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Research Article

Nitrogen dynamic in wheat (*Triticum aestivum* L.) agroecosystem as influenced by intra- and interspecific competition

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The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Highlights

- The nitrogen translocation efficiency and nitrogen harvest index were highest in interspecific competition.
- Dry matter accumulation and N content at anthesis was higher than maturity stage in competition condition.
- The highest grain yield was obtained in a lower N translocation efficiency in no competition condition.

Abstract

Background: The study of both intra- and interspecific competitions in Wheat (*Triticum aestivum* L.) agroecosystem is quite complex and it is essential to understand the influence of nitrogen in these competitions.

Objective: The aim of this study was to evaluate the effect of different competitive models on nitrogen balance in wheat ecosystem agriculture (Chamran cultivar).

Methods: A field experiment was performed using split–plot based on randomized complete block design (RCBD) with three replications. The main and sub-plots consisted of different nitrogen rates (control, 50, 100 and 150 kg nitrogen ha^{-1}) and different competitive patterns (no, intraspecific, interspecific competition and intra- and interspecific in combination) were applied to the sub-plots, respectively. Weed density in the interspecies competition was applied through the equal planting of two narrow leaves (*Avena sativa* L.) and broadleaf (*Sinapis arvensis* L.) weed species.

Results: The dry matter (DM) accumulation and nitrogen content (NC) at anthesis was higher than that at maturity stage for all competition treatments as well as nitrogen rates. The trend of nitrogen translocation efficiency (NTE) and nitrogen harvest index (NHI) was different from dry matter translocation efficiency (DMTE), and both were highest in interspecific competition treatments. Moreover, the highest grain yield in no competition treatment resulted in a lower dry matter and NTE.

Conclusions: It was concluded that the capacity for nitrogen accumulation in the stem, was associated with a high nitrogen uptake, nitrogen assimilation and high post-anthesis nitrogen remobilization efficiency. In additions, high NHI could be used in the development of cultivars with the desired N balance.

1 Introduction

Competition among plants has involved a struggle for limited resources such as sunlight, space, water, and nutrients in the soil (Poffenbarger et al., 2015; Anten and Bastiaans, 2016). It is also a very important part of plant interactions, which can be harmful to both.

Individuals involved. Plants can be better adapted to obtain resources, out-compete other plants and maintain their growth, so plants can be grown in competition without major effects on their growth if they have different individual adaptations (Beres et al., 2010). Plants undergo two types of competition: intraspecific (among their own species), and interspecific (with plants of another species) (Hansen et al., 1999). Intraspecific competition is the most aggressive, because the same species of plants have the same needs and same resource-obtaining structures (Olechowicz et al., 2017). There are three principal effects of intraspecific competition outlined: the average size of a plant decreases as density increases, the size structure of the population becomes hierarchical and self-thinning or density-dependent mortality occurs (Blackshaw, 2005).

The inter-specific competitive ability of a crop may be due to the ability to reduce weed growth (crop competitive effect), tolerance to weed pressure by maintaining grain yield (crop competitive response). They are important since the use of resources and yield stability are desirable in crops growing in association with weeds (Mason et al., 2007). Some physiological, morphological, and biochemical characters are thought to control weed competitiveness (Azim Khan and Marwat, 2006). Tillering capacity, wheat height, ground cover, canopy structure, early biomass accumulation, light interception, wheat height, timing of spike emergence and flag leaf length have been figured out to support competitiveness (Hussain et al., 2002; Asadi et al., 2013). From an agronomic point of view, gains in seeding density lead to increased yields in wheat and higher levels of weed suppression (Fahad et al., 2015). Hence, changing the crop density was a more reliable method than cultivar selection, to reduce competition between weed and crop.

During intra- and interspecific competition, the crop plants normally exert antagonistic effects upon each other for maximum utilization of resources. A comprehensive understanding of intra- and interspecific competitions between weed and crop is needed to implement a successful integrated and sustainable competition management program for the control of weed. Moreover, good knowledge of population dynamics of weed (i.e. interspecific competition) is also a necessity. Similarly, higher seed rate (i.e. intraspecific competition) plays a vital role in suppressing weeds but the yield is decreased above optimum seed rate. In higher crop densities, there is potential to suppress weeds because increasing seed density increases intraspecific competition of the crop population more than it increases interspecific competition (Azim Khan and Marwat, 2006). It has been identified that many characteristics such as rapid germination with high root development, high seed vigor, greater plant height, rapid leaf area and canopy formation and high LAI which make crops more competitive. These features by the crop resource capture, particularly reducing light quantity beneath of the canopy led to reducing weed seedling growth (Olesen et al., 2004).

Nitrogen is one of the most important nutrients added to increase crop yield. It is still unclear how change in soil nitrogen levels affects competitive interactions between crops and weeds, but it can affect germination percentage of weed seeds and their establishment. In fact, many weeds are high-N consumers and competitive interactions between crops and weeds can be influenced by nitrogen fertilizer (Dalga, 2016). Therefore, manipulation of crop fertilization may be a way to reducing weed interference in field crops (Blackshaw et al., 2004). In addition, the competitive crop should combine superior competitive ability with high NUE against weeds. For this purpose, it is important to note that nitrogen application can significantly affect the competitive interactions between weeds and crop and that application of nitrogen often raises the competitiveness of crop less than the weeds (Giambalvo et al., 2010). In wheat, seeding rate has a significant effect on grain yield, and studies show that higher seeding rate in wheat is one of the tools for achieving higher crop grain yield, but seeding rates above the optimum lead to decrease grain yields due to increasing intraspecific competition among crops (Fang et al., 2010; Bhatta et al., 2017). In fact, in wheat, both remobilization of assimilates stored in vegetative crop parts and current assimilation transmitted directly to grains contribute to grain yield and can buffer the yield against undesirable competition during grain filling.

Other researchers stated that seeding rates above the optimum (i.e. increased in intraspecific competition) led to the greater accumulation of DM during pre-anthesis period, but whether these stored assimilates contribute to greater grain yield is unclear (Tompkins et al., 1991; Arduini et al., 2006). The aim of this study was to evaluate the effect of intra- and interspecific competition on accumulation and contribution of DM and N balance in wheat agroecosystem.

Other researchers have stated that seeding rates above the optimum by increased intraspecific competition led to the greater accumulation of dry matter pre-anthesis period, but it is still unclear whether these stored assimilates contribute to greater grain yield or not. Moreover, the similarities between the effects of interspecific competition and intraspecific competition on the accumulation of dry matter has not been determined yet (Tompkins et al., 1991; Arduini et al., 2006). Therefore, a study was conducted to assess the effect of intra- and interspecific competition on accumulation and contribution of dry matter and nitrogen balance in wheat agro-ecosystem.

2 MATERIAL AND METHODS

The field experiment was carried out in the Agricultural Faculty of Shahid Chamran University of Ahvaz (Latitude: 31.3183 °N, Longitude: 48.6706 °E and Elevation above sea level: 17 m) in Iran during 2012 and 2013 growing season. This region is semiarid, with the minimum and maximum temperature of 4 °C and 44 °C respectively, during the wheat growing season. In addition, the average annual precipitation based on long-term climate data (1957-2013) was 222.6 mm for this site. Soil physicochemical characteristics of experimental soil (0 – 30 cm depth) before crop planting was shown in Table 1.

The experiment was split-plot based on randomized complete block design (RCBD) with three replications. The main and sub-plots consisted of the four levels of N fertilizer (Control, 50, 100 and 150 kg nitrogen ha^{-1}, nitrogen source: NO_3 in form of urea fertilizer.) and competitiveness patterns, respectively. The pattern of competition included: without competition (W_0D_1: free from weed and optimum wheat planting density); intraspecific competition (W_0D_2: free from weed and high wheat planting density); interspecific competition (W_1D_1: high weed density and optimum wheat planting density); intra- and interspecific competition (W_1D_2: high weed and wheat density). Optimum and high density of Chamran wheat was180 and 360 kg of wheat per hectare, respectively. Inter-species competition was carried out through cultivation of two common weed species (*Avena sativa* L. and *Sinapis arvensis* L.) in wheat fields of the study area. Each plot consisted of eight rows of 4 m in length, inter-row and intra-row spacing were 20 cm and 3 cm, respectively. In each season, plant samples harvested at anthesis and maturity were separated into leaves, culm and chaff at anthesis, and grain at maturity. These segments were immediately oven dried for 48 h at 70 °C then weighed. In this experiment, an area of two square meters from each plot was harvested for determination of Grain yield by cutting the wheat plants directly. The determination of total Nitrogen concentration in grains and vegetative samples was carried out by using standard macro- Kjeldahl method (Kjeldahl, 1883). Nitrogen content (NC) was obtained by multiplying the dry matter (DM) weight with nitrogen concentration. In addition, the parameters of DM, nitrogen accumulation and translocation for this particular wheat cultivar during grain filling were calculated according to Arduini et al. (2006) and Masoni et al. (2007):

Table 1 - Soil physicochemical characteristics of experimental location before planting

Soil depth	Soil texture	pH	Electrical Conductivity (EC)	Organic Carbon (OC)	Total nitrogen	Available potassium	Available phosphorus
(cm)			(dS m^{-1})	(%)		(Mg ha^{-1})	
0-30	sandy loam	7.9	0.48	0.53	0.043	165	15

Dry matter translocation (DMT) (ton ha^{-1}) = DM at anthesis (leaves+ culm+ chaff) –DM at maturity (leaves+ culms+ chaff).

$$\text{Dry matter translocation efficiency (DMTE) (\%)} = \frac{\text{DMT}}{\text{DM at anthesis}} \times 100$$

Nitrogen translocation (NT) (kg ha^{-1}) = NC at anthesis (leaves+ culms+ chaff) – NC at maturity (leaves+ culms+ chaff).

$$\text{Nitrogen translocation efficiency (NTE) (\%)} = \frac{\text{NT}}{\text{NC at anthesis}} \times 100$$

$$\text{Contribution of pre-anthesis assimilates to grain (CPAAG) (\%)} = \frac{\text{DMT}}{\text{grain yield}} \times 100$$

Nitrogen lost (–) or gained (Kg/ha) = NC at maturity – NC at anthesis.

$$\text{Nitrogen at anthesis lost or gained (\%)} = \frac{\text{Nitrogen lost or gained}}{\text{NC at anthesis}} \times 100$$

$$\text{Harvest index (HI)} = \frac{\text{Grain yield}}{\text{total aboveground biomass at maturity}} \times 100$$

$$\text{Nitrogen harvest index (NHI)} = \frac{\text{Grain Nitrogen}}{\text{total NC of aboveground parts at maturity}} \times 100$$

Significant differences in nitrogen rate, wheat cultivar and their interactions were determined for each the crop traits under study using ANOVA at $p < 0.05$ (LSD test) with the SAS Version 9.2 Software Package.

3 Results and Discussion

3.1 Biomass dynamic

Wheat DM distribution at anthesis and maturity stages was significantly influenced by nitrogen rates and intra- and interspecific competitions (Table 2). The DM at anthesis and maturity stages significantly increased upon application of different nitrogen rates when compared to control, which resulted in raise grain yield (Table 2). Furthermore, grain yield was positively correlated to total DM at maturity and anthesis (r = 0.79**, r = 0.62**, respectively) (Table 3). There was a reduction of dry matter (leaves, culms and chaff) at anthesis and maturity stages, although wheat DM was higher at anthesis. wheat DM accumulation and partitioning into various crop parts were different owing to competition (Dordas and Sioulas, 2009; Galon et al., 2011; Galon et al., 2017) and fertilization treatments (Agostinetto et al., 2017), while biomass increased during the post-anthesis period in all fertilization treatments, suggesting that wheat DM production was dependent on nitrogen supply (Dordas and Sioulas, 2009). When the value of nitrogen decreased, it reduced dry matter production, especially in leaf (Paula et al., 2011). Finally, it influenced photo-assimilate production and distribution to the reproductive organs. The rate of current dry matter assimilation and remobilization among genotypes was dependent on environmental conditions and competition. Under adverse conditions to leaves photosynthesis, growth and nutrient uptake during grain filling stage, reserve material deposited

Table 2 - Effect of intra- and interspecific competition and different nitrogen rates on dry matter dynamic and nitrogen efficiency in two stages plant growth (anthesis and maturity)

Treatment	Anthesis			Maturity					DMTE	CPAAG	Harvest Index
	Leave + Culms	Chaff	Total Veg.*	Leave + Culms	Chaff	Total Veg.*	Grain	Total			
	(ton ha^{-1})			(ton ha^{-1})					(%)		
Nitrogen rates											
N_0	5.94c	2.83c	8.77c	5.48c	1.97c	7.44c	3.98c	11.43c	14.59c	39.41b	34.22a
N_{50}	9.67b	3.90b	12.58b	7.85b	2.58b	10.42b	5.62b	16.04b	22.99b	60.76ab	34.80a
N_{100}	10.43ab	4.23ab	14.66ab	8.20b	2.72ab	10.92b	5.33b	16.25b	25.29a	74.07a	32.56a
N_{150}	11.44a	4.72a	16.16a	9.70a	3.02a	12.73a	6.94a	19.68a	20.92b	54.83ab	34.84a
Plant × Weed density											
$D_1 \times W_0$	10.49a	4.30a	14.79a	9.06a	2.98a	12.04a	6.62a	18.66a	17.68b	45.3b	34.89a
$D_1 \times W_1$	9.05b	3.76b	12.82b	7.45b	2.63ab	10.08b	5.55ab	15.63b	20.33ab	54.7ab	35.1a
$D_2 \times W_0$	9.33b	4.03ab	13.36ab	7.49b	2.35b	9.84b	5.1b	14.94b	25.68a	69.8a	33.89a
$D_2 \times W_1$	8.60b	3.59b	12.19b	7.23b	2.32b	9.54b	4.6b	14.15b	20.11ab	59.3ab	32.57a
Interactions											
$N_0 \times D_1 \times W_0$	6.77ef	3.15efg	9.92hig	6.58bcd	2.12cde	8.70efgh	4.30def	13.00defg	11.3cd	29.0d	32.7abc
$N_0 \times D_1 \times W_1$	5.69f	2.59g	8.27i	4.93d	2.20cde	7.13fgh	4.70def	11.85eg	13.5bcd	35.2cd	38.3ab
$N_0 \times D_2 \times W_0$	5.89f	2.97fg	8.86hi	5.08bcd	1.70e	6.78h	3.30f	10.07g	23.0abcd	65.8abcd	32.2abc
$N_0 \times D_2 \times W_1$	5.40f	2.61g	8.00i	5.25bcd	1.85de	7.10gh	3.60ef	10.75fg	10.5d	27.6d	33.7abc
$N_{50} \times D_1 \times W_0$	12.42a	4.76ab	17.18ab	9.76ab	3.27ab	13.03ab	6.93bc	19.96ab	23.9ad	66.6abcd	34.5abc
$N_{50} \times D_1 \times W_1$	9.50bcd	3.69cdef	13.19def	7.16abcd	2.51bcde	9.67def	4.48def	14.15cdefg	26.5abc	78.4abc	31.5bc
$N_{50} \times D_2 \times W_0$	8.75cde	3.70cdef	12.46efg	7.07abcd	2.33cde	9.40defg	6.00bcd	15.46cde	24.4abcd	52.3abcd	38.9a
$N_{50} \times D_2 \times W_1$	8.00de	3.48defg	11.51fgh	7.37abcd	2.19cde	9.56defg	5.00cdef	14.60cdef	17.2abcd	45.7bcd	32.3abc
$N_{100} \times D_1 \times W_0$	10.26b	4.15bcd	14.41bcde	9.10ab	2.70bcd	11.80bcd	5.87bcd	17.64bc	18.6abcd	48.4bcd	33.4abc
$N_{100} \times D_1 \times W_1$	9.94bcd	4.17abcd	14.10cdef	8.11abc	2.89bc	11.00bcde	5.46cde	16.50bcd	21.9abcd	62.9abcd	32.7abc
$N_{100} \times D_2 \times W_0$	14.20ab	4.58abc	16.11abc	8.18abc	2.72bc	10.90bcde	5.87bcd	16.77bcd	32.5a	86.1ab	34.7abc
$N_{100} \times D_2 \times W_1$	10.11bcd	4.00bcde	14.12cdef	7.40abcd	2.56bcde	9.96bcde	4.12def	14.00cdefg	29.3ab	98.9a	29.4c
$N_{150} \times D_1 \times W_0$	12.52a	5.16a	17.67a	10.78a	3.83a	14.61a	9.39a	24.00a	17.0abcd	37.2cd	38.9a
$N_{150} \times D_1 \times W_1$	11.09ab	4.61abc	15.70abcd	9.78ab	2.92bc	12.70abc	7.57ab	20.00ab	19.4abcd	42.2bcd	37.9ab
$N_{150} \times D_2 \times W_0$	11.25ab	4.86ab	19.00abcd	9.66ab	2.64bcd	12.30abc	5.20cdef	17.47bc	23.9abcd	75.0abcd	29.6c
$N_{150} \times D_2 \times W_1$	10.89ab	4.26abcd	15.14abcde	8.91abc	2.69bcd	11.60bcd	5.63bcde	17.19bcd	23.5abcd	64.9abcd	32.9abc

D_1: 180 kg ha^{-1} (optimum wheat density), D_2: 300 kg ha^{-1} (high wheat density), W_0: control (absent weed), W_1: weed present (30 weed.m^{-2}). * Total Veg. (Vegetative) = Culms + Chaff + leaves, CPAAG = Contribution of pre-anthesis assimilates to grain, DMTE = Dry matter translocation efficiency. Means in a column followed by different letter are statistically significant according to LSD test (P<0.05).

Table 3 - Linear Pearson correlation coefficient between various nitrogen and dry matter parameters

Treatment	Grain yield	Dry matter (anthesis)	Vegetative dry matter (Maturity)	DMTE	CPAAG	Harvest Index	NC (Grain)	NTE	Nitrogen harvest index	NC (anthesis)	NCVP (maturity)
Grain yield	1										
Dry matter (anthesis)	0.62**	1									
Vegetative dry matter (Maturity)	0.79**	0.88**	1								
DMTE	-0.23^{ns}	0.40**	-0.07^{ns}	1							
CPAAG	-0.38**	0.35*	-0.09^{ns}	0.95**	1						
Harvest Index	0.66**	-0.02^{ns}	0.09^{ns}	-0.27^{ns}	0.50**	1					
NC (Grain)	0.96**	0.66**	0.83**	-0.19^{ns}	-0.30*	0.54**	1				
NTE	-0.39**	-0.31*	-0.49**	0.29*	0.24^{ns}	-0.03^{ns}	-0.44**	1			
Nitrogen harvest index	0.10^{ns}	-0.51**	-0.41**	-0.33*	-0.48**	0.68**	0.05^{ns}	0.46**	1		
NC (anthesis)	0.70**	0.89**	0.87**	0.50^{ns}	0.14^{ns}	0.10ns	0.79**	-0.19^{ns}	-0.38**	1	
NCVP (maturity)	0.77**	0.85**	0.92**	0.02^{ns}	-0.03^{ns}	0.13^{ns}	0.87**	-0.55**	-0.44**	0.92**	1

^{ns} *P*>0.05, * *P*<0.05, ** *P*<0.01, DMTE: dry matter translocation efficiency, CPAAG: Contribution of pre-anthesis assimilates to grain, NTE: nitrogen translocation efficiency, NC: nitrogen Content, NCVP: nitrogen content at vegetative parts.

in vegetative crop parts before anthesis stage can buffer grain yield (Tahir and Nakata, 2005). Also, DM production may be reduced from anthesis to maturity stage (Aynehband et al., 2010).

Intra- and interspecific competition treatments demonstrated remarkable differences with respect to the changes of the vegetative DM at critical stages (anthesis and maturity stages). By increasing competition, DM at critical stages, especially in grain yield was decreased. Also, these treatments had a significant effect on DMTE (Table 2). High DM at anthesis lead to a low proportion of remobilized DM. For example, DMTE under no Intra- and interspecific competitions (D_1W_0) (17.68%) was significantly lower than both intra- and interspecific competition treatments (D_2W_1) (20.11%), while the wheat DM at anthesis stage was higher (Table 2). Moreover, wheat DMTE was influenced by nitrogen fertilizer application and it was higher in 100 kg N ha^{-1} than other nitrogen levels. In other words, DMTE was lowest in control. High variability in the contribution of stored assimilate was observed prior to anthesis stage to wheat grain yield, and the proportion of yield obtained through remobilization of DM before anthesis was estimated from 7 to 57% (Masoni et al., 2007). Most of these changes can be attributed to diversity in crop management, plant genotypes, soil types and climate conditions (Cox et al., 1986). In addition, the different conditions of competitiveness had different effects on nitrogen accumulation and DM during the pre- and post-anthesis stages. Arduini et al. (2006) mentioned that stored carbon and nitrogen contributed to total grain carbon and nitrogen was 64 and 81%, respectively.

Findings indicate that the contribution of DM remobilization to grain yield remarkably differed among competition treatments i.e. than fifty percent under no competition (D_1W_0) and more than 50% in all other competition treatments (Table 2). Similar observations were presented by other researchers (Alvaro et al., 2008; Ercoli et al., 2008). The contribution of pre-anthesis assimilates to grain (CPAAG) significantly differed among intra- and interspecific competitions and within N rates and ranged from 27.6 – 98.85 of grain dry weight (Table 2). The D_1W_0 and D_2W_1 treatments with high N application (100 and 150 kg ha^{-1}) showed higher CPAAG than low N application. In lower N applications, intensive in intra- and interspecific competition (D_2W_1) was provided the low supply of nitrogen during the post-anthesis stage. This position was probably conducive to lower rates of photosynthesis and, in turn, a lower supply of assimilates for grain filling; thereby reducing the transmission of assimilates before anthesis. Mason et al. (2007) found that wheat D DM accumulation was greater compared to DM remobilization during grain filling and hence the contribution of remobilization to grain yield did not achieve 30%. Also, the nitrogen remobilization calculated for 73 to 82% of grain NC. Moreover, accumulation of phosphorus was lower than remobilization of P during grain filling, but differences among remobilization and accumulation of nitrogen were greater than that for P. Therefore, most of the grain carbohydrates and the grain nitrogen resulted from current photosynthesis carbon metabolism produced during grain filling and the remobilization of accumulated nitrogen before anthesis stage, respectively. Thus, the factors that reduced photosynthesis during the grain filling had a lower effect on the supply of nitrogen to grain than on the carbohydrates supply.

The results showed that there was a positive correlation between the CPAAG and HI (r = 0.5**) but there was no correlation between HI and the DMTE (r = -27^{ns}) (Table 3). Also, we found that harvest index was not significantly affected by competition treatments and nitrogen rates (Table 2). The results are comparable to Dordas (2009) when N application was not affected on HI.

3.2 Nitrogen balance

The results of Table 4 showed that, at anthesis stage, the total N content of wheat vegetative parts including leave, chaff and culms was significantly higher in plants treated with nitrogen fertilizer compared to control and it increased by the addition of nitrogen fertilizer. It appears that NC was associated with both variations in nitrogen concentration and DM (Tables 2 and 4). Moreover, the NC of vegetative parts in intra- and interspecific competition treatments was significantly less when compared with no competition. Therefore, it is likely that intra- and interspecific competitions have different effects on plant capability to accumulate nitrogen in vegetative parts before anthesis. Khan et al. (2017) stated that nitrogen accumulation and divided it into the different plant parts and DM were affected by nitrogen fertilization. Information about these important factors is necessary to understand the processes of plant growth and development better. This better understanding may aid in resource manipulation for achieving optimum crop yield. In addition, Dordas and Sioulas (2009) found that there may be variation in DM of wheat, under the influence of nitrogen application, due to differences in the amount of photosynthetically active solar radiation (PAR) intercepted by the crops during competition, and also from efficient use of this radiation by plants. They also found that nitrogen accumulation and DM before anthesis stage are most important sources of nitrogenous compounds and photosynthetic products for grain growth and development. Moreover, grain growth is supported by current photosynthesis, occurring primarily in the inflorescences and flag leaf as well as by translocation of photosynthetic product in the plant canopy. In grain filling period, there are many critical factors determining final grain yield such as planting date, genotype, density, environment conditions, water and nutrients deficit which may influence the remobilization and relative flow of nitrogen and carbon to the grain (Arduini et al., 2006; Masoni et al., 2007; Aynehband et al., 2010; Fageria, 2009).

The NC in grain was decreased more than vegetative parts with increasing competition at the maturity stage. On the other hand, plants allocated more nitrogen to vegetative parts than to grain. There was a positive correlation between NC at anthesis and NC of vegetative parts at maturity stage (r = 0.92) (Table 3). Nitrogen remobilization was much more (by 7.52%) in unfertilized plants than fertilized ones at the 150 kg N ha^{-1} (Table 4). In contrast to decreased translocation efficiency, nitrogen content increased in wheat grain yield and vegetative parts with increase in nitrogen rate. There was no significant difference in NTE among intra- and interspecific competition

Table 4 - Nitrogen concentration, content, translocation efficiency and Nitrogen balance at anthesis and maturity in wheat agroecosystem as affected by intra- and interspecific competition and different nitrogen rates

Treatment	Anthesis		Maturity					Nitrogen translocation efficiency (NTE)	Nitrogen harvest Index (NHI)	Nitrogen at anthesis lost or gained	Nitrogen lost (-) or gained
	Nitrogen concentration	Nitrogen content (NC)	Nitrogen concentration		Nitrogen content (NC)						
	Total*	Total*	Total Veg.*	Grain	Total Veg.*	Grain	Total				
	(g kg^{-1})	(kg kg^{-1})	(g kg^{-1})		(kg kg^{-1})				(%)		(kg ha^{-1})
Nitrogen rate											
N_0	11.7c	102.7c	3.1d	20.6d	23.4d	82.2c	105.6c	77.2a	74.8a	11.32a	2.88a
N_{50}	12.9bc	179.5b	3.9c	22.9c	41.8c	130.6b	172.5b	76.3a	72.5a	1.53a	-7.00b
N_{100}	13.4b	196.4b	5.1b	24.2b	56.0b	129.74b	185.8b	71.3b	68.0b	-9.71a	-10.65c
N_{150}	16.5a	267.9a	59a	25.3a	75.6a	178.6a	254.1a	71.4b	66.6b	-11.23a	-13.80d
Plant × Weed density											
$D_1 \times W_0$	16.2a	246.0a	5.2a	25.7a	65.0a	174.5a	239.6a	72.0a	70.2a	-4.20a	-6.37b
$D_1 \times W_1$	13.8b	181.9b	4.9b	23.3b	51.3b	130.7b	182.0b	73.7a	69.8a	15.00a	0.21d
$D_2 \times W_0$	12.8bc	173.7bc	4.2c	22.9b	43.3c	117.9bc	161.2bc	75.3a	70.9a	-13.86a	-12.30a
$D_2 \times W_1$	11.7c	145.2c	3.7d	21.0c	37.2c	97.9c	135.0c	75.2a	71.0a	-5.12a	-10.20c
Interactions											
$N_0 \times D_1 \times W_0$	12.6cde	124.4h-k	3.7g	22.2efg	32.3hij	94.98ef	127.2fg	74.0a-d	71.6bcd	-22.82b	2.81ab
$N_0 \times D_1 \times W_1$	11.5ef	947.0k	3.6g	21.0gh	25.5ijk	99.2ef	124.6fg	73.0a-d	75.8ab	90.63a	28.98a
$N_0 \times D_2 \times W_0$	12.0ef	104.9jk	2.9h	20.2hi	19.6jk	65.9f	85.4g	80.8ab	73.6abc	-49.92b	-19.49ab
$N_0 \times D_2 \times W_1$	10.8ef	868.0k	2.3i	19.0i	16.3k	68.7f	85.0g	80.9a	78.3a	-2.74b	-1.78ab
$N_{50} \times D_1 \times W_0$	16.6b	284.0b	4.7ef	26.3a	62.1cd	181.9bc	244.0bc	78.0abc	71.0bcd	7.31ab	-39.98ab
$N_{50} \times D_1 \times W_1$	12.7cde	167.8fgh	4.5f	22.7ef	43.9fgh	102.3df	146.2efg	73.7a-d	66.5a-f	-23.18b	-21.53ab
$N_{50} \times D_2 \times W_0$	12.3de	153.0g-j	3.7g	22.4efg	35.4ghi	136.6b-e	172.0df	77.0a-d	76.0ab	30.78ab	18.97a
$N_{50} \times D_2 \times W_1$	99.0f	113.2ijk	2.7i	20.2hi	25.9ijk	101.8def	127.7fg	76.5a-d	76.4ab	21.44ab	14.44a
$N_{100} \times D_1 \times W_0$	16.5b	237.8bcd	5.7b	26.0bc	67.6ba	152.9bcd	220.6cd	71.7cd	66.7def	-12.63b	-17.17ab
$N_{100} \times D_1 \times W_1$	14.5bcd	205.3def	5.2cde	24.5cd	57.7cde	134.4b-e	192.1cde	71.9cd	67.2c-f	-11.67b	-13.19ab
$N_{100} \times D_2 \times W_0$	11.4ef	183.2efg	4.8def	24.4d	52.7def	142.2b-e	194.9cde	70.8cd	70.2b-e	12.46ab	11.72ab
$N_{100} \times D_2 \times W_1$	11.3ef	159.5f-i	4.6f	21.8fg	46.1efg	89.4ef	135.5efg	70.8cd	62.5ef	-27.00b	-23.95ab
$N_{150} \times D_1 \times W_0$	19.1a	337.8.a	6.7a	27.5a	98.3a	268.3a	366.6a	70.8cd	71.4bcd	11.32ab	29.85a
$N_{150} \times D_1 \times W_1$	16.6b	259.7bc	6.3a	24.8bcd	78.3b	187.0b	265.3b	69.5d	69.7b-e	4.55ab	5.57ab
$N_{150} \times D_2 \times W_0$	15.7b	252.8bcd	5.3bc	24.5cd	65.4bcd	127.2de	192.6cde	72.8bcd	63.9ef	-39.41b	-60.23b
$N_{150} \times D_2 \times W_1$	14.7bc	221.4cde	5.3bcd	23.4de	60.3cd	131.7cde	192.0cde	72.6cd	61.2c-f	-21.41b	-29.44ab

D_1: 180 kg ha^{-1} (optimum wheat density), D_2: 300 kg ha^{-1} (high wheat density), W_0: control (absent weed), W_1: weed present (30 weed.m^{-2}).
* Total or Total Veg. (Vegetative) = Culms + Chaff + leaves. Means in a column followed by different letter are statistically significant according to LSD test (P<0.05).

treatments. Similarly, NTE taken up pre-anthesis was changeable and it was not independent of the genotypes (Tompkins et al., 1991). In our research, the low amount of N remobilization efficiency (NRE) under no competition treatments (D_1W_0) (Table 4) was likely because of the lower DMTE (Table 2). Wheat cultivars with low densities had low net DM productivity and light interception efficiency (Wall and Kanemasu, 1990). Moreover, the higher remobilization was likely related to the higher DM of the crop at heading, which demonstrates the potential source for remobilization (Przulj and Momcilovic, 2001; Aynehband et al., 2011).

Grain and total vegetative N contents at maturity stage decreased in no competition (D_1W_1) and intra- and interspecific competition (D_2W_1) by 43.89 and 42.8%, respectively (Table 4). There was positive significant correlation between NC of grain with NC at anthesis and NCVP at maturity (r = 0.79**, r = 0.87**, respectively). Also, there was no significant correlation between NHI and grain NC (Table 3). N absorption by cereals is principally pre-anthesis. So, over 80% of the final NC in the plant is present at anthesis. The nitrogen accumulated pre-anthesis can support almost 75 to 90% of the final NC of the winter wheat grains (Cox et al., 1986). The relationship between remobilized nitrogen and the nitrogen absorption capacity of plants is the important factor to determine the extent of nitrogen accumulation. Moreover, high levels of nitrogen fertilization during pre-anthesis resulted in a reduction in NRE and render nitrogen remobilization (Aynehband et al., 2014; Xu et al., 2018).

Although, both intra- and interspecific competitions decreased grain and total NC at maturity stage (Table 4), the NHI was not significantly affected by competition effects (Table 4). Because the percentage of grain and total NC decreased under competition (56%), was similar. Also, interspecific competition treatment (D_1W_1) showed the lowest NHI (69.8%). On the other hand, these treated plants were able to maintain lower NTE (Table 4). In addition, there was no significant difference between intra- and interspecific competition treatments (D_1W_1 and D_2W_0) for NTE. Ercoli et al. (2008) reported that in different conditions, the relative contribution of remobilization to grain yield relates to source/sink interactions during grain filling period. It is expected that the higher accumulation of pre-grain filling reserves will result in a yield advantage, especially at higher nitrogen status, when the crop is grown in competition until anthesis stage. Nevertheless, it has been confirmed that increase in reserve capacity before anthesis growth will not be effective to increase grain yield if the periods of drought or nitrogen supply restricted the crop growth before and after anthesis stage for a short time (Ercoli et al., 2008).

When the N content at anthesis was compared to the NC at maturity stage, gains and losses of N contents were found in these growth stages in response to competition and no competition treatments and N rates (Table 4). N losses and average gains of nitrogen ranged from 1.78 – 60.23 kg ha^{-1} (averaged over N rates) and 2.81 – 29.85 kg N ha^{-1}, respectively. N lost or gained was linked to the nitrogen contents at anthesis and maturity stage and these alternations varied among competition treatments (Table 4). These results indicate that nitrogen gains relate mainly to the NC at anthesis stage. The highest NC at anthesis (337.8 kg ha^{-1}) showed the highest amount of nitrogen gains (29.85 kg ha^{-1}). Moreover, between competition treatments, D_2W_1 showed the highest N gains and losses, respectively. It was reported that 11% of available nitrogen for redistribution was lost as gaseous NH_3 (Dordas, 2009). It is likely that when nitrogen decline in plant tops due to limited the capacity of inflorescence to store nitrogen can cause to reduction in plant carbohydrates (Aynehband et al., 2010). Przulj and Momcilovic (2011) showed that nitrogen losses of barley cultivars in high content of nitrogen (above 150 kg ha^{-1}) are mainly dependent on plant NC at anthesis. Also, they stated that the cultivars with a high capacity for nitrogen accumulation before anthesis, high NHI and high remobilization efficiency could be used in the development of cultivars with the favorable nitrogen balance when the genetic variation was present for these indices.

4 Conclusions

In general, wheat dry matter accumulation and N content appear to be higher at anthesis than that in maturity stage for competition treatments and N rates as well. Lower DMTE causes a decrease in NRE under no competition treatments. In contrast to N rates, higher amounts of DM at anthesis achieved in a lower DMTE. The trend of NHI and NTE were different from DMTE. These indices were highest in interspecific competition treatments. Moreover, the highest grain yield in no competition treatment obtained from the lowest DM and NTE. It was concluded that the capacity for nitrogen accumulation in the wheat stem, was accompanied by a high nitrogen uptake and assimilation, and high NRE at post-anthesis.

5 Contributions

SA: designed and performed experiments, analyzed data and wrote the manuscript with support from AA and AR. AA: designed experiments, supervised the research.

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