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Full Length Research Paper

Agronomic assessment of grain yield and nitrogen loss and gain of old and modern wheat cultivars under warm climate

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In cereals, the main source of nitrogen for grains is nitrogen remobilized from vegetative parts shown to be depended on environmental and genotype factors. Field experiments were conducted to study the effect of various N rates on four Iranian wheat cultivars which have been released at different periods. The experimental design was split plots, arranged in randomized complete block with three replications. Results showed that cultivar differences in dry matter and nitrogen translocation efficiencies were related to nitrogen and biomass accumulated in plant reserve parts at both anthesis and maturity. Cultivar dry matter translocation efficiencies ranged from 17.9 in Zagros to 35.4% in Dena, nitrogen translocation efficiencies from 73.8 in Zagros to 86.7% in Dena and contribution of pre-anthesis assimilates to grains from 29.3 in Zagros to 69.8% in Dena. It has to indicate that all of them were greatest in the modern wheat cultivar. Increase in N application, decreased the contribution of pre-anthesis assimilates to grains and increased the N gain. Highest N losses were obtained at both 0 and 150 kg N ha^{-1} in the modern wheat cultivar. Results indicated that in high N application level, modern cultivar (i.e. Dena) had the best grain yield because of the greatest dry matter translocation efficiency; contribution of pre-anthesis assimilates to grains with better nitrogen use and translocation. Therefore, the modern subtropical wheat cultivar was shown the best responses to highest N fertilizer applications.

Key words: Nitrogen, wheat, dry matter, cultivar, efficiency.

INTRODUCTION

Nitrogen is the most important nutrient which affect the assimilate production and distribution and also affecting directly and indirectly the source-sink relation. Moreover, N can influence the leaf area development, maintenance of the photosynthetic efficiency and dry matter partitioning to reproductive organs (Arduini et al., 2006).

Grains are the most active sink for carbon and N assimilates in cereal after flowering. Whereas most of the carbohydrates are provided by current photosynthesis, the major fraction of seed N is derived by mobilization of N accumulated before anthesis in vegetative organs (Cartelle et al., 2006). Studies have shown that grain N in wheat mainly represents N accumulated in the vegetative parts until anthesis and translocated to kernel during the reproductive phase. N distribution showed that 60 - 92% of the N accumulation in the wheat grain originates from mobilization from vegetative tissue after anthesis (Loffler et al., 1985).

In warm type climate, the weather after anthesis is usually hot and dry. Therefore, grain yield depends on the pre-anthesis stem dry matter reserves more than current photosynthesis. In these regions, properties of the genotype and condition of growing during the pre - and post - anthesis periods are likely to have different effects on N accumulation (Cox et al., 1985). Although Cox et al.

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(1986) did not found any relationship between grain protein concentration and N mobilization, N mobilization efficiency and grain N yield, but Bulman and Smith (1994) reported that post-anthesis N uptake was positively associated with lower utilization efficiency, higher N concentration and lower grain yield. Also, Loffler et al. (1985) found a positive correlation between nitrogen harvest index and grain protein concentration and suggested that increases in nitrogen harvest index or total N at maturity may increase grain protein concentration without reducing yield. Ercolli et al. (2008) reported that post-anthesis dry matter and N accumulation and translocation in durum wheat plants were increased by N availability. In their research high - N plants had higher grain yield compared to unfertilized ones, as N deficiency reduced plant dry weight and plant storage capacity.

Dordas (2009) reported that fertilization increased the N in plant tissue and affected the dry matter accumulation and partitioning in wheat. In addition, fertilization affected N translocation and movement from vegetative parts of the plant to the grain. Therefore, its suggested that the pre-anthesis contribution of biomass to N accumulation was more important than N concentration. In other view, Arduini et al. (2006) reported that the post-heading N accumulation was by far higher in modern than in old wheat cultivar, whereas translocation was highest in modern ones. Also, the percentage contribution of N translocation to grain N was by far higher in old than in modern cultivars. In addition, Alvaro et al. (2008) found that dry matter mobilization efficiency switched from 9% in old wheat cultivars to 20% in modern ones. Also, changes over the time in days from sowing to anthesis were positively associated with changes in crop dry weight and green area index between modern cultivars. Moreover, Masoni et al. (2007) with study of the behavior of pre-anthesis and post-anthesis dry matter accumulation and grain yield between old and modern wheat varieties, reported that the old variety showed the lowest value and the modernest one the highest. Also, they reported that dry matter accumulation during grain filling was much greater than dry matter translocation. Continuous translocation to grain yield did not reach 30%, while for nitrogen the reserve was accounted for 73 to 82% of grain N content.

The objective of this research was to study the effect of N fertilization levels on dry matter, nitrogen accumu-lation and translocation of old and modern bread wheat cultivars grown under warm climate in Iran.

MATERIALS AND METHODS

The experiment was conducted on Research Station Farm at the Agricultural faculty of Shahid Chamran University of Ahvaz, Iran, (31°20′ N latitude and 48°41′ E longitudes) at an elevation of 20 m above mean sea level during 2008 - 2009 growing season. The climate of the region is classified as warm and semiarid. The most and least temperature averages during the growing season are 37.2 and 5.7, respectively. The annual rainfall average was 250 - 350 mm. The soil type was sandy loam with PH 7.7 and a 0.54% average organic matter. Soil sample analysis indicated that at the depth of the 0 - 30 cm soil layers contained 0.049% nitrogen, 14 mg kg^{-1} phosphorus and 160 mg kg^{-1} potassium.

Four wheat genotypes were used including old cultivars named Zagros and Chenab and modern cultivars named Chamran and Dena. Experimental design was split plot based on randomized complete block with three replications. The main plots consisted of different nitrogen fertilizer rates (that is 0, 50, 100 and 150 kg N ha^{-1}) and sub-plots consisted of the four wheat cultivars. These genotypes were released by Iranian plant breeding institute. Nitrogen source was used as NO_3 in form of Urea fertilizer. Some general information about these wheat genotypes are: all lines, spring type (planted on early Nov.), hexaploid, 2n = 42, bread wheat and irrigated type. Also, other breeding background and agronomic characteristics are present in Table 1. Each plot consisted of 7 rows, 3 m in length, interrow spacing was 20 cm and interplant spacing was 3 cm.

Plant samples were taken at anthesis and maturity. After each harvest, plants were separated into leaf plus culm and chaff at anthesis, and also grain at maturity. These segments were immediately dried in a dry oven at 70°C for 48 h and weighted. Grain yield was determined by harvesting a 2 m^2 area from each plot. All dry vegetative samples and also grains were first ground and then plant N concentration was determined by standard macro-Kjeldahl procedure. N content was calculated by multiplying the N concentration by dry weight. Moreover, the following parameters, related to dry matter and N accumulation and translocation within the wheat plant during grain filling, were calculated according to Arduini et al. (2006) and Masoni et al. (2007), as follow:

1. Dry matter translocation (Mg ha^{-1}) = Dry matter at anthesis – [(leaf + culm) + chaff] dry matter at maturity.
2. Dry matter translocation efficiency (%) = (Dry matter translocation / Dry matter at anthesis) × 100.
3. Contribution of pre-anthesis assimilates to grain (%) = (Dry matter translocation / grain yield) × 100.
4. Harvest index (HI) = Grain yield / total aboveground biomass at maturity.
5. Nitrogen translocation (Kg ha^{-1}) = N content at anthesis – [(leaf + culm) + chaff] N content at maturity.
6. Nitrogen translocation efficiency (%) = (N translocation / N content at anthesis) × 100.
7. Nitrogen lost (–) or gained (Kg ha^{-1}) = N content at maturity – N content at anthesis.
8. Nitrogen at anthesis lost or gained (%) = (N lost or gained / N content at anthesis) × 100.
9. Nitrogen harvest index (NHI) = Grain N / total N content of aboveground parts at maturity.

Data were statistically analyzed according to ANOVA, in order to test the main effects of Nitrogen rate, variety and their interactions. LSD test was used to separate the means.

RESULTS AND DISSCUSSION

Biomass translocation

Differences in dry matter at anthesis and maturity were observed among cultivars (Table 2). The application of all N fertilizers significantly increased aboveground dry matter at both anthesis and maturity which resulted in greater

Table 1. Year released, origin, Pedigree and agronomic characteristics of 4 spring wheat genotypes.

Genotype	Year released	Origin	Pedigree	Agronomic characteristics
Zagros	1978	CIMMYT	Tans" /Vee//opata	Semi dwarf, medium maturity, disease resistance, tolerant to heat, medium quality
Chenab	1984	Pakistan	Stm/3/Kal//V534/Jit716	Semi dwarf, medium maturity, susceptible to disease, tolerant to drought and heat, medium quality
Chamran	1998	CIMMYT	Attila M85836-50Y-OM-OY-3M-OY	Semi dwarf, medium maturity, resistant to disease, tolerant to drought and heat, medium quality, high yielding
Dena	2003	CIMMYT	Kauz* 2/Opta//Kauz	Semi dwarf, medium maturity, susceptible to disease, tolerant to drought, medium quality

grain yield than unfertilized plot (Table 2). In addition, grain yield was positively correlated to total dry matter at anthesis and maturity 0.56^{**} and 0.89^{**}, respec-tively (Table 4). Moreover, a decrease in vegetative dry matter between anthesis and maturity was observed both in leaf + culm and in chaff when the dry matter at anthesis was higher. Dordas et al. (2009) reported that dry matter accumulation and partitioning into different plant parts were different due to fertilization treatments. While, aboveground biomass increased at post anthesis in all fertilization treatments. These authors suggested that dry matter production was directly related to N supply and when this amount of N abated it causes to inhibit dry matter production, especially in leaves. This affects the production of photoassimilates and the distribution of assimilates to the reproductive organs. Tahir and Nakata (2005) reported that when reserved material deposited in vegetative plant parts at the pre – anthesis it may buffer grain yield when conditions become adverse to photo-synthesis and mineral uptake during grain filling. In their study, the relative importance of current assimilation and remobilization changes among genotypes and it was strongly related to environmental condition. Although, these vegetative dry matter may be decreased from anthesis to maturity (Cartelle et al., 2006).

Wheat cultivars markedly showed differences with res-pect to the changes in vegetative dry matter at anthesis and maturity and also showed an impact on dry matter translocation efficiency (Table 2). Great dry matter at anthesis resulted in a low proportion of mobilized dry matter. For instance, Dena (modern cultivar) showed the higher dry matter translocation efficiency (35.4%) than old cultivars when the dry matter at anthesis was higher (11.6 Mg ha^{-1}). Dry matter translocation efficiency also was affected by nitrogen fertilizer application. However, dry matter translocation efficiency was greater in 0 and 50 kg N ha^{-1} than other N supplies. Arduini et al. (2006) reported the modern wheat cultivars showed a by far higher post-heading dry matter accumulation compared to the old cultivar, to which corresponded a consistently lower remobilization for these cultivars. As a result, the contribution of dry matter remobilization to grain yield markedly differed among the varieties which being more than 50% in old and less than 20% in modern wheat cultivars. Similar results also reported by Frederick and Bauer (1999) and Przulj and Momcilovic (2001). The con-tribution of pre-anthesis assimilates to grain ranged from 6.5 - 87.9 of grain dry weight and significantly differed among cultivars and within N rates (Table 2). Cultivars that received low N application showed with higher contri-bution of pre-anthesis assimilates than cultivars receiving high N fertilizer. With N applications, cultivars had more supply of N during the post-anthesis stage. This condition is presumably conductive to higher rates of photo-synthesis and, in turn, to a higher supply of assimilates for grain fill, thus reducing the need for translocation of pre-anthesis assimilates. Alvaro et al. (2008) reported that the amount of dry matter remobilization, dry matter remobilization efficiency and contribution of pre-anthesis assimilates to grain from the main stem structures to growing grains increased significantly in Italian wheat cultivars. The greatest changes in the percentage of dry matter remobilization by the different main stem com-ponents occurred among old and modern Italian wheat cultivars: the relative contribution of main stem increased significantly by 21% from old to modern cultivars. Similar result also reported by Masoni et al. (2007).

Positive correlation was observed between harvest index (HI) and dry matter translocation efficiency (0.34^{*}) but not for the contribution of pre-anthesis assimilates and harvest index (0.21^{ns}) (Table 4). No significant corre-lation was found between HI and grain yield (Table 4). Also, the harvest index values were not significantly different between cultivars and N rates. Similar result was reported by Dordas (2009) when N application did not affect the harvest index.

Nitrogen losses and gains

The N content at anthesis in total vegetative parts (leaf + culm and chaff) was higher in plants receiving N fertilizer than in control and increased with the addition of N supplement (Table 3). Wheat cultivars were differed in their ability to accumulate N in vegetative parts prior to

Table 2. Dry matter at anthesis and maturity in vegetative and reproductive parts, dry matter translocation efficiency, and harvest Index as affected by different N fertilizer rate and wheat cultivar.

Treatments	Anthesis			Maturity					DMTE‡	CPA§	HI†
	Leaf + Culm	Chaff	Total*	Leaf + Culm	Chaff	Total* vegetative	Grain	Total			
	(Mg ha^{-1})			(Mg ha^{-1})					%		
Nitrogen (N)											
N_0	8.5 b ¶	2.3 b	10.8 b	5.1 b	2 b	7.1 b	5.6 b	12.7 b	34.1 a	68.3 a	44.2 a
N_{50}	8.6 b	2.3 b	10.9 b	5.1 b	2 b	7.1 b	5.7 b	12.9 b	33.7 a	67.2 a	44.2 a
N_{100}	9.4 a	2.8 a	12.2 a	7.1 a	2.4 a	9.6 a	7.4 a	17.1 a	20.3 b	36 b	43.9 a
N_{150}	9.2 a	2.7 ab	11.9 a	7.5 a	2.4 a	10 a	7.7 a	17.7 a	15 b	23.4 b	43.3 a
Cultivar (C)											
Zagros	8.2 b	1.8 b	10.1 b	6.3 a	1.9 c	8.2 b	6.6 ab	14.9 ab	17.9 c	29.3 c	44.4 a
Chenab	9.1 a	2.7 a	11.9 a	6.4 a	2.5 a	8.9 a	6.7 ab	15.7 a	24.6 b	49.2 b	43 a
Chamran	9.3 a	2.8 a	12.2 a	6.9 a	2.2 b	9.1 a	7 a	16.1 a	25.3 b	46.7 b	43.3 a
Dena	9 a	2.6 a	11.6 a	5.3 b	2.2 b	7.5 b	6.2 b	13.8 b	35.4 a	69.8 a	44.8 a
N × C											
N_0 × Zagros	7.7 e	1.6 j	9.3 d	5.8 c-e	1.9 e	7.8 e-g	6.1 e-g	13.9 e-g	16.1 cd	25.7 de	43.7 a-d
N_0 × Chenab	8.3 de	2.2 f-i	10.6 cd	4.4 fg	1.8 e	6.3 hi	4.9 f	11.2 hi	40.7 ab	87.9 a	43.6 b-d
N_0 × Chamran	10.3 a	3.6 a	13.9 a	6.4 b-d	2.5 bc	9 c-e	6.5 b-e	15.5 c-e	36.8 ab	76 a-c	42 cd
N_0 × Dena	7.6 e	1.7 ij	9.4 d	3.6 g	1.7 e	5.3 i	4.9 f	10.2 i	42.7 a	83.8 ab	47.4 a
N_{50} × Zagros	8.3 de	1.9 h-j	10.2 cd	5 ef	1.7 e	6.8 gh	5.9 ef	12.7 f-i	32.7 ab	57.6 bc	46.2 ab
N_{50} × Chenab	9.7 a-c	2.9 b-e	12.6 ab	5.3 d-f	2.5 bc	7.8 e-g	6.3 c-e	14.2 d-g	37.2 ab	76.2 a-c	44.6 a-d
N_{50} × Chamran	8.2 de	2.4 e-h	10.6 cd	5.4 d-f	1.8 e	7.2 f-h	5.9 ef	13.2 e-h	31.8 ab	59.8 a-c	44.7 a-d
N_{50} × Dena	8.2 de	2 g-j	10.3 cd	4.8 e-g	2 de	6.8 gh	4.9 f	11.8 h-i	33.3 ab	75.2 a-c	41.3 d
N_{100} × Zagros	8.3 de	1.9 h-j	10.2 cd	6.7 bc	1.9 e	8.7 c-f	7.1 a-e	15.8 b-e	14.1 d	20.7 de	44.8 a-d
N_{100} × Chenab	9.7 a-c	3.1 a-d	12.8 ab	8.1 a	2.8 ab	10.9 a	7.8 ab	18.8 a	14.1 d	26.1 de	42.6 b-d
N_{100} × Chamran	9.9 ab	2.9 b-f	12.8 ab	8.2 a	2.5 b	10.8 ab	8.1 a	18.9 a	16 cd	25.5 de	42.9 b-d
N_{100} × Dena	9.6 a-c	3.2 a-c	12.9 ab	5.5 c-f	2.4 b-d	8 d-g	6.7 b-e	14.7 c-f	37.3 ab	71.6 a-c	45.4 a-c
N_{150} × Zagros	8.6 c-e	2 g-j	10.7 cd	7.6 ab	2.1 c-e	9.7 a-c	7.4 a-d	17.1 a-c	8.7 d	13.1 e	43 b-d
N_{150} × Chenab	9.9 b-d	2.6 c-g	11.5 bc	7.7 ab	3 a	10.8 ab	7.7 a-c	18.5 a	14.1 d	6.5 e	41.3 d
N_{150} × Chamran	8.7 c-e	2.6 d-g	11.3 bc	7.5 ab	1.9 e	9.4 b-d	7.4 a-d	16.8 a-d	16.8 cd	25.4 de	43.7 a-d
N_{150} × Dena	10.6 a	3.5 ab	14.1 a	7.3 ab	2.8 ab	10.1 a-c	8.3 a	18.4 ab	28.2 bc	48.5 cd	45 a-c

* Total or Total vegetative = Leaf + Culm + Chaff, ‡ Dry matter translocation efficiency, § Contribution of pre-anthesis assimilates to grain, † Harvest Index. ¶ In each section means followed by the same letter within columns are not significantly different ($p < 0.05$) according to LSD test.

Table 3. Nitrogen concentration and N content at anthesis and maturity in vegetative and reproductive parts, N translocation efficiency, and N harvest index as affected by different N fertilizer rate and wheat cultivar.

Treatments	Anthesis		Maturity					NTE‡	NHI†
	Total*	Total*	Total* vegetative	Grain	Total* vegetative	Grain	Total		
	N concentration (g kg^{-1})	N content (kg ha^{-1})	N concentration (g kg^{-1})		N content (kg ha^{-1})			%	
Nitrogen (N)									
N_0	13.5 c ¶	144.4 c	3.2 b	20.5 c	23.3 b	115.8 c	139.1 b	83.2 a	83.5 a
N_{50}	14.5 c	159.2 c	3.2 b	20.2 c	23.1 b	118.4 c	141.6 b	84.9 a	83.4 a
N_{100}	16.2 b	199.7 b	5.3 a	23.3 b	53.6 a	175.4 b	229 a	74 b	77.7 b
N_{150}	18.5 a	221.8 a	5.4 a	26 a	55 a	200.6 a	255.6 a	73.9 b	78.5 b
Cultivar (C)									
Zagros	14.3 c	145.5 c	4.5 a	22.3 b	38.7 b	150 ab	188.8 b	73.8 c	79.9 b
Chenab	16.8 a	201.1 a	4.7 a	23.4 a	45.6 a	159.6 a	205.3 ab	78.2 b	79.1 b
Chamran	16.4 ab	197.8 a	4.8 a	23.1 ab	46.7 a	164.6 a	211.3 a	77.4 b	79.3 b
Dena	15.2 bc	180.8 b	3 b	21 .1 c	23.9 c	136 b	159.9 c	86.7 a	84.8 a
N × C									
N_0 × Zagros	13 ef	121 e	4.3 c	20.4 bc	34.1 de	126.5 b-d	160.6 b-d	71.9 cd	78.8 cd
N_0 × Chenab	13.6 ef	145 de	3.1 d-g	21.4 bc	19.6 fg	105.2 cd	124.9 de	86.2 ab	84.2 ab
N_0 × Chamran	12.2 f	170.7 cd	2.8 e-g	20.7 bc	25.8 d-g	135.5 bc	161.3 b-d	84.7 ab	84 ab
N_0 × Dena	15.1 c-e	141.1 de	2.5 g	19.4 cd	13.8 g	95.81 d	109.6 e	89.9 a	87.2 a
N_{50} × Zagros	13.3 ef	135.5 e	3.4 d-f	20.7 bc	23.4 d-g	122.2 b-d	145.6 c-e	82.5 b	83.9 ab
N_{50} × Chenab	14.7 d-f	186.5 c	3.5 c-e	21.9 b	27.9 d-f	140 bc	168 b-d	84.3 ab	83.2 ab
N_{50} × Chamran	17.1 b-d	182.9 c	3.1 d-g	20 b-d	22.7 e-g	119.45 b-d	142.2 c-e	87.2 ab	84 ab
N_{50} × Dena	12.7 ef	131.9 e	2.6 fg	18.2 d	18.4 fg	92.1 d	110.6 e	85.8 ab	82.6 bc
N_{100} × Zagros	13.9 ef	142.3 de	3.9 cd	21.6 b	34.3 de	154.9 b	189.2 b	75.5 c	81.6 bc
N_{100} × Chenab	18.8 ab	242.7 b	6.4 b	24.9 a	71 ab	196.3 a	267.4 a	70.3 c-e	73.6 ef
N_{100} × Chamran	18.8 ab	241.3 b	7.5 a	25.3 a	81.7 a	206.8 a	288 a	66 de	71.6 f
N_{100} × Dena	13.4 ef	172.6 cd	3.4 d-g	21.3 bc	27.4 d-f	143.5 b	171 bc	84 ab	84 ab
N_{150} × Zagros	17.1 b-d	183.1 c	6.5 b	26.4 a	63.2 bc	196.3 a	259.9 a	65.3 e	75.5 d-f
N_{150} × Chenab	19.9 a	230.2 b	5.9 b	25.4 a	63.9 bc	197.1 a	261 a	72.1 cd	75.5 d-f
N_{150} × Chamran	17.5 a-c	196.4 c	5.9 b	26.6 a	56.7 c	196.6 a	253.3 a	71.5 c-e	77.5 de
N_{150} × Dena	19.5 ab	277.7 a	3.5 c-e	25.5 a	36.1 d	212.4 a	248.5 a	87 ab	85.4 ab

* Total or total vegetative = Leaf + Culm + Chaff, ‡ Nitrogen translocation efficiency, † Nitrogen harvest index. ¶ In each section, means followed by the same letter within columns are not significantly different ($p < 0.05$) according to LSD test.

anthesis. Therefore, it seems that plant N content was associated with both variations in dry matter and N concentration (Tables 2 and 3). Ercolli et al. (2008) reported that the two modern wheat varieties showed a similar behavior, for dry matter accumulation. Also, N fertilizer rate and water stress induced similar changes in dry matter yield, accumulation and remobilization of assimilates and grain quality in these varieties. That was due to the close genetic background of the two varieties. Also, Przulj and Momcilovic (2001) found a variation in N accumulation and remobilization to the kernel of the spring barley. Also, N remobilization, N remobilization efficiency and nitrogen harvest index were mainly influenced by the barley cultivars. Therefore they suggested that, differences among cultivars for N remobilization were related to the statues of dry matter and N accumulation at anthesis.

At the maturity stage the N content was declined more in vegetative parts than dry matter. Nitrogen content of vegetative parts (leaf + culm + chaff) at maturity was positively correlated (0.61^{**}) with N content at anthesis (Table 4). Unfertilized plants remobilized about 11% more N than fertilized plants (Table 3). In fact, all N contents and N concentrations in vegetative parts and grain yield were increased with the addition of N rates but, nitrogen translocation efficiency was declined (Table 3). Our result

Table 4. Simple correlation coefficient between various dry matter and nitrogen parameters.

Treatments	Grain yield	Anthesis DM	Maturity VDM ×	DMTE ‡	CPA §	HI †	Grain N content	NTE¶	NHI *	N content at anthesis	N content of vegetative parts at maturity
Grain yield	1										
Anthesis DM	0.56**	1									
Maturity VDM ×	0.89**	0.55**	1								
DMTE ‡	-0.62**	0.13 ns	0.73**	1							
CPA §	-0.68**	0.12 ns	0.73**	0.97**	1						
HI †	0.1ns	-0.02 ns	-0.32*	0.34*	0.21 ns	1					
Grain N content	0.95**	0.5**	0.89**	-0.66 **	-0.7 **	0.01 ns	1				
NTE ¶	-0.57**	0.37 ns	-0.62**	0.86**	0.83**	0.33**	-0.64**	1			
NHI *	-0.43**	-0.06 ns	-0.68**	0.74**	0.67**	-0.57**	-0.53**	0.88**	1		
N content at anthesis	0.68**	0.7**	0.71**	-0.26 ns	-0.27*	-0.14 ns	0.72**	-0.21 ns	-0.4**	1	
N content of vegetative pats at maturity	0.73**	0.28*	0.86**	-0.77**	-0.74**	-0.34*	0.81**	-0.88**	-0.9**	0.61**	1

×Vegetative dry matter, ‡ Dry matter translocation efficiency, § Contribution of pre-anthesis assimilates to grain, † Harvest Index, ¶ Nitrogen translocation efficiency, *Nitrogen harvest index.

showed no large differences for N translocation efficiency among wheat cultivars. Similarly, it was reported that in wheat, the translocation efficiency of N taken up before anthesis was variable and it depended on the genotypes examined (Van Sanford and MacKown, 1987). But, Barbottin et al. (2005) reported that in contrast to reduction of remobilized nitrogen, nitrogen remobilization efficiency was the highest at the low nitrogen supplement, in all irrigated condition. In our study, the low value of nitrogen remobilization efficiency in Zagros (old cultivar) was probably due to lower dry matter translocation efficiency (Table 2) and also lower radiation use efficiency (data not shown). In addition, the N remobilization efficiency was highly variable among our tested cultivars. Wall and Kanemasu (1990) reported that the wheat cultivars with low crop densities had low light interception efficiency and net dry matter productivity. In addition, the higher remobilization in this was probably linked to the higher dry matter of the crop at heading that represents the potential source for remobilization (Tompkins et al., 1991; Przulj and Momcilovic, 2001).

Grain N yield and total N content at maturity increased with the addition of N fertilizer from N_0 to N_{150} by 42 and 46%, respectively (Table 3). N_{150} had shown the best effect for these parameters, for all cultivars. Also, grain N content was negatively correlated with nitrogen translocation efficiency and nitrogen harvest index (Table 4). Nitrogen absorption by cereals is thought to take place mainly before anthesis. Thus, over 80% of the final N content is present in the plant at anthesis and the N accumulated before anthesis in winter wheat can count for as much as 75–90% of the final N content of the grains (Cox et al. 1985; Heitholt et al., 1990). It is reported that in wheat the extent of N accumulation is determined by the relationships between the capacity of the plants to absorb and remobilized N (Fageria and Baligar, 2005). Also, Cox et al. (1986) showed that higher levels of nitrogen fertilization before flowering lead to a decrease in nitrogen remobilization efficiency and also renders nitrogen remobilization. Moreover, Barbottin et al. (2005) reported that, the effect of the environment on the relationship between nitrogen uptake at flowering and nitrogen remobilization depended on nitrogen uptake during grain-filling period and wheat genotypes.

Although, N fertilizer increased N content at anthesis (Table 3), the nitrogen harvest index (NHI) was significantly affected by N application for Dena. In all N application rates, Dena showed the best nitrogen harvest index. This is a cultivar with high protein (data not shown) which is capable to preserve great N translocation efficiency (Table 3) and dry matter translocation efficiency (Table 2). Similar result was reported by Loffler et al. (1985) in which increases in nitrogen harvest index or total N at maturity may increase grain protein concentration without reducing yield. They suggested that nitrogen harvest index can be used as a selection criterion to improve grain yield

Table 5. N lost (–) or gained, N content at anthesis, gain yield and percentage of N at anthesis lost (–) or gained as affected by different N fertilizer rate and cultivar.

Treatments	N lost (–) or gained (kg ha^{-1})	N content at anthesis (kg ha^{-1})	Grain yield (Mg ha^{-1})	Percentage of N at anthesis lost or gained %
Nitrogen (N)				
N_0	-5.33 ab ¶	144.4 c	5.6 b	-1.1 ab
N_{50}	-17.5 b	159.2 c	5.7 b	-9.4 b
N_{100}	29.32 a	199.7 b	7.4 a	16.1 a
N_{150}	33.75 a	221.8 a	7.7 a	18.8 a
Cultivar (C)				
Zagros	43.3 a	145.5 c	6.6 ab	29 a
Chenab	4.21 b	201.1 a	6.7 ab	0.6 b
Chamran	13.4 b	197.8 a	7 a	5.7 b
Dena	-20.8 c	180.8 b	6.2 b	-10.9 c
N × C				
N_0 × Zagros	39.6 a-d	121 e	6.1 e-g	32.2 ab
N_0 × Chenab	-20.1 e-g	145 de	4.9 f	-12.8 d-f
N_0 × Chamran	-9.3 d-g	170.7 cd	6.5 b-e	-4.65 c-f
N_0 × Dena	-31.4 g	141.1 de	4.9 f	-19.4 f
N_{50} × Zagros	10.1 b-g	135.5 e	5.9 ef	7.8 c-f
N_{50} × Chenab	-18.5 e-g	186.5 c	6.3 c-e	-9.1 d-f
N_{50} × Chamran	-40.7 g	182.9 c	5.9 ef	-20.8 f
N_{50} × Dena	-21.2 fg	131.9 e	4.9 f	-15.4 ef
N_{100} × Zagros	46.9 a-c	142.3 de	7.1 a-e	34.3 ab
N_{100} × Chenab	24.6 b-f	242.7 b	7.8 ab	10.6 b-e
N_{100} × Chamran	47.2 a-c	241.3 b	8.1 a	19.6 a-c
N_{100} × Dena	-1.5 c-g	172.6 cd	6.7 b-e	0.01 c-f
N_{150} × Zagros	76.4 a	183.1 c	7.4 a-d	41.8 a
N_{150} × Chenab	30.8 a-e	230.2 b	7.7 a-c	13.7 a-d
N_{150} × Chamran	56.8 ab	196.4 c	7.4 a-d	28.7 ab
N_{150} × Dena	-29.1 g	277.7 a	8.3 a	-8.8 c-e

¶ In each section, means followed by the same letter within columns are not significantly different ($p < 0.05$) according to LSD test.

while maintaining the grain protein concentration.

When the N content of aboveground plant parts at anthesis and maturity are compared, it indicated that both gains and losses were observed under these growth stages irrespective of cultivar and N treatment (Table 5).

The nitrogen losses ranged from 1.5 - 40.7 kg N ha^{-1}. Nitrogen gains ranged from 10.1 - 76.4 kg N ha^{-1}. Nitrogen lost or gained was related to both N contents at anthesis and grain yield development and these alternations were varied among cultivars (Table 5). Our study indicated that, N gains depend primarily on the N content at anthesis. The highest cultivar N content at anthesis (277.7 kg ha^{-1}) show the high value of N loss (-29.1 kg ha^{-1}). Also, in all N rates, Zagros and Dena had N gains and losses, respectively. Harper et al. (1987) found that 11% of the potential N available for redistribution was lost as volatile NH_3. It is probable when N decline in plant tops can cause to cease plant carbohydrates, a situation which limit capacity of inflorescence to store N. Przulj and Momcilovic (2001) reported that in barley cultivars N losses mainly depended on plant N content at anthesis, exactly, when plant N content was over 150 kg ha^{-1}.They also suggested that when the genetic variation for N accumulation, remobilization and utilization was present, the cultivars with a high capacity for N accumulation at pre-anthesis, high remobilization efficiency and high nitrogen harvest index could be used in the development of cultivars with the desired N balance.

In conclusion, dry matter accumulation and N content and concentration were always greater at anthesis than maturity for all wheat cultivars and also in all N rates. Lower amounts of dry matter at anthesis resulted in a greater dry matter translocation efficiency. But, this parameter was decreased with increase in N application. Nitrogen translocation efficiency and nitrogen harvest index had similar trends as the same as dry matter translocation efficiency. But both were highest in the modern wheat cultivar than old one. At the highest N application rates, grain yield, dry matter translocation efficiency, nitrogen translocation efficiency and nitrogen harvest index were greatest in modern cultivar. In addition, greatest N losses also occurred at the highest N rates. Consequently, high amounts of N accumulated at anthesis led to better N gain at maturity.

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