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Effect of Water Deficit and Soil Nitrogen on Dry Matter and Nitrogen Accumulation and Mobilization in Durum Wheat under Semi-Arid Environment

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ABSTRACT

The effects of water deficit and nitrogen (N) application were evaluated on dry matter (DM) and N remobilization in eight durum wheat varieties. Cham5, Cham3, Om Quis, Kayar Tunis and Hourani Nawawi had the highest DM remobilization under wetter environment ranging from 16.7 to 16.8%, rising to 20.7 to 23.7% in the drier environment. Cham 5 and Cham 3 also showed higher N translocation to grains (values=67.3 and 72.9%) under drier conditions. N deficiency significantly ($P<0.05$) increased N remobilization to grain in Deir Alla 6 and Hourani Nawawi; increasing N rate from 0 to 200 kg urea ha^{-1} decreased N remobilization from 40.8 to 20.8% and from 40.3 to 32.3% in Deir Alla 6 and Hourani Nawawi, respectively. In conclusion, some varieties showed high capacity for DM and N translocation under unfavorable conditions and they could be considered as a potential source of genes for plant breeding.

Keywords: Durum Wheat, Nitrogen, Remobilization of Dry Matter, Remobilization of N, Water Deficit.

INTRODUCTION

Durum wheat *Triticum durum* L. is an important primary crop in West Asia and North Africa (WANA), providing the principle food source for the majority of the people in the countries of WANA region, with annual consumption average of more than 150 kg person^{-1} which is considered the highest level in the world (FAO, 1988). Nitrogen (N) and soil moisture are important components of durum wheat production technology with high yielding varieties since wheat is mostly grown in semiarid climatic conditions where moisture and low soil fertility are usually the limiting factors (Martin et al., 2006; Abdel-Ghani, 2008). Wheat in WANA region is cultivated under rainfed condition in areas receiving more than 300 mm annual rainfall, which are characterised by high inter- and intra-seasonal variation in terms of amount and distribution of rainfall (Abdel-Ghani, 2008). Rainfall variability and soil nutrient deficiency are the main causes for low productivity (Abdel-Ghani, 2008, Al-Rawashdeh and Abdel-Ghani 2008; Al Nasir and Abdel-Ghani 2010). Therefore, one major objective under rain fed farming system is to improve the productivity of growing crops by soil fertility enrichment and selecting more adapted genotypes for low soil moisture and nutrient deficiency.

Two physiological processes are involved in grain growth: utilization of photosynthesis during grain filling and remobilization of substances accumulated before anthesis to grain. In wheat, available carbon assimilates

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for grain growth is determined by carbon assimilation during grain filling period plus assimilates reserve stored in vegetative parts before anthesis (Austin et al., 1977; Papakosta et al., 1991). Rawson and Evans (1971) reported that contribution of pre-anthesis accumulated reserves to grain weight ranged from 5 to 30%, indicating the importance of pre-anthesis storage for attaining high grain yield of wheat, and grain filling was positively and significantly correlated with dry matter (DM) and N translocation efficiency. Accumulation of N in the grains is entirely dependent on mobilization of N previously accumulated in other organs of the plant. Leaves are the main N reservoir of the plant during vegetative growth (Asseng and van Herwaarden, 2003; Papakosta and Gagianas, 1991; Plaut et al., 2004). The glumes and stem each contributed 23% of the N incorporated by the grains. The flag leaf contributed 24%, leaf 2 supplied 11%, leaf 3 supplied 4%, and all the other leaves only 0.5%. Lower leaves, which were either severely senesced or dead by anthesis, presumably had exported most of their N to other developing organs prior to grain filling. The roots contributed 16% of the N incorporated by the grains (Simpson et al., 1983).

Cultural practices and moisture availability have a strong influence on N uptake and translocation of assimilate during the grain filling period. Rate and timing of N are critical in terms of their effects on yield and plant growth (Pietola et al., 1999; Costa Crusciol, et al., 2003). Li et al. (2003) reported that a water limitation and a high N level can lead to a poor N efficiency for spring wheat. Moreover, low soil moisture can adversely affect N mobility in the soil and consequently uptake by the plant (Kraimer et al., 2001; Yuan et al., 2005). Results of other studies showed that remobilization of reserves to grain become greater when plants are grown under water deficit than under irrigation (Bidinger et al., 1977, Aggarwal and Sinha, 1984). Moreover, large movement of assimilates can also occur under low soil fertility conditions (Yoshida, 1972; Papakosta and Gagianas, 1991).

Genetic variability in carbohydrates and nitrogenous compound accumulation in the vegetative organs of wheat before anthesis has been reported in several studies (Gallagher et al., 1976; Austin et al., 1977; Papakosta and Gagianas, 1991). According to Aggarwal and Sinha (1984), drought tolerant varieties substantially mobilized more pre-anthesis assimilates both under the irrigated and non-irrigated conditions than a moderately tolerant once.

The objectives of this study were: (i) to assess under field condition the response of eight durum wheat cultivars adapted semi-arid regions of Jordan to dry conditions and different N application rates and (ii) to investigate the relative importance of remobilized carbohydrate and N stored before anthesis in the stem to grains under dry condition and N deficiency.

MATERIALS AND METHODS

The field experiments were carried out at at Rabbeh (31° 16' N, 35° 45' E, and ca 920 meters above sea level) and Ghweer (31° 14' N, 35° 45' E, and ca 820 meters above sea level) agricultural stations (in short RAS and GAS respectively) belonging to the National Center for Agricultural Research and Extension (NCARE), Jordan in 2008/2009 cropping season. The former is less dry with a relatively moderate rainfall (310 mm long-term annual average), and the latter is dry with 220 mm long-tem annual average. The experimental design was a randomized complete block (RCBD) design with factorial arrangement of treatments (varieties and N application rates) with three replications. Plots were 4 m long and consisted of six rows placed 30 cm apart. Three N fertilizer levels were included 0, 100 and 200 kg urea ha^{-1} with eight durum wheat varieties, namely; Cham5, Cham1, Cham3, Amon, Deir Alla, Om Quis, Kayar Tunis and Hourani Nawawi obtained from NCARE. The maximum N application rate was selected to match wheat crop N demands under Jordanian conditions which ranged from 95–140 kg N ha^{-1} (Al-Rawasdeh and Abdel-Ghani 2008). N was split applied; the first dose was applied at planting time and the second portion was added at tillering stage. Cham1 is an ICARDA-cultivar suitable for high input conditions and Cham 3 an ICARDA-cultivar with better stress tolerances than Cham 1 (Elings1993). Cham 5 is a high-yielding durum wheat cultivar with resistance to different abiotic and biotic stresses, was released in 1993/94 for the dry areas in Syria (http://www. icarda. cgiar.org/ ICARDA_ photogallery/ Wheat/wheat.html). Om-quais is a semi- dwarf that was developed from Omrabi 6 introduced from ICARDA, Hourani Nawawi is a selection from a tall landrace originating from Lebanon (Elings1993). Deir Alla is a adapted durum wheat variety was released in 1972 for the dry areas in Jordan. Amon and Kayar Tunis are a semi-tall, semi-late, well-adapted Jordanian conditions. All varieties used in this study are improved, certified and recommended for wheat growers in Jordan.

Seeds of the eight cultivars were sown on 15 December 2008 at both locations, at a rate of 100 kg ha^{-1}. Before planting, germination test was carried out to calculate the actual seeding rates. The plots were weeded manually three times at two weeks intervals. Since the sensitivity of wheat to water stress is particularly acute during the grain-filling period and grain filling often occurs when temperatures are increasing and moisture supply is decreasing which accentuates the drought effect, supplementary irrigation was performed at RAS in grain filling stage. Various studies demonstrated that post-anthesis (i.e. during grain filling) is the most critical stage that leads to substantial yield losses in response to water deficit (Kobata et al., 1992; Palta et al., 1994; Yang et al., 2001, 2003). Irrigation was performed at four to five days interval starting from April 21st at a rate of irrigated water equivalent to 25 mm of fresh water at the first three supplementary irrigations (April 21st, April 25th and May 1st 2009) and 28 mm in the last irrigation (May 7th 2009).

Two rows were harvested during anthesis from the second and third inner rows of each plot after removing a half meter from the both sides to avoid border effects and at maturity stage (i.e. when 95% of the peduncles turned yellow), the other two inner rows were used to determine biological and grain yield. Collected plants were subsequently dried in 75 °C for 72 h and weighed. Plant samples were analyzed for total N content using the standard macro-Kjeldahl procedure. N uptake was determined by multiplying dry weight of plant parts (grain and straw) by N concentration and summing over parts for total aboveground biomass plant uptake.

Dry matter translocation (DMT) and N translocation (NT) were calculated as the decrease of stem (*plus* leaf sheaths) dry weight between anthesis and the end of grain filling, as an indicator of carbohydrate and N remobilization to the grains. DMT efficiency (DMTe, %) , the contribution of preanthesis stem assimilates to grain yield (CPA), N translocation efficiency (NTe), contribution of preanthesis N assimilate to grain (CPAN) and N harvest index (NHI) were calculated according to Papakosta and Gagianas, (1991) as follows:

1. DMTe (%) = (DMT / DM at anthesis) × 100.
2. CPA (%) = (DMT / grain yield) × 100.
3. NTe (%) = (NT / N content at anthesis) × 100.
4. CPAN (%) =(NT / N content in grain) × 100.
5. NHI = Grain N / total N content of aboveground parts at maturity.

Data was also collected for seven additional parameters: plant height at maturity (cm; from soil surface to tip of spike excluding awns), number of spikes m^{-2}, thousand kernel weight (g), days to heading from emergence (50% of spikes fully emerged from flag leave) and days to maturity from emergence (50% of peduncles turned yellow). All parameters were recorded on plot basis

Analysis of variance (*ANOVA*) was used to test location, variety and N application rate effects as well as their interactions on different parameters. Data were analyzed by two way analysis of variance using the SAS statistical package (SAS institute, 2003), and the differences between the means were compared using Fisher's least significant difference (*LSD*) at $P<0.05$ (Steel and Torrie, 1980).

Results

Weather data

Precipitation in the 2008/2009 cropping season was higher at RAS than at GAS. However, in general, this season at both locations is relatively dry with only 207 and 178 mm annual rainfall with 83 and 42 mm below the long term average in RAS and GAS, respectively (Figure 1). Effective rainfall sufficient for germination started in mid-February at both locations. Although heavy rainfall was received in October at both locations, poor rainfall was recorded in the following months until mid-February 2009. High intensity rainfall (about 72 and 91% of the total rainfall in RAS and GAS, respectively) was received between mid-February and March, while no rainfall was detected after 22nd of March at both locations. At the experimental locations, high temperature was prevailing at the end of growing season (i.e. during April and May) which accentuates the drought effect (Figure 1).

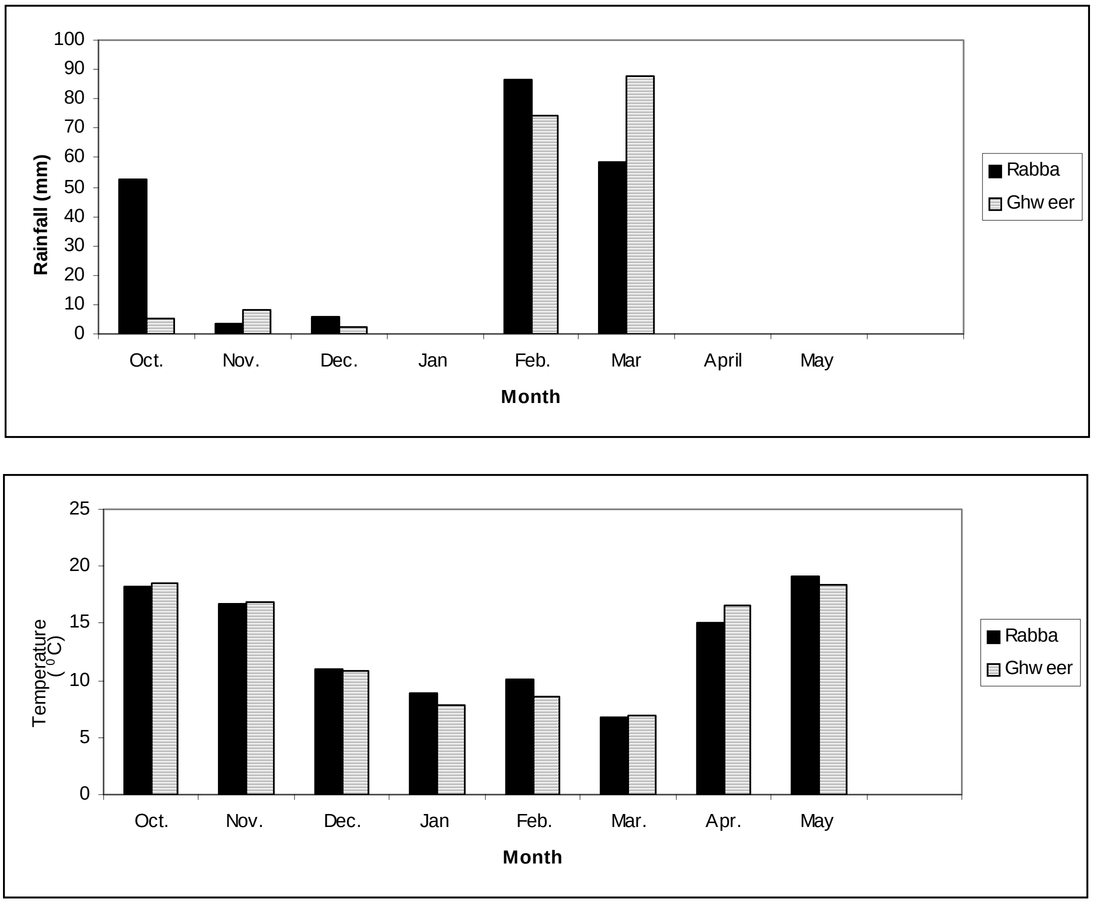

Figure 1. Weather data of the experimental sites: Rainfall distribution and monthly average temperature from Oct. to May during 2008/2009 cropping season

Effect of location

At GAS, above ground DM weight at anthesis and maturity, grain yield, thousand kernel weight, number of spikes m^{-2} and number of kernels $spike^{-1}$ were about 29.2, 49.2, 37.3, 15.1, 14.7 and 35.6% less than that obtained at RAS, respectively (Tables 1 and 2). Days to heading and days to maturity was shortened by 3 to 7 days at GAS compared to RAS (Table 1). DM translocated from vegetative organs (above ground DM) to developing kernels was significantly ($P \leq 0.01$) decreased by 26.6%, whereas DMTe and CPA were considerably increased at GAS by 18.0 and 47.8%, respectively (Tables 1).

Table 1. Plant height, yield component and phonological traits as affected by water availability, N application rate and variety.

Factor		**Yield components**			**Phenological**	
	Plant height (cm)	**Thousand Kernel weight**	**No. of spikes m^{-2}**	**Seeds $Spike^{-1}$**	**Days to heading**	**Days to maturity**
Location						
RAS	45.8	35.2	106.9	32.9	61.6	95.9
GAS	32.4	29.9	91.2	21.2	58.9	88.9
LSD (0.05)	2.3	0.8	6.2	2.5	0.6	0.9
N level (NL) (kg urea ha^{-1})						
0	37.18	32.6	94.6	25.6	59.3	92.2
100	40.12	32.5	102.4	27.0	60.5	91.9
200	40.12	32.4	100.1	26.7	61.0	93.0
LDS (0.05)	2.8	1.0	7.6	3.1	0.8	Ns
Variety						
Cham 5	34.5	32.2	98.2	29.9	60.1	91.6
Cham1	36.6	33.6	98.9	26.5	60.5	92.2
Cham3	42.2	33.8	97.8	31.3	59.5	93.3
Amon	35.9	31.4	107.8	26.4	61.1	91.5
Deir Alla 6	41.0	32.7	101.2	25.9	60.3	92.5
Om Quis	42.3	33.5	99.0	20.4	59.5	93.2
Kayar Tunis	39.7	32.7	93.8	28.9	60.5	92.1
Hourani Nawawi	41.0	30.3	95.9	27.2	60.7	92.6
LDS (0.05)	4.6	1.6	12.4	5.0	1.2	Ns
Interactions						
L×NL	ns	Ns	ns	ns	ns	Ns
L×V	ns	Ns	ns	**	ns	Ns
NL×V	ns	**	ns	ns	**	Ns
L×NL×V	ns	Ns	ns	ns	ns	Ns

Significant at the *0.05 and **0.01 probability levels, ns= non-significant; RAS, Rabba Agricultural Station with supplementary irrigation during grain filling; GAS, Ghweer Agricultural Station with water deficit during grain filling

Above ground N uptake at anthesis and maturity, grain N uptake, NT, NTe, CPAN and NHI as affected by location, N application rate and variety are presented in table 4. N uptake was significantly ($P<0.01$) reduced by 35.4, 48.7 and 38.7% in vegetative organs (aboveground DM) at anthesis and maturity and grains in GAS compared to RAS, respectively. Pre-anthesis N translocated to grains was significantly (*P*<0.01) increased by 14.7% under supplementary irrigation at RAS (Table 4). NTe, CPAN and NHI were increased at GAS by 92.8, 22.0 and 80.6%, respectively.

Effect of N application rate

N application caused significant (*P*<0.01) increase in plant height, above ground DM at anthesis and maturity, grain yield and some yield related traits such as number of spikes m^{-2} and thousand kernel weight (Table 1). However, days to heading and days to maturity were slightly affected by increasing N application. High N rate (200 kg urea ha^{-1}) increased these parameter to a higher extent than moderate (100 kg urea ha^{-1}) and 0 kg urea ha^{-1} treatments. TDM, DMTe and CPA were significantly (*P*<0.01) decreased from 403.1 to 322.2 kg ha^{-1}, from 22.6 to 27.7% and from 18.1 to 15.3% by increasing N application rate from 0 to 200 kg urea ha^{-1}, respectively (Table 2). In general, N uptake at anthesis and maturity, grain N uptake, NHI were significantly (*P*<0.01) increased by increasing N application rate, whereas traits such as NTe and CPAN% were significantly (*P*<0.01) reduced (Table 3). However, NT was not significantly affected. Above ground N uptake at anthesis and grain N uptake increased from 35.2 to 39 kg ha^{-1}, from 43.5 to 52.1 kg ha^{-1} and from 22.6 to 26.6 kg ha^{-1}, whereas NTe and CPAN decreased from 71.1 to 58.7% and from 42.7 to 40.5% by increasing N application from 0 to 200 kg urea ha^{-1}, respectively.

Varietal Differences

Wheat varieties showed highly significant (P < 0.01) differences for all agronomic traits investigated in this experiment (Table 1). Plant height was varied among varieties from 35.9 cm in Amon to 42.3 in Om Quis. All over varieties, thousand kernel weight, number of spikes m^{-2}, number of seeds $spike^{-1}$ ranged from 30.3 to 33.8 g, 93.8 to 107.8 and 20.4 to 31.3, respectively. All varieties headed within 2 days starting 59 days after sowing and varieties reached maturity within 91– 93 days.

The variation among varieties in above ground dry matter weight at anthesis and maturity, grain yield and dry matter translocation related is presented in Table 2. The total vegetative yield at anthesis and biological yield ranged from 2216.3 and 2571.4 kg ha^{-1} in Hourani Nawawi to 2521.3 and 3010.9 kg ha^{-1} in Cham1, respectively. The highest grain yield was obtained in Cham3 (1007.9 kg ha^{-1}), while the lowest grain yield was detected Om Quis (666.5 kg ha^{-1}). DMT, and DMTe (%) differed significantly among varieties, P<0.01 (Tables 2). Estimates of DMT and DMTe (%) ranged from 291.4 to 466.7 kg ha^{-1} and from 38.9 to 55.8%, respectively. Cham 3, Om Quis and Hourani Nawawi exhibited the highest DMTe (52.3, 50.5 and 50.8%, respectively) compared with the other varieties. CPA (%) ranged from 14.1% in Deir Alla 6 to 21.3% in Cham3.

Table 2. Above ground dry matter weight at anthesis and maturity, grain yield and dry matter translocation related traits as affected by water availability, N application rate and variety.

Factor	Above ground Dry matter		Grain Yield	DMT	DMTe (%)	CPA (%)
	Anthesis	Maturity				
	---------------------------------------Kg ha^{-1}---------------------------------					
Location (L)						
RAS	3060.2	3680.2	1029.8	421.4	42.8	13.8
GAS	1561.1	1897.4	645.4	309.1	50.5	20.4
LSD (0.05)	105.0	125.1	64.5	49.6	5.7	2.2
N level (NL) (kg urea ha^{-1})						
0	2300.8	2642.3	744.7	403.1	22.6	18.1
100	2278.7	2774.8	866.4	370.4	26.6	17.9
200	2369.9	2949.4	901.8	322.2	27.7	15.3
LSD (0.05)	Ns	153.3	78.9	60.7	6.9	2.7
Variety (V)						
Cham 5	2227.2	2747.1	896.2	376.2	42.1	18.9
Cham1	2521.3	3010.9	806.4	316.8	41.9	13.6
Cham3	2251.7	2792.9	1007.9	466.7	52.3	21.3
Amon	2464.0	2965.9	886.8	384.6	50.5	16.7
Deir Alla 6	2209.8	2745.7	827.4	291.4	38.9	14.1
Om Quis	2240.3	2583.4	666.5	323.4	50.8	16.2
Kayar Tunis	2401.0	2893.2	851.7	359.5	40.8	17.2
Hourani Nawaw	2216.3	2571.4	758.0	403.0	55.8	19.1
LSD (0.05)	209..9	250.3	128.9	99.1	11.3	4.3
Interactions						
L×NL	ns	ns	ns	ns	ns	ns
L×V	**	**	**	ns	*	*
NL×V	*	ns	ns	**	*	*
L×NL×V	*	**	ns	ns	ns	*

Significant at the *0.05 and **0.01 probability levels, ns= nonsignificant; RAS, Rabba Agricultural Station with supplementary irrigation during grain filling; GAS, Ghweer Agricultural Station with water deficit during grain filling; DMT, dry matter translocation; DMTe%, dry matter translocation efficiency of pre-anthesis carbohydrate reserves; CPA%, the contribution of pre-anthesis stem assimilates to grain yield%.

Interactive effects

There was a significant variety × location interaction for for TDM, DMTe and CPA from the pre-anthesis carbohydrate reserves, indicating that the varieties responded to prevailing condition at experimental locations differentially (Table 3). At GAS, the CPA to grain yield was increased in all tested varieties; the CPA ranged from 10.3 to 20.2% and from 16.7 to 23.7% at RAS and GAS, respectively. Among varieties, Cham5, Cham3, Om Quis, Kayar Tunis and Hourani Nawawi had the highest percent of DM remobilization to grain at GAS; DM remobilization to grain in these varieties was estimated to be 16.7-16.8% at RAS with relatively high DMTe (range=40.9 to 57.2%), rising to 20.7-23.7% at GAS. At Rabba, DMTe was less than 40% in Cham1, Amon, Deir Alla 6, ranged from 40.9 to 47.9% in Cham5, Cham3, Om Quis and Kayar Tunis and exceeded 59% in Hourani Nawawi. CPA was relatively high at GAS and RAS in Cham 3 (Values =20.2 and 19.7% respectively) with 47.9% and 56.6% DMTe, respectively.

Table 3. Interactive effect of water availability and varieties on above ground dry matter weight at anthesis and maturity, grain yield and dry matter translocation related traits.

Location	Cultivar	Above ground Dry matter		Grain Yield	DMT	DMTe (%)	CPA (%)
		Anthesis	Maturity				
		Kg ha^{-1}					
RAS	Cham 5	3200.7	3833.1	1076.9	444.3	43.3	14.0
	Cham1	3194.7	3803.0	943.6	335.2	38.8	10.3
	Cham3	2863.6	3545.4	1257.9	576.1	47.9	20.2
	Amon	3115.1	3892.2	1196.3	418.8	37.8	13.6
	Deir Alla 6	2945.4	3749.0	1145.0	341.4	29.8	11.5
	Om Quis	3088.0	3572.0	847.3	363.4	44.3	11.7
	Kayar Tunis	3309.8	3851.0	963.7	422.4	40.9	12.5
	Hourani Nawaw	2857.3	3196.1	807.6	469.0	59.1	16.4
GAS	Cham 5	1253.7	1661.0	715.4	308.1	40.9	23.7
	Cham1	1848.0	2218.8	669.2	298.4	45.0	16.8
	Cham3	1639.9	2040.4	758.0	357.3	56.6	22.4
	Amon	1812.9	2039.7	577.2	350.4	63.2	19.7
	Deir Alla 6	1474.2	1742.4	509.8	241.4	48.2	16.7
	Om Quis	1392.7	1594.9	485.7	283.4	57.2	20.7
	Kayar Tunis	1492.2	1935.3	739.7	295.6	40.7	21.8
	Hourani Nawaw	1575.2	1946.7	708.4	337.0	52.5	21.7
	LSD (0.05)	296.8	353.9	182.3	ns	16.3	6.14

ns= non-significant; RAS, Rabba Agricultural Station with supplementary irrigation during grain filling; GAS, Ghweer Agricultural Station with water deficit during grain filling; DMT, dry matter translocation; DMTe%, dry matter translocation efficiency of pre-anthesis carbohydrate reserves; CPA%, the contribution of pre-anthesis stem assimilates to grain yield%.

Table 4. Above ground N uptake at anthesis and maturity, grain N uptake and N translocation related traits as affected by water availability, N application rate and variety.

Factor	Above ground N uptake		N uptake in grain	NT	NTe (%)	CPAN %	NHI
	Anthesis	Maturity					
	Kg ha^{-1}						
Location (L)							
RAS	44.9	62.8	31.8	16.3	46.1	31.0	0.50
GAS	29.0	32.2	19.5	13.9	88.9	56.1	0.61
LSD (0.05)	2.2	2.8	2.1	1.7	8.6	3.41	0.02
N level (NL) (kg urea ha^{-1})							
0	35.2	43.5	22.6	14.3	71.1	42.7	0.53
100	36.8	47.0	26.6	16.4	72.8	46.8	0.58
200	39.0	52.1	26.6	14.6	58.7	40.5	0.55
LSD (0.05)	2.7	3.4	2.6	2.1	10.6	4.2	0.03
Variety (V)							
Cham 5	34.2	43.5	26.1	16.9	70.0	54.7	0.64
Cham1	40.4	47.3	24.7	18.0	80.7	46.4	0.53
Cham3	36.4	51.1	31.1	16.5	71.1	47.7	0.62
Amon	38.8	47.3	25.9	17.3	79.9	46.2	0.54
Deir Alla 6	35.4	49.9	25.9	11.5	57.7	35.6	0.53

Factor	Above ground N uptake		N uptake in grain	NT	NTe (%)	CPAN %	NHI
Om Quis	35.6	43.1	20.2	12.8	66.2	37.7	0.49
Kayar Tunis	39.5	51.3	27.0	15.3	56.7	40.1	0.55
Hourani Nawawi	35.3	46.9	23.9	12.4	57.8	37.7	0.53
LSD (0.05)	4.4	5.6	4.2	3.4	17.3	6.8	0.05
Interactions							
L×NL	ns	*	ns	ns	ns	ns	ns
L×V	**	**	ns	*	**	**	**
NL×V	ns	ns	ns	ns	ns	*	**
L×NL×V	ns	ns	ns	ns	ns	ns	**

ns= non-significant; RAS, Rabba Agricultural Station with supplementary irrigation during grain filling; GAS, Ghweer Agricultural Station with water deficit during grain filling; NT, N translocation; NTe, N translocation efficiency%; CPAN, contribution of preanthesis assimilate to grain%; NHI, N harvest index.

N uptake at GAS was decreased in all plant parts; however reductions varied in different varieties under study (Table 5). NTe and CPAN ranged among varieties from 27.3 to 58.6% and from 59.5 to 88.7% for NTe and from 22.8 to 38.0% and from 46.6 to 72.9% for CPAN under RAS and GAS, respectively (Table 1). Mobilization of pre-stored N was higher under water deficit (GAS) in Cham 5 and Cham 3 (values=67.3 and 72.9%) with high NTe (85.7 and 88.4%, respectively) than other studied varieties (CPAN range= 46.6 to 52.1%).

Table 5. Interactive effect of water availability and varieties on above ground N uptake at anthesis and maturity, grain N uptake and N translocation related traits.

Water availability	Variety	Above ground N uptake		N uptake in grain	TN	NTe (%)	NHI	CPAN %
		Anthesis	Maturity					
		-----------------------------kg ha^{-1}------------------------						
RAS	Cham 5	44.2	59.8	31.7	16.2	54.3	0.53	36.6
	Cham1	46.8	60.1	29.4	16.2	58.6	0.48	34.6
	Cham3	41.4	69.8	40.4	12.0	30.3	0.57	28.0
	Amon	46.5	63.7	34.9	17.7	53.6	0.54	38.0
	Deir Alla 6	43.9	70.7	36.6	9.7	27.3	0.52	22.8
	Om Quis	44.5	56.3	24.7	12.9	53.6	0.44	28.8
	Kayar Tunis	50.9	65.0	30.7	16.6	54.0	0.47	32.4
	Hourani Nawaw	41.3	57.2	25.5	9.6	37.3	0.45	23.3
GAS	Cham 5	24.2	27.1	20.5	17.6	85.7	0.76	72.9
	Cham1	34.6	34.5	19.9	19.9	88.7	0.58	58.2
	Cham3	31.4	32.3	21.9	21.0	88.4	0.66	67.3
	Amon	31.0	30.9	16.8	16.9	88.5	0.55	54.4
	Deir Alla 6	26.9	29.0	15.3	13.2	88.2	0.53	48.4
	Om Quis	26.7	29.8	15.8	12.6	78.8	0.54	46.6
	Kayar Tunis	28.2	37.6	23.3	13.9	59.5	0.63	49.0
	Hourani Nawaw	29.2	36.5	22.4	15.1	78.3	0.60	52.1
	LSD (0.05)	6.2	7..9	ns	4.9	24.5	0.07	9.6

ns= non-significant; RAS, Rabba Agricultural Station with supplementary irrigation during grain filling; GAS, Ghweer Agricultural Station with water deficit during grain filling; NT, N translocation; NTe, N translocation efficiency%; CPAN, contribution of preanthesis assimilate to grain%; NHI, N harvest index.

Among varieties, the highest amount of DMT and N remobilization from stem reserves was obtained at 0 kg ha^{-1} than at moderate and high N application rate (100 and 200 kg ha^{-1}) (Table 6). CPA ranged from 14.8 to 25.0%, from 10.1 to 20.6% and from 8.4 to 21.2% and CPAN ranged from 32.3 to 55.2, from 36.8 to 56.3% and from 20.8 to 52.7% under 0, 100 and 200 kg urea ha^{-1}, respectively. DMTe and NTe were significantly ($P<0.01$) decreased by N deficiency (0 kg urea ha^{-1}). N deficiency clearly increased NTe and CPAN in Deir Alla 6 and Hourani Nawawi (Table 7). Under high N application rate (200 kg urea ha^{-1}), NTe decreased from 63.0 to 49.0% and from 63.5 to 36.7% and CPAN decreased from 40.8 to 20.8% and from 40.3 to 32.3% in Deir Alla 6 and Hourani Nawawi, respectively.

Table 6. Interactive effect of nitrogen level and varieties on above ground dry matter weight at anthesis and maturity, grain yield and dry matter translocation related traits.

N Kg urea ha^{-1}	Variety	Above ground Dry matter		Grain Yield	DMT	DMTe (%)	CPA (%)
		Anthesis	Maturity				
		---Kg ha^{-1}---					
0	Cham 5	2188.5	2727.2	848.0	309.3	36.0	14.8
	Cham1	2702.8	2998.7	780.3	484.3	62.1	19.0
	Cham3	2167.0	2420.0	771.7	518.7	72.8	25.0
	Amon	2512.0	2812.3	753.7	453.2	66.0	18.6
	Deir Alla 6	2222.3	2605.0	796.0	386.3	53.0	17.3
	Om Quis	2109.7	2306.7	570.7	373.7	62.9	17.3
	Kayar Tunis	2304.2	2772.0	741.0	273.2	36.8	13.6
	Hourani Nawaw	2199.5	2496.7	723.2	426.2	62.8	18.8
100	Cham 5	2267.0	2793.3	992.8	466.5	45.3	20.6
	Cham1	2685.0	3202.3	787.7	270.3	36.3	10.1
	Cham3	2186.3	2799.7	1132.8	519.5	49.4	22.6
	Amon	2266.5	2750.2	889.5	405.8	54.7	19.8
	Deir Alla 6	2092.3	2761.7	986.3	299.0	32.2	16.4
	Om Quis	2355.7	2687.3	678.3	346.7	53.6	18.8
	Kayar Tunis	2346.7	2854.2	850.7	343.2	39.0	18.0
	Hourani Nawaw	2030.3	2349.3	630.8	312.0	52.5	17.3
200	Cham 5	2226.0	2720.7	847.7	352.8	45.0	21.2
	Cham1	2176.2	2831.7	851.2	195.8	27.5	11.6
	Cham3	2401.8	3159.2	1119.3	362.0	34.7	16.3
	Amon	2613.5	3335.3	1017.2	294.8	30.9	11.6
	Deir Alla 6	2314.8	2870.5	744.8	189.0	31.7	8.4
	Om Quis	2255.7	2756.3	750.5	250.0	35.9	12.4
	Kayar Tunis	2552.2	3053.3	963.3	462.2	46.5	19.9
	Hourani Nawaw	2419.0	2868.2	920.0	470.8	52.3	21.2
	LSD (0.05)	363.6	ns	ns	171.6	19.6	7.5

ns= non-significant; DMT, dry matter translocation; DMTe%, dry matter translocation efficiency of pre-anthesis carbohydrate reserves; CPA%, the contribution of pre-anthesis stem assimilates to grain yield%.

Table 7. Interactive effect of nitrogen level and varieties on Above ground N uptake at anthesis and maturity, grain N uptake and N translocation related traits.

Nitrogen	Variety	Above ground N uptake		N uptake in grain	TN	NTe (%)	NHI	CPA N%
		Anthesis	Maturity					
		--------------------------------kg ha^{-1}------------------						
0	Cham 5	34.9	42.6	25.2	17.5	71.6	0.63	55.2
	Cham1	41.7	48.1	23.4	17.0	74.0	0.50	42.3
	Cham3	34.6	44.2	25.2	15.6	77.1	0.58	48.3
	Amon	39.6	45.2	22.2	16.5	92.8	0.48	43.3
	Deir Alla 6	31.3	42.9	23.5	11.9	65.9	0.55	40.8
	Om Quis	31.0	38.2	16.7	9.5	63.0	0.44	32.3
	Kayar Tunis	36.0	44.8	21.9	13.0	60.8	0.51	39.0
	Hourani Nawaw	32.4	41.9	22.5	13.1	63.5	0.53	40.3
100	Cham 5	33.1	42.8	27.1	17.4	69.6	0.67	56.3
	Cham1	43.1	46.2	23.4	20.3	95.0	0.49	47.0
	Cham3	35.5	55.7	26.7	16.5	75.9	0.65	48.7
	Amon	37.5	44.5	27.0	20.1	85.5	0.60	55.2
	Deir Alla 6	34.8	50.6	30.1	14.4	58.4	0.61	45.2
	Om Quis	37.6	42.7	20.4	15.3	76.5	0.52	44.8
	Kayar Tunis	39.0	52.7	27.7	13.9	48.2	0.56	36.8
	Hourani Nawaw	33.8	40.7	20.1	13.2	73.2	0.51	40.5
200	Cham 5	34.6	45.0	26.1	15.8	68.8	0.63	52.7
	Cham1	37.3	47.6	27.1	16.8	73.0	0.60	49.8
	Cham3	39.1	53.3	31.6	17.5	60.3	0.62	46.0
	Amon	39.2	52.3	28.4	15.4	61.5	0.55	40.2
	Deir Alla 6	40.2	56.1	24.1	8.2	49.0	0.41	20.8
	Om Quis	38.3	48.2	23.6	13.6	59.2	0.50	35.8
	Kayar Tunis	43.7	56.4	31.5	18.8	61.2	0.58	46.3
	Hourani Nawaw	39.6	58.1	29.4	10.9	36.7	0.54	32.3
	LSD (0.05)	ns	ns	ns	ns	ns	0.08	12.0

ns= non-significant; NT, N translocation; NTe, N translocation efficiency%; CPAN, contribution of preanthesis assimilate to grain%; NHI, N harvest index.

DISCUSSION

Effect of water deficit on plant parameters

At anthesis and maturity, grain yield, yield components and other growth parameters of all varieties declined at GAS (under water deficit), but reductions were more severe in Cham5. Moreover, significant ($P<0.01$) reductions was observed in the aboveground DM at anthesis and maturity at the drier location (GAS). Other authors (Ehdaie et al. 1988; Jaradat 1991; and Abdel-Ghani et al. 2005) reported that drought and heat stress are major environmental factors reducing grain production of rainfed wheat in semiarid regions. All yield components significantly ($P<0.01$) contributed to the reduction in grain yield. The inadequate water availability, including rainfall and soil-moisture storage capacity, in quantity and distribution combined with heat stress during the life cycle of wheat growth restrict the expression of full genetic potential of the plant (Al-Rawashdeh and Abdel-Ghani 2008). Grain yield reduction was found to be more severe when the stress occurred suddenly rather than gradually (Stone and Nicholas, 1995b), and when drought occurs at early stages of grain filling rather than at later stages (Stone and Nicholas, 1995). Under drought, kernel growth is reduced depending upon the degree of water stress and on the rate of stress development, thereby limiting final grain yield (Kobata et al., 1992; Nicholas and Turner, 1992).

Low grain yield was obtained in the current study even though supplementary irrigation was performed at RAS during grain filling. Previous field experimental work performed by Al-Rawashdeh and Abdel-Ghani (2008) showed two to three times higher grain yield than those obtained in the current study. The main reason behind that that the rainfall regime of the semiarid dryland is characterized by great variability, causing the emergence time and the growth rate to vary depending on the amount of rains effective for germination. The late effective rains enough for germination at both experimental locations were received late in the middle of February. Other studies showed consistently that late planted wheat was less in yield potential and exhibited reductions in yield components than early planting (Thill et al., 1978; McLeod et al., 1992; Qasim et al., 2008). Therefore, when rains sufficient for germination came late, we should expect lower yields.

In the current study considerable amount of stem reserves was translocated to grains indicating the vital importance of remobilization and translocation of pre-anthesis stored carbohydrates in grain yield of wheat. In drier environment (GAS), plants remobilized more pre-anthesis assimilates for grains, indicating that plants relied to some extent on pre-stored assimilates to fill the grain. Other studies showed that under water limiting environment, there is a rapid decline in photosynthesis after anthesis, which limits the contribution of current assimilates to the grain and consequently post-anthesis water deficits lead to early senescence and more mobilization of pre-anthesis stored assimilates to grains in cereals (Kobata et al., 1992; Palta et al., 1994; Yang et al., 2001, 2003). Under normal condition, grain yield during grain-filling in cereal depends on carbohydrate created from both current assimilates and from carbohydrate stored in vegetative tissues during pre-anthesis (Schnyder 1993) and the dimension of the current assimilates is mainly due to natural senescence and the effect of various stresses (Aggarwal and Sinha 1984; Blum 1998Yang and Zhang 2006; Mohammadi-Bazargani et al., 2011). Drought increases the portion of the grain matter originating from stem reserves, with values ranging from near 10% under water non-limiting environment to greater than 40 % when water stress or heat stress is prevailing (Aggarwal and Sinha 1984; Austin et al., 1977; Bidinger et al., 1977; Davidson and Chevalier 1992; Ehdaie and Waines 1989; Palta et al., 1994; Rawson and Evans 1971; Yang et al. 2000). Water stress after anthesis causes active mobilization of stored carbohydrate reserves from vegetative parts to the grain and the contribution of assimilate becomes more intensive if water stress occurs during grain filling (Yang et al., 2000).

One reasonable approach to achieve an acceptable wheat yield under water limiting environment is the use of the potential of remobilization of carbohydrate stored in vegetative tissue to the grains. When the photosynthesis is decreased after pollination when drought is prevailing, assimilates produced prior the flowering become more important because the next stages of the plant growth relies on the translocation of stem reserves to the grain (Aggarwal and Sinha 1984; Gavuzzi et al. 1997). Water stress leads to early maturing of plant which also activates stem carbohydrates remobilization to grains (Kobata et al. 1992; Yang et al. 2001; Zhang et al. 1998). Consequently, the amount of translocated carbohydrate is successfully used to select genotypes that could tolerate terminal drought stress. Drought tolerant genotypes which have the high potential for the reserve of photosynthetic assimilates also have high efficiency in translocation of these assimilate to grains under water deficit (Aggarwal and Sinha 1984; Gavuzzi et al. 1997). In the current study, the contribution of preathesis assimilates to grain ranged from 10.3% in Cham1 to 20.2% in Cham3 under RAS and from 16.7% in Cham1 to 23.7% in Cham5 under GAS indicating that the greatest amount carbohydrate in kernels is related to the post-anthesis assimilates. The varieties under study responded differently to water stress with respect to DM remobilization and the contribution of DM to grain yield. Cham5, Cham3, Om Quis, Kayar Tunis and Hourani Nawawi relied on considerable pre-anthesis assimilates for grain filling under water deficit indicating their ability to tolerate drought by high pre-anthesis assimilates remobilization to grain.

DMT and DMTe are important indicators for the efficiency of genotypes to remobilize assimilates from the vegetative parts at anthesis stage to grain at maturity stage. A considerable genetic variability among varieties was observed for DMTe, ranging from 29.8 to 59.1% and from 40.9 to 63.2% at RAS (with supplementary irrigation) and GAS (with water deficit), respectively. Three varieties (Cham3, Amon, Om Quis and Hourani Nawawi) had higher DMTe of carbohydrates at the drier location (GAS). Therefore we can conclude that remobilization and translocation of assimilates have main role in the grain yield in these varieties. The amount of participation assimilates presorted in vegetative parts in the drier environment (GAS) was 56.6%, 63.2, 57.2 and 52.5% in Cham3, Amon, Om Quis and Hourani Nawawi respectively. Therefore, we can conclude that remobilization and translocation of assimilates from vegetative parts during grain filling had a main contribution to grain yield under water deficit in these varieties. Estimates of relative contributions of stem reserves to total grain mass per ear or to grain yield would vary among the different reports, according to the experimental conditions and cultivar; these contributions were estimated to be between 6% and 73% (Austin et al., 1977; Bidinger et al., 1977; Gallagher et al., 1976; Papakosta and Gagianas, 1991)

In the present study, a drastic reduction in N uptake was occurred under drier environment (GAS) and even under high N application, which mainly due to water shortage which leads to N insolubility. Environmental conditions during the pre- and post-anthesis periods are likely to have different effects on N accumulation. N uptake is influenced by available water (Clarke et al. 1990), degree of association between the roots and soil particles and the level of N supply (Cox et al. 1985, Papakosta and Gagianas 1991). N uptake under water limitations and a high N level can lead to poor N uptake efficiency since low soil moisture can adversely affect N mobility in the soil, leading to reduction in N uptake (Kraimer et al. 2001; Li et al. 2003; Yuan et al. 2005). The decrease in N uptake under water-deficit is also a consequence of the diminished plant growth that affects plant demand for N (Li et al., 2003; Nicolas et al., 1985; Plaut et al., 2004). The accelerated senescence of the stressed organs is the cause of the increase in remobilization in the water-deficit plants (Yang et al., 2001). Our results showed that water deficit enhanced N rembolization to grain and NTe with considerable genetic variability among varieties. Cham 5 and Cham3 had the highest amount of N remobilization from pre-anthesis reserves than other varieties under water deficit. It has been previously estimated that two-thirds of grain

N in wheat is derived from N assimilation before anthesis and one-thirds from assimilation during grain development (Pavlov and Kolesnik, 1974).

Effect of N application rate

It is obvious that the N level is also an important factor that influencing the accumulation and translocation of DM. The Above ground DM weight at anthesis and maturity, grain yield and yield components were significantly higher ($P<0.01$) in fertilized than at unfertilized plots. When abundant N favor the growth of culm and leaves and bigger vegetative mass will be developed. These results indicates that soil N is an important factor in achieving high grain and biomass yields due to high assimilation rate (Ortiz-Monasterio et al., 1992; Foulkes et al., 1998; Austin, 1977; Raun and Gordon, 1991; Derici and Schepers, 2001).

Previous studies showed that grain N in wheat mainly represents N accumulated in the vegetative parts until anthesis and translocated to kernel during grain filling. N in the form of protein and amino acids is the main component of the pre-anthesis portion that is potentially available for grain filling (Schnyder 1993). It was estimated that two-thirds of grain N in wheat is is taken up during vegetative growth and translocated during the grain filling period (Pavlov and Kolesnik 1974). Variation in final spike N can be also associated with the variation in total N uptake (Sanford and MacKown 1987). Treatments received higher N application rate showed lower contributions of preanthesis assimilate, N remobilization and NTe than unfertilized plants indicating that N deficiency enhanced N remobilization from vegetative organs to grains during grain filling. In wheat, a surplus of soil N at grain filling favors postanthesis N uptake and reduces the mobilization of preanthesis N (Papakosta and Gagianas 1991) and large movement of assimilates can occur under low soil fertility conditions (Yoshida 1972).

Results obtained in this study revealed that N availability may have a dominating effect on the extent of DM and N partitioning in wheat. In consequence, a considerable variation in NHI (0.41 to 0.67) was found indicating a wide range in efficiency of N accumulation in grain. In our study, significant differences in NHI were found between control (unfertilized plots) and plots fertilized with 100 and 200 kg N ha^{-1} (Table 1). Increasing doses of N led to an increase in NHI. N application rate and varieties significantly ($P<0.01$) interacted on NHI; Cham 5 and Amon varieties exhibited the highest NHI value, in these two varieties, the highest value of NHI was recorded under high N application rate, while the lowest value was obtained in unfertilized plots. This could be explained by the high N assimilation and accumulation of N in grains during grain filling in fertilized plot compared to unfertilized plots. Other studies (Le Gouis et al. 2000; Barraclough et al. 2010; Rahimizadeh et al. 2010) reported non-significant change in NHI with increasing doses of N up to 120 kg N/ha, afterwards NHI began to decline. NHI was also found to be conservative in rice (*Oryza sativa L.*), maize (*Zea mays L.*) and wheat over a wide range of N regimes (Wetselaar and Farquhar 1980). The majority of the varieties had higher values for NTe in the control than in fertilized plots.

In conclusion, unfavorable conditions (water limiting and N starvation) enhanced the amount of translocated carbohydrate and N. When environmental factors are favorable, fewer portions of DM and N are translocated to grains under favorable (more available water and more N) than under unfavorable conditions (less N and less available water). A high capacity for carbohydrate and N translocation efficiency during grain filling could be used as selection criteria to improve the productivity of wheat under unfavorable environments. Cham3, Amon, Om Quis and Hourani Nawawi showed a high capacity for carbohydrate and N translocation efficiency, and accordingly they could also be considered as a potential source of genes to adapt to unfavorable conditions. Growing such varieties would provide the savings in mineral fertilizers and minimize their possible harmful effects on the environment.

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تأثير نقص الماء ونيتروجين التربة على تراكم و حركة المادة الجافة و االنيتروجين في القمح القاسي تحت الظروف شبه الجافة

عادل حسن عبد الغني [1]، صدام الضلاعين [2]، سائد جوسيف عويس [1]، نضال المجالي [3]، دعاء المجالي [3]، فرح الناصر [1]

ملخـص

تهدف هذة الدراسة، إلى تقييم تأثير نقص الماء و كمية اضافة النيتروجين على تراكم المادة الجافة والنيتروجين وحركتهما في ثمانية اصناف من القمح القاسي. أظهرت الأصناف شام5، شام3، أم قيس، خيار تونس، حوراني نووي أعلى نسبة تحرك للمادة الجافة للحبوب، وتراوحت بين 16.7 الى 16.8% تحت الظروف الأرطب وارتفعت إلى نسبة تراوحت ما بين 20.7 الى 23.7 % تحت الظروف الأجف. اظهرالصنفان شام5 و شام3 ايضا اعلى نسبة تحرك للنيتروجين الى الحبوب تحت الظروف الأجف، حيث تراوحت القيم ما بين 67.3 الى 72.9% على الترتيب. ادى نقص النتيروجين الى زيادة معنوية في حركة النيتروجين للحبوب في صنف ديرعلا 6 و حوراني نووي. ادت زيادة النيتروجين من 0 الى 200 كغم الى نقص في حركة النيتروجين من 40.8 الى 20.8% و من40.3 الى 23.3% في صنف ديرعلا 6 و حوراني نووي على الترتيب. و في النتيجة، أظهرت بعض الأصناف قدرة عالية في نقل المادة الجافة و النيتروجين تحت الظروف غير الملائمة، مما يجعلها مصدرا للجينات لمربي النبات.

الكلمات الدالة: القمح القاسي، النيتروجين، حركة المادة الجافة، حركة النيتروجين، نقص الماء.

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