrogen across two years are presented in Table 4 (high-N) and Table 5 (low-N). Favorable significant GCA effects were expressed by positive estimates for all studied traits.

**Table5.** *Estimates of general combining ability effects (gi) of all traits in $F_1$'s under high N conditions across two seasons*

| Parents | NUE | NUPE | NUTE | NHI |
|---|---|---|---|---|
| L25 | -0.74* | 0.71* | -0.10* | -0.22 |
| L26 | 1.27* | 1.79* | -0.03* | -0.31 |
| L27 | 0.77* | 0.21 | 0.04* | -0.76* |
| Gem 7 | -0.39* | -0.29 | -0.01 | -0.12 |
| Gem 9 | -0.73* | -1.27** | 0.04* | 0.75* |
| Giza 168 | -0.19 | -1.15* | 0.05* | 0.66 |
| SEgi | 0.38 | 0.32 | 0.03 | 0.70 |
| SEgi-gj | 0.59 | 0.50 | 0.05 | 1.08 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively*

In general, the best general combiners in $F_1$'s for NUE and NUPE were L26 followed by L27 and L25 parents under both high-N and low-N. For NUTE, the best combiners were L27, Gem9 and Gz168 under high-N and Gem9 under low-N. However, for NHI, the best combiners were Gem9 under high-N and Gem9 and Gz 168 under low-N. On the contrary, the worst general combiners in $F_1$'s were Gem 9, Gem 7 and Giza 168 for NUE and NUPE traits under both high–N and low–N environments.

**Table6.** *Estimates of general combining ability effects (gi) of all traits in F1's diallel crosses under low N conditions across two years*

| Parents | **NUE** | **NUPE** | **NUTE** | **NHI** |
|---|---|---|---|---|
| L25 | 2.35** | 2.21* | -0.14* | -1.82* |
| L26 | 2.35** | 5.17** | -0.23* | -0.89 |
| L27 | 2.46** | 2.03** | -0.11* | -0.55 |
| Gem 7 | -2.20** | -2.47* | -0.13* | -0.55 |
| Gem 9 | -3.60** | -4.94** | 0.71* | 1.38* |
| Giza 168 | -1.36** | -2.00* | -0.10* | 2.43** |
| $SE_{gi}$ | 0.83 | 1.05 | 0.06 | 1.66 |
| $SE_{gi-gj}$ | 1.37 | 1.62 | 0.09 | 2.57 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively*

It is worthy to note that the best general combiners in this study (L25, L26 and L27) showed also high *per se* performance for the most studied NUE traits under both high and low–N environments.

### 3.4. SCA effects

Estimates of specific combining ability (SCA) effects of the $F_1$ crosses for the studied traits under the two levels of N are presented in Tables (6 and 7). The best crosses in SCA effects were considered those exhibited significant positive SCA effects for all studied traits. The rank of $F_1$ crosses for SCA effects was changed from under high–N to under low–N conditions. Under high–N, the best cross for SCA effects of was the $F_1$ cross L26 x Gz 168 followed by the $F_1$ L27 x Gem7 in two traits (NUE and NUTE), the $F_1$ L25 x L26 for NUTE and the $F_1$ L25 x Gz 168, L26 x L27, and L26 x Gem7 for NUPE and L27 x Gem9 for NUTE. These $F_1$'s include at least one parent of high GCA effects under high N.

**Table7.** *Estimates of specific combining ability effects (ŝij) of F1's under high N conditions across two seasons*

| **Crosses** | **NUE** | **NUPE** | **NUTE** | **NHI** |
|---|---|---|---|---|
| L25 X L26 | 0.63 | -0.79 | 0.09* | 1.52 |
| L25 X L27 | -1.58* | -0.16 | -0.09* | 0.55 |
| L25 X Gem 7 | -0.49 | 0.004 | -0.03 | -0.30 |
| L25 X Gem 9 | 0.46 | 0.85 | -0.03 | -0.45 |
| L25 X Gz 168 | 0.39 | 1.19* | -0.05 | 0.41 |

| | | | | |
|---|---|---|---|---|
| L26 X L27 | -0.18 | 1.27* | -0.09* | 0.91 |
| L26 X Gem 7 | -0.44 | 1.87* | -0.12* | 0.12 |
| L26 X Gem 9 | 0.60 | 0.16 | 0.01 | 1.29 |
| L26 X Gz 168 | 1.53* | -0.92 | 0.14* | 0.97 |
| L27 X Gem 7 | 2.64* | -2.18* | 0.33* | -0.36 |
| L27 X Gem 9 | 0.52 | -2.13* | 0.19* | -0.32 |
| L27 X Gz168 | 0.44 | 1.00* | -0.05 | -0.70 |
| Gem 7 X Gem9 | -0.90 | 0.87 | -0.13* | -0.24 |
| Gem 7 X Gz 168 | 0.52 | -0.06 | 0.03 | -1.89 |
| Gem 9 X Gz 168 | -0.46 | -0.37 | -0.01 | -0.10 |
| $SE_{Sij}$ | 1.05 | 0.89 | 0.09 | 1.91 |
| $SE_{Sij-Sik}$ | 1.57 | 1.32 | 0.10 | 2.16 |
| $SE_{Sij-Skl}$ | 1.45 | 1.23 | 0.12 | 2.85 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively*

Under low–N conditions, the best SCA effects were shown the by F$_1$'s L25 x Gz168 for NUE and NUPE, L2 x Gem9 and L27 x Gem9 for NUPE and L25 x L 26, L25 x L27 and L27 x Gem9 for NUTE trait. Again these F$_1$'s include at least one parent of high GCA effects under low-N.

**Table8.** *Estimates of specific combining ability effects (ŝij) of F1's under low N conditions across two years*

| **Crosses** | **NUE** | **NUPE** | **NUTE** | **NHI** |
|---|---|---|---|---|
| L25 X L26 | 0.59 | -5.22** | 0.30** | 1.75 |
| L25 X L27 | -0.40 | -4.31** | 0.24* | 0.39 |
| L25X Gem 7 | 2.09 | 2.43 | 0.10 | 1.36 |
| L25 X gem 9 | -2.08 | 4.81** | -0.92* | 2.11 |
| L25 X Gz 168 | 2.46* | 6.15** | -0.01 | -2.11 |
| L26 X L27 | 1.19 | 3.80* | 0.04 | -0.66 |
| L26 X Gem 7 | -0.19 | 0.36 | 0.09 | -0.81 |
| L26 X Gem 9 | -0.88 | 5.42** | -0.88** | 1.90 |
| L26 X Gz 168 | -1.79 | -0.8 | 0.06 | -2.15 |
| L27 X Gem 7 | 1.54 | -2.88 | 0.28** | -1.48 |
| L27 X Gem 9 | -1.57 | 10.63** | -1.07** | -1.42 |
| L27 X Gz168 | 0.16 | -4.22** | 0.27* | 0.67 |
| Gem 7 X Gem9 | -0.37 | 0.04 | -0.68** | -0.35 |
| Gem 7 X Gz 168 | -1.09 | 2.12 | -0.02 | 0.43 |
| Gem 9 X Gz 168 | -1.09 | -1.41 | -0.42* | 0.29 |
| $SE_{Sij}$ | 2.43 | 2.88 | 0.16 | 4.58 |
| $SE_{Sij-Sik}$ | 3.63 | 3.25 | 0.24 | 5.16 |
| $SE_{Sij-Skl}$ | 3.36 | 3.98 | 0.22 | 6.84 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively*

Results of Gorny *et al.* (2011) on wheat crosses appear to be in accord with similar N-Shortage – induced increases in the importance of non–additive effects for grain yield and components of NUE previously reported in maize (Di Fonzo *et al.*, 1982, Medici *et al.*, 2004 and Al-Naggar *et al*. 2008, 2011, 2015a) and those for NUE in grain sorghum (Al-Naggar *et al*. 2006, 2007 b). Gorny *et al*. (2011), who reported that under high N-fertilization, the efficincy components were incanted in a manner favorable for wheat selection (preponderance of additive effects ) however the enhanced contribution of non-additive gene effects and increased dominance under N-limited conditions could impede wheat selection to improve the N efficiency and adaptation to less luxurious fertilization regimes. They concluded that selection methods that eliminate masking non-additive influences and take advantage of the additive variance should be employed to improve those traits.

### 3.5. Correlations between XP vs GCAF1 effects and XF1 vs SCAF1 effects

Rank correlation coefficients calculated between mean performances of parents (Xp) and their GCA effects of $F_1$'s for studied characters are presented in Table (9). Significant ($P\leq 0.05$ or 0.01) and positive correlations between Xp and $GCA_{F1}$ effects existed for all studied traits under both high-N and low-N. In general, the magnitude of correlation coefficient between Xp and $GCA_{F1}$ effects was very high (> 0.91 in 7 out of 10 cases ) and was higher at low-N than high-N in all studied traits, except NHI. The highest correlation coefficient under low-N between Xp and GCA was observed for NUPE (1.00) followed by 0.98 for NUE and 0.95 for NUTE. These results indicate that the best performing parents for grain yield and nitrogen use efficiency and their components are also the best general combiners and *vice versa*, and therefore, the mean performance of a given parent under low-N and high-N is an indication of its general combining ability. This conclusion was previously reported by Le Gouis *et al*., (2000) and Yildirim *et al*. (2007) in wheat and Meseka *et al*. (2013) and Al-Naggar *et al*., (2008, 2015 a, b, c) in maize. Le Gouis *et al.* (2000) reported that when GCA effects are largely superior to SCA effects, the correlation between *per se* value and GCA would give an indication about the possibility to use the means of the two parents to predict the value of hybrid. Yildirim *et al*. (2007) reported that *per se* values of parent for grain yield and nitrogen use efficiency were positively correlated with GCA effects of themselves at N0 level; this can be used to obtain high N use efficient lines.

**Table9.** *Rank correlation coefficients among means performance of parents (Xp) and their GCA effects for F1,s and between XF1 and SCAF1 effects under high and low–N environments across two seasons*

| Traits | $X_P$ *vs* GCA | | $X_{F1}$ *vs* $SCA_{F1}$ | |
|---|---|---|---|---|
| | HN | LN | HN | LN |
| NUE | 0.95** | 0.98** | 0.79** | -0.02 |
| NUPE | 0.95** | 1.00** | 0.70** | -0.08 |
| NUTE | 0.83** | 0.95** | 0.90** | -0.09 |
| NHI | 0.61** | 0.38* | 0.03 | -0.12 |

** And** indicate significant at 0.05 and 0.01 probability levels, respectively.*

For $F_1$ crosses, under low-N, all studied traits showed very low in-magnitude values of negative and non-significant correlation coefficients between $X_{F1}$ and $SCA_{F1}$ effects ranging from r= -0.02 to r= -0.12 (Table 9). All studied NUE traits did not show significant correlation coefficients between $X_{F1}$ and $SCA_{F1}$ effects under low-N environment. Therefore, it could be concluded that under low-N, the mean performance of a given $F_1$ cross of wheat is not an indication of its specific combining ability. This conclusion was previously reported by Al-Naggar *et al*. (2014, 2015 a, b).

On the contrary, under high-N, there were significant and positive correlation coefficients (ranging from 0.70 to 0.90 ) between $X_{F1}$ and $SCA_{F1}$ effects for the three nitrogen use efficiency traits NUE, NUPE and NUTE, indicating that under high-N, the mean performance of a given $F_1$ cross could be considered as an indication of its specific combining ability, especially for NUE, NUPE and NUTE.

Summarizing the above mentioned results, it cloud be concluded that low-N stress affects on the associations between mean performance of $F_1$'s and their SCA effects and so conclusions generated from results under high-N differ from those generated from results under low-N. Only indication under high-N and low-N are similar for the association between mean performance of parents and their GCA effects. Thus, under either low-N or high-N the mean performance of a given parent could be considered an indication of its general combining ability. But under high-N only, the mean performance of a given $F_1$ cross could be considered an indication of its SCA effects.

## IV. CONCLUSIONS

This study suggested the existence of a greater portion of additive and additive x additive than that of non–additive genetic variance in controlling the inheritance of all studied nitrogen use efficiency traits under the two levels of nitrogen. In general, the best general combiners in $F_1$'s for NUE and NUPE traits were L26 followed by L27 and L25 parents under both high-N and low-N. For NUTE, the best combiners were L27, Gem9 and Gz168 under high-N and Gem9 under low-N. However, for NHI, the best combiners were Gem9 under high-N and Gem9 and Gz 168 under low-N. Under low–N conditions, the best SCA effects were shown the by $F_1$'s L25 x Gz168 for NUE and

NUPE, L2 x Gem9 and L27 x Gem9 for NUPE and L25 x L 26, L25 x L27 and L27 x Gem9 for NUTE trait. These $F_1$'s include at least one parent of high GCA effects under low-N. The study concluded that under either low-N or high-N, the mean performance of a given parent could be considered an indication of its general combining ability effects. But under high-N only, the mean performance of a given $F_1$ cross could be considered an indication of its SCA effects in $F_1$ generation.

## REFERENCES

[1] A.O.A.C. (1990). Official Methods of Association of Analytical Chemists. 15th ed. Washington D.C.,USA. 290p.

[2] Al- Naggar, A. M. M.; R. Shabana; M.M.M. Atta and T.H.Al-Khalil (2015a). Regression of Grain Yield of Maize Inbred Lines and Their Diallel Crosses on Elevated Levels of Soil-Nitrogen. International Journal of Plant & Soil Science, Vol.4 (6): 499-512.

[3] Al- Naggar, A. M. M.; R. Shabana; M.M.M. Atta and T.H. Al-Khalil (2015b). Maize response to elevated plant density combined with lowered N-fertilizer rate is genotype-dependent. The Crop Journal, Vol. (3):96-109.

[4] Al- Naggar, A. M. M.; R. Shabana; M.M.M. Atta and T.H. Al-Khalil (2015c). Response of genetic parameters of low-N tolerance adaptive traits to decreasing soil-N rate in maize (*Zea mays* L.). Applied Science Reports, 9 (2): 110-122.

[5] Al- Naggar, A. M.; M. M. M. Atta and M. M. Amein (2009). Maize genotypic differences in nitrogen use efficiency under low soil-N conditions. Egypt. J. of Appl. Sci., 24(3B): 528-546.

[6] Al-Naggar, A. M. M.; R. Shabana and T. H. Al-Khalil (2010). Tolerance of 28 maize hybrids and populations to low-nitrogen. Egypt. J. Plant Breed. 14(2): 103-114.

[7] Al- Naggar, A. M. M.; R. Shabana and T. H. Al-Khalil (2011). Differential nitrogen use efficiency in maize genotypes of narrow- *vs* broad – base genetic background. Egypt. J. Plant Breed. 15(1): 41-56.

[8] Al- Naggar, A. M. M.; R. Shabana; M.M.M. Atta and T.H.Al-Khalil (2014). Genetic parameters controlling some maize adaptive traits to elevated plant densities combined with reduced N-rates. World Research Journal of Agronomy, Vol. 3, Issue 2 : 70-82.

[9] Al- Naggar, A.M. M.; D. A. El-Kadi and Zeinab S. A. Abo–Zaid (2006). Genetic parameters of grain sorghum traits contributing to low – N tolerance. Egypt. J. Plant Breed. 10 (2) :79-102.

[10] Al- Naggar, A. M. M.; D. A. El-Kadi and Zeinab S. A. Abo–Zaid (2007).. Inheritance of nitrogen use efficiency traits in grain sorghum under low- and high-N. Egypt. J. Plant Breed. 11 (3): 181-206.

[11] Al- Naggar, A. M.; R. Shabana; A. A. Mahmoud and S. A. M. Shaboon (2008). Genetic improvement of maize for low-soil nitrogen tolerance *via* $S_1$ recurrent selection. Egypt. J. Plant Breed. 12 (2): 255-277.

[12] Al-Naggar, A. M. M. and Shehab- El- Deen, M.T. (2012). Predicted and actual gain from selection for early maturing and high yielding wheat genotypes under water stress conditions. Egypt. J. Plant Breed. 16 (3) : 73 -92.

[13] Baresel, J.P., Zimmermann G. and Reents H.J. (2008). Effects of genotype and environment on N uptake and N partition in organically grown winter wheat (*Triticum aestivum* L.) in Germany. Euphytica 163:347–354.

[14] Barraclough, P.B., Howarth J.R., Jones J., Lopez-Bellido R., Parmar S., Shepherd C.E.and Hawkesford M.J. (2010). Nitrogen efficiency of wheat: genotypic and environmental variation and prospects for improvement. Eur. J. Agron. 33:1–11

[15] Brancourt-Hulmel, M., Heumez E., Pluchard P., Beghin D., Depatureaux C., Giraud A and, Le Gouis J. (2005). Indirect versus direct selection of winter wheat for low-input or high-input levels. Crop Sci. 45:1427–1431.

[16] Ceccarelli, S. (1994). Specific adaptation and breeding for marginal conditions. Euphytica 77:205–219

[17] Ceccarelli, S. (1996). Adaptation to low/high input cultivation. Euphytica. 92: 203-214.

[18] Dawson, J.C., Huggins D.R. and Jones S.S. (2008) Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. Field Crop Res 107:89–101.

[19] Dhugga, K.S. and Waines J.G. (1989). Analysis of nitrogen accumulation and use in bread and durum wheat. Crop Sci. 29:1232–1239

[20] Di Fonzo, N., Motto M., Maggiore T., Sabatino R. and Salamini F.(1982). N-uptake, translocation and relationships among N-related traits in maize as affected by genotype. Agronomie 2:789–796.

[21] El Bassam, N. (1998) A concept of selection for ‘low-input’ wheat varieties. Euphytica 100:95–100

[22] Fageria, N.K. and Baligar V.C. (2005). Enhancing nitrogen use efficiency in crop plants. Adv. Agron. 88:97-185.

[23] Good, A.G., Shrawat A.K., Muench D.G. (2004). Can less yield more? Is reducing nutrient input into the environment compatible with maintaining crop production? Trends Plant Sci 9:597–605.

[24] Gorny, A.G. and Ratajczak D. (2008). Efficiency of nitrogen and phosphorus utilization in progenies of factorial crosses between European and exotic cultivars of spring barley. J Appl Genet 49:349–355.

[25] Gorny, A.D. and Sodkiewicz T. (2001). Genetic analysis of the nitrogen and phosphorus utilization efficiencies in mature spring barley plants. Plant Breed 120:129–132.

[26] Gorny, A.G., Banaszak Z., Lugowska B. and Ratajczak D. (2011). Inheritance of the efficiency of nitrogen uptake and utilization in winter wheat (*Triticum aestivum* L.) under diverse nutrition levels. Euphytica. 77: 191–206.

[27] Gorny, A.G., Garczyn´ski S., Banaszak Z. and Ługowska B. (2006a). Genetic variation in the efficiency of nitrogen utilization and photosynthetic activity of flag leaves among the old and modern germplasm of winter wheat. J. Appl. Genet. 47:231–237.

[28] Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing system. / Aust. J. Biol. Sci. 9: 463_/493.

[29] Hirel, B., Le Gouis J., Ney B. and Gallais A. (2007). The challenge of improving nitrogenuse efficiency in crops plants: towards a more central role of genetic vari-ability and quantitative genetics within integrated approaches. J. Exp. Bot. 58,2369–2387.

[30] Huggins, D.R. and Pan W.L. (2003). Key indicators for assessing nitrogen use efficiency in cereal-based agroecosystems. J. Crop Prod. 8:157–185.

[31] Kiche,y T., Hirel B., Heumez E., Dubois F. and Le Gouis J. (2007). Wheat genetic variability for post-anthesis nitrogen absorption and remobilisation revealed by 15N labeling and correlations with agronomic traits and nitrogen physiological markers. Field Crop Res 102:22–32.

[32] Lammerts van Bueren, E.T., Østergard H., Goldringer I. and Scholten O. (2008). Plant breeding for organic and sustainable, lowinput agriculture: Dealing with genotype-environment interactions. Proceedings of the EUCARPIA symposium of working group organic plant breeding, 7–9 Nov 2007, Wageningen. Euphytica 2008, doi:10.1007/s10681-008-9731-4, pp 1–72.

[33] Laperche, A., Brancourt-Hulmel M., Heumez E., Gardet O. and Le Gouis J. (2006). Estimation of genetic parameters of a DH wheat population grown at different N stress levels characterized by probe genotypes. Theor Appl Genet 112:797–807.

[34] Le Gouis, J, Be´ghin D, Heumez E, Pluchard P (2000). Genetic differences for nitrogen uptake and nitrogen utilization efficiencies in winter wheat. Eur. J. Agron. 12:163–173.

[35] Le Gouis, J, Be´ghin D, Heumez E, Pluchard P (2002). Diallel analysis of winter wheat at two nitrogen levels. Crop Sci. 42:1129–1134.

[36] Medici, L.O., Pereira MB, Lea P.J., Azevedo R.A. (2004) Diallel analysis of maize lines with contrasting responses to applied nitrogen. J Agric Sci 142:535–541.

[37] Meseka, S.K., Menkir A., Ibrahim A.E.S. and Ajala S.O. (2006). Genetic analysis of performance of maize inbred lines selected for tolerance to drought under low nitrogen. Maydica 51: 487- 495.

[38] Moll, R.H., Kamprath E.J. and Jackson W.A. (1982). Analysis and interpretation of factors which contribute to efficiency to nitrogen utilization. Agron. J. 75: 562–564.

[39] Ortiz-Monasterio, J.I., Sayre K.D., Rajaram S. and McMahon M. (1997). Genetic progress in wheat yield and nitrogen use efficiency under four N rates. Crop Sci. 37(3): 898-904.

[40] Presterl, T., Groh S., Landbeck M., Seitz G., Schmidt W., Geiger H.H. (2008). Nitrogen uptake and utilization efficiency of European maize hybrids developed under conditions of low and high nitrogen input. Plant Breed 121:480–486.

[41] Sattelmacher B, Horst WJ, Becker HC (1994). Factors that contribute to genetic variation for nutrient efficiency of crop plants. Z Pflanzenerna¨hr Bodenk 157:215–224

[42] Singh R.K., B.D. Chaudhary, 1985 Biometrical Methods in Quantitative Genetics Analysis. 2nd ed. Kalyani Publishers,New Delhi, India.

[43] Steel, R.G.D., Torrie J.H. and Dickey D. (1997). Principles and Procedure of Statistics. A Biometrical Approach 3rd Ed. McGraw Hill BookCo. Inc., New York. pp. 352-358.

[44] Sylvester-Bradley, R. and Kindred D. R. (2009). Analysing nitrogen responses of cereals to prioritize routes to the improvement of nitrogen use efficiency. Journal of Experimental Botany 60(7), 1939–1951.

[45] Van Ginkel, M., Ortiz-Monasterio J.I., Trethowan R. and Hernandez E. (2001). Methodology for selecting segregating populations for improved N-use efficiency in bread wheat. Euphytica 119:223–230.

[46] Wolfe, M.S., Baresel J.P., Desclaux D., Goldringer I., Hoad S., Kovacs G., Lo¨schenberger F., Miedaner T., Østergard H., **Lammerts** van Bueren E.T. (2008). Developments in breeding cereals for organic agriculture. Euphytica 163:323–346.

[47] Yildirim M, Bahar B, Genc I, Korkmaz K, Karnez E (2007) Diallel analysis of wheat parents and their F2 progenies under medium and low level of available N in soil. J Plant Nutr 30:937–945.