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RESEARCH ARTICLE

Nitrogen and Cultivated Bulb Weight Effects on Radiation and Nitrogen-Use Efficiency, Carbon Partitioning and Production of Persian Shallot (*Allium altissimum* Regel.)

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Abstract

Persian shallot (*Allium altissimum* Regel.) was grown under fully irrigated conditions in a 2-year-field experiment (2010 - 2012) in the northeast of Iran to study and determine (i) radiation and nitrogen-use efficiency, (ii) growth analysis, (iii) carbon partitioning, and (iv) biomass production under different rates of nitrogen and cultivated bulb weights. The field experiment was performed as a randomized complete block design with a factorial arrangement of four nitrogen levels (control (100), 200, 250, and 300 kg ha^{-1}) and two levels of cultivated bulb weight (10 - 20 and 20 - 30 g) with three replications in both years of the experiment. Our results showed that increasing the nitrogen rate and bulb weight significantly enhanced Persian shallot production. Radiation-use efficiency (1.06 to 1.27 g MJ^{-1}), maximum crop growth rate (8.3 to 11.2 g m^{-2} d^{-1}), and maximum leaf area index (1.3 to 2.6) showed a positive correlation with nitrogen rate and bulb weight. Nevertheless, nitrogen-use efficiency (0.87 to 2.38 g bulb per g nitrogen) indicated a negative relationship with applied nitrogen rate. Moreover, increasing the nitrogen application rate increased the carbon allocation to above-ground organs. On the other hand, nitrogen limited conditions increased the carbon allocation to underground organs and carbon remobilization from stem and leaves to bulbs during the late growth season. Increasing the nitrogen application rate and bulb weight may be appropriate practices for enhancing Persian shallot production; however, evaluation of the impact of nitrogen on the quality of bulbs needs to be investigated.

Key words: agronomic characteristics, allocation, growth analysis, Persian shallot, plant production

Introduction

The *Allium* genus is one of the most diverse and taxonomically difficult assemblies of the monocots (Fritsch 1996). The antibacterial, antifungal, antiviral, antiprotozoal, and antihelmintic characteristics of the *Allium* genus are well established (Zammouri et al. 2008). Persian shallot (*Allium altissimum*) is native and endemic of Iran and grows as a wild plant on the pastures and mountainous regions (Rubatzky and Yamaguchi 1997) and is quite resistant to cold and freezing stress.

Persian shallot is a perennial plant which needs a vernalization period about 60 - 80 days (0 - 4°C) for starting the germination process (Arefi 2011). The storage tissue of Persian shallot is bulb, white-skinned, and usually consists of a single main bulb or rarely a small bulblet attached to main one (Mohammadi 2010). Generally, the main bulbs are harvested and the bulblets are stored for cultivation in the next year. The sowing date of this plant is mainly at the end of autumn, as roots grow during winter and emergence generally happens in mid-March under Iran's conditions. Consequently, leaf area and inflorescence axis start the exponential growth in early May and bulbs harvest whenever all leaves become yellowish.

The key to sustainable agriculture production lies in increased output per unit input. Efficiency in agriculture can be defined as the ratio between output and input (Van Duivenbooden et al. 2000). Biomass production is mainly determined by the amount of photosynthetically active radia-

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tion (PAR) intercepted by the canopy and the efficiency with which it is used to produce biomass, referred to as radiation-use efficiency (RUE) (Sun et al. 2009). Dry matter accumulation generally shows a linear relationship to cumulative intercepted radiation (Caviglia and Sadras 2001). Some reports estimated RUE values for other members of cultivated *Alliums* such as garlic (*Allium sativum* L.) (RUE = 2 g MJ^{-1}) and onion (*Allium cepa* L.) (RUE = 0.98 g MJ^{-1}) (Rizzalli et al. 2002; Tei et al. 1996). However, there is no previous record of Persian shallot RUE.

Nitrogen fertilizer application rates have increased dramatically in Iran's agricultural systems (Tavakkoli and Oweis 2004). Therefore, a better understanding of the plants' demands to nitrogen improve the nitrogen use efficiency (NUE) and avoids over fertilization (Zhu et al. 2005). The NUE values for onion was between 0.59 to 0.78 under different rates of nitrogen application. In addition, increasing the nitrogen fertilizer application from 56 to 168 kg N ha^{-1} decreases the NUE by 18% in onion plants (Drost et al 2002). Filabi et al. (2012) showed that increasing nitrogen application significantly enhanced the total biomass production of garlic. Furthermore, increasing nitrogen fertilizer application sharply decreases the NUE and harvest index in garlic plants (Filabi et al. 2012). Hocking et al. (1997) found a significant negative correlation between nitrogen application rate and nitrogen-use efficiency of canola (*Brassica napus* L.) under semi-arid conditions.

Dry matter partitioning between different organs is obviously an important issue which directly influences horticultural crop production (Marcelis 1996) which is highly influenced by environmental conditions and different management practices (Rizzalli et al. 2002). Furthermore, nitrogen application influences root/shoot partitioning (Hutchings and John 2004) by increasing dry matter partitioning to vegetative organs (Arduini et al. 2006). In view of the lack of studies on Persian shallot growth and agronomic characteristics, the main objectives of the current study were to determine radiation- and nitrogen-use efficiencies, growth analysis, carbon partitioning, and bulb yield under different nitrogen applications and cultivated bulb weights.

Material and Methods

Study area

The field experiment was carried out during two growing seasons (2010 and 2011) at the Research Field, Faculty of Agriculture, Ferdowsi University of Mashhad (latitude: 36°15' N, longitude: 59°28' Elevation: 999 m), Iran. The climatic condition of the study location is semi-dry with 263 mm annual precipitation. Maximum and minimum temperatures and precipitation rate for both years of this study are shown in Fig. 1. The soil type of the experimental field was silty loam (pH = 7.5), containing total nitrogen (200 ppm), total phosphorus (9.4 ppm), and total potassium (120 ppm)

Fig. 1. Annual growth cycle of Persian shallot.

with an EC of 0.11 dSm^{-1}.

Experimental design and statistical analysis

The field experiment was performed as a randomized complete block design (RCBD) with a factorial arrangement of four nitrogen application levels and two levels of bulb weight with three replications. The two bulb weight levels included (10 - 20 and 20 - 30 g) and four levels of nitrogen fertilizer application were (control (100), 200, 250, and 300 kg ha^{-1}). In order to compare the impact of the applied treatments on study parameters, an analysis of variance (ANOVA) was performed as a standard procedure for the randomized complete block design (RCBD) with a factorial arrangement. The t-test was used to find significant differences across treatments. Analysis of variance performed by SAS 9.1 and PROC GLM procedure (SAS Institute, Cary, NC).

Field conditions and measurements

Persian shallot bulbs were planted in early November (10 plant m^{-2}) in 4 × 3 m plots and fully irrigated by 7-day-intervals after emergence (early March). The amount of irrigated water was 700 mm during the growth period for both years of the experiment. Nitrogen fertilizer applied along with irrigated water at emergence (50 kg ha^{-1}), leaf exponential growth (50 kg ha^{-1}), and flowering (50 kg ha^{-1}) stages and weeds were controlled by hand when needed. Different growth stages of Persian shallot are shown in Fig. 2. Leaf, stem, flowers, and bulbs were sampled eight times after emergence to harvest and at each sampling time, leaf area (one side of green leaves) was measured using a leaf area-meter (AT Delta-T-Dias II). Collected materials were weighted after drying in an oven at 45°C for 72 h.

Radiation and nitrogen use efficiencies and dry matter partitioning

Agronomic nitrogen-use efficiency calculated by (Raun and Johnson 1999):

$$NUE= \frac{BY}{NP} \quad (1)$$

Where NUE is nitrogen-use efficiency (g bulb g N^{-1}), BY is bulb yield (g m^{-2}), and NP is nitrogen application rate (g N m^{-2}).

Daily values of LAI calculated by fitting a peak logistic function based on leaf area sampling (Lizaso et al. 2003):

$$y = \frac{a + b \times 4(\exp(-(x-c)/d))}{(1+exp(-(x-c)/d)^2} \qquad (2)$$

Where α is the intercept point, β is maximum LAI, c and d are the time to reach the maximum LAI and inflection point, respectively. Daily values of radiation obtained from Khorasan province meteorological organization and 50% of this radiation assumed as photosynthetically active radiation (PAR) (Goudriaan and Monteith 1990). Consequently, the daily radiation absorption of the plants was calculated according to Goudriaan and Monteith (1990):

$$I_{abs} = I_o(1-exp^{(K.LAI)}) \qquad (3)$$

Where I_{abs} is absorbed radiation by canopy, I_o is amount of radiation at the top of the canopy, and k is light extinction coefficient (0.7) (Rezvan 2012). Radiation-use efficiency (RUE) was estimated as the slope of the linear regression ($y=a+bx$) of cumulative dry matter versus cumulative absorbed PAR (Sinclair and Horie 1989).

The partitioning of dry matter to leaves, shoots, flowers (inflorescence + inflorescence's stem), and bulbs was calculated in each sampling interval (Evans 1990):

$$PC_i = \frac{\Delta DM_i}{\Delta DM_{total}} \qquad (4)$$

Where PC_i is the partitioning coefficient of the organ i for each growth phase, ΔDMi and ΔDM_{total} are the dry matter variations during this phase of the organ i and total dry weight, respectively. Calculation of growth degree days performed based on cardinal temperatures as reported in Eyshi Rezaei et al. (2012) was calculated after emergence.

Growth analysis

A logistic function was fitted for determination and trend of total biomass of Persian shallot (Retta et al. 1995). In addition, Crop Growth Rate (CGR) (g m^{-2} day^{-1}) was calculated by derivative of the logistic function (Calera et al. 2004):

$$y = \frac{a}{1+b^{-cx}} \qquad (5)$$

$$CGR = \frac{abce^{-cx}}{1+be^{-cx}} \qquad (6)$$

Where y is the total biomass (g m^{-2}), a, b, and c are function parameters which were obtained from fitting the function with observed data, and x is number of days after emergence.

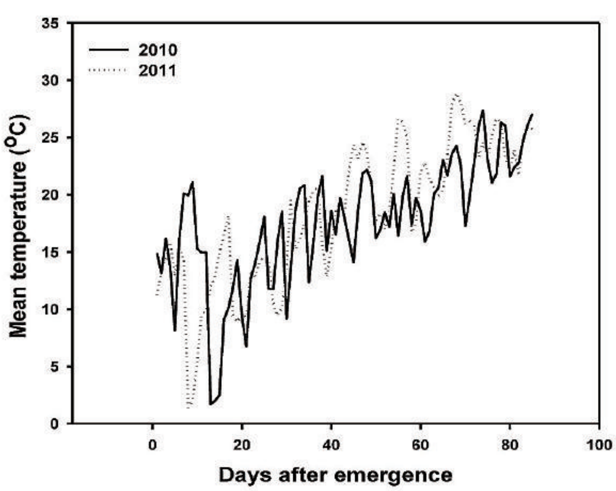

Fig. 2. Daily mean temperature across study growth seasons

Results

Plant production and growth analysis

Leaf area index (LAI)

Results of the current study showed that application of different nitrogen fertilizer rates and cultivated bulb weight significantly (P > 0.05) influenced production and growth rate of Persian shallot. The full cover of canopy (maximum LAI) obtained around 600 (°C day^{-1}) GDD under all applied treatments in both years (Figs. 3a and 3b). Increasing the nitrogen application rate and cultivated bulb weight remarkably enhanced LAI expansion rate in both years of the study (Fig. 3c). In addition, bulb weight showed a higher influence on LAI than nitrogen application rates. Using 300 kg ha^{-1} nitrogen application along with lighter (10 - 20 g) cultivated bulbs resulted in lower LAI than using 100 kg ha^{-1} nitrogen and heavier (20 - 30 g) bulbs (Fig. 3). Maximum LAI (2.6 and 2.3 in first and second year, respectively) obtained under 300 kg ha^{-1} nitrogen and 20-30 g cultivated bulbs (Figs. 3a and 3b).

Bulb and grain yield

Persian shallot bulb and grain yield showed the same response to increasing nitrogen application and bulb weight in both years of the study. Bulb and grain yield increased by 18 and 13%, respectively, under the highest rate of nitrogen application and 20 - 30 g bulb weight compared to the control (Figs. 4a and 4b). However, increasing nitrogen application did not show a significant impact on bulb and grain yield under 10 - 20 g cultivated bulb weight in both years (Figs. 4a and 4b).

On the other hand, increasing the cultivated bulb weight (23 and 20% enhancement in bulb and grain yield) showed a higher impact on Persian shallot production than nitrogen increase (Figs. 4a and 4b). The highest and lowest bulb and grain yield obtained at 300 kg ha^{-1} nitrogen application + 20-30 g cultivated bulbs (342 and 37 g m^{-2}) and 100 kg ha^{-1} nitrogen + 10 - 20 g cultivated bulbs (236 and 25 g m^{-2}), respectively (Figs. 4a and 4b).

Growth analysis

Persian shallot CGR showed a moderate increasing trend until 200°C day^{-1} and showed a sharper increasing slope from 200 to 400°C day^{-1} and a downward trend which started after 400°C day^{-1} until the end of the growth season under all applied treatments and both years (Figs. 5a and 5b). Persian

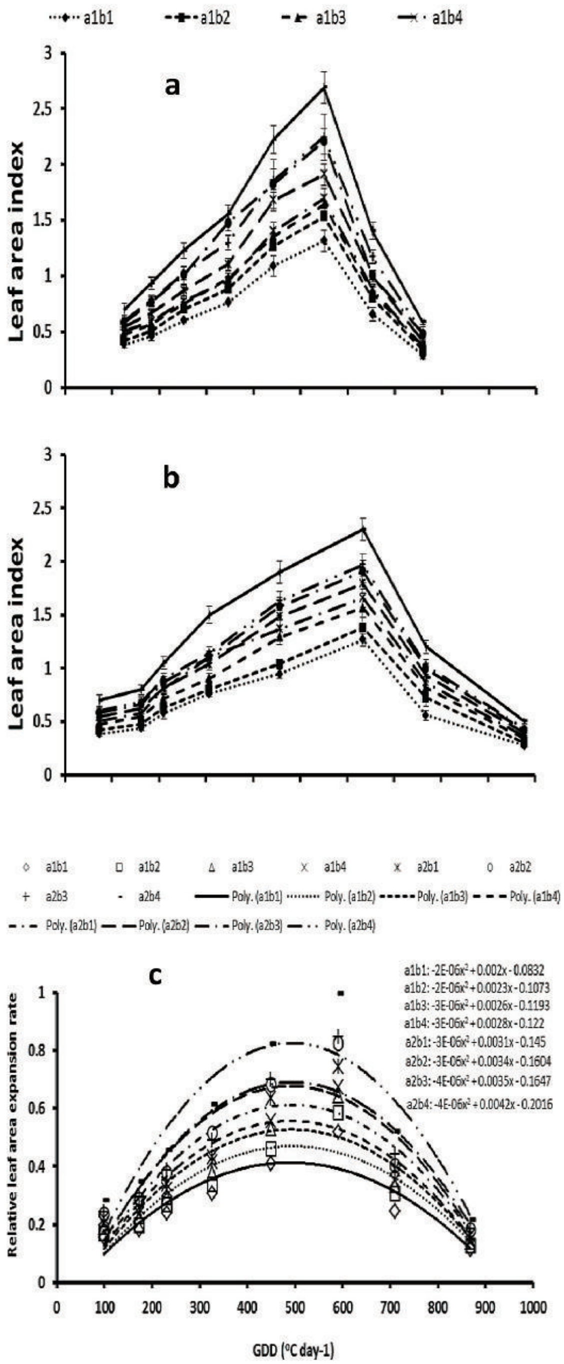

Fig. 3. Trend of leaf area index (LAI) under different nitrogen application rates and cultivated bulb weight in 2010 (a) and 2011 (b) and trend of relative leaf area expansion rate (average of both years) (c) during growth period (There are no significant differences between averages with similar overlap range according to standard error). (a: cultivated bulb weight, a1: 10-20 g and a2: 20-30 g. b: nitrogen application rate, b1: control, b2: 200 kg ha^{-1}, b3: 250 kg ha^{-1} and b4: 300 kg ha^{-1})

shallot showed the same fluctuation trend during the growth period under all study treatments. However, increasing the nitrogen application rate from 100 to 300 kg ha^{-1} and cultivated bulb weight from 10 - 20 to 20 - 30 g enhanced the CGR growing slope. Therefore, our results comfirmed a direct positive correlation between nitrogen application and bulb weight with CGR. The highest values of maximum CGR

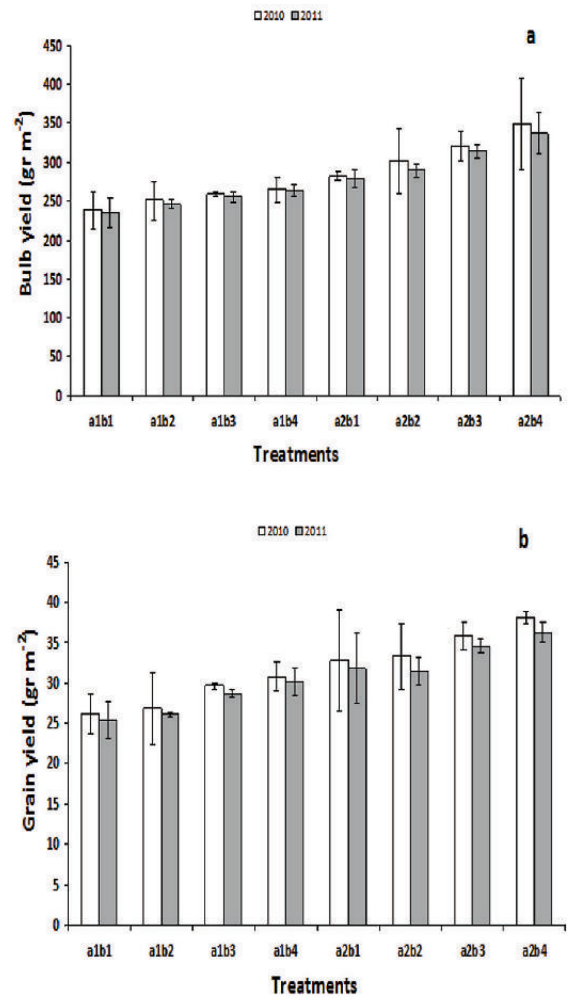

Fig. 4. Effect of different nitrogen application rates and cultivated bulb weight on bulb (a) and grain (b) yields of Persian shallot (There are no significant differences between averages with similar overlap range according to standard division). (a: cultivated bulb weight, a1: 10-20 g and a2: 20-30 g. b: nitrogen application rate, b1: control, b2: 200 kg ha^{-1}, b3: 250 kg ha^{-1} and b4: 300 kg ha^{-1})

were 8.3 (second year) and 11.2 (first year) g m^{-2} day^{-1} under 300 kg ha^{-1} nitrogen + 20 - 30 g cultivated bulbs (Figs. 5a and 5b).

The trend of cumulative total biomass showed a significant difference ($P < 0.05$) between various rates of nitrogen application and cultivated bulb yield (Figs. 6a and 6b). The total biomass trend did not show any difference up to 200°C day^{-1} across applied treatments, nevertheless increasing the nitrogen application rate under heavier cultivated bulbs notably raised the total biomass production of Persian shallot (Figs. 6a and 6b). The highest biomass production was gained under 300 kg ha^{-1} nitrogen and 20 - 30 g cultivated bulbs weight conditions in the first (508 g m^{-2}) and second (480 g m^{-2}) years.

Radiation-use efficiency

Nitrogen showed a higher influence on radiation-use efficiency of Persian shallot than weight of cultivated bulb (Fig. 7). Radiation-use efficiency showed a linear relationship with an increase in the nitrogen application rate in both years of the

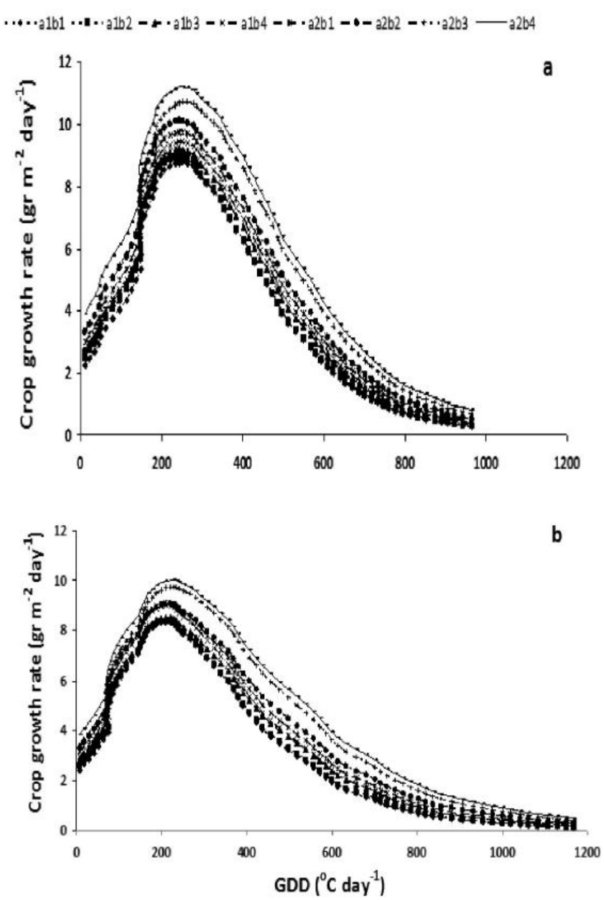

Fig. 5. Trend of crop growth rate (CGR) under different nitrogen application rates and cultivated bulb weight across 2010 (a) and 2011 (b) growing seasons. (a: cultivated bulb weight, a1: 10-20 g and a2: 20-30 g. b: nitrogen application rate, b1: control, b2: 200 kg ha^{-1}, b3: 250 kg ha^{-1} and b4: 300 kg ha^{-1})

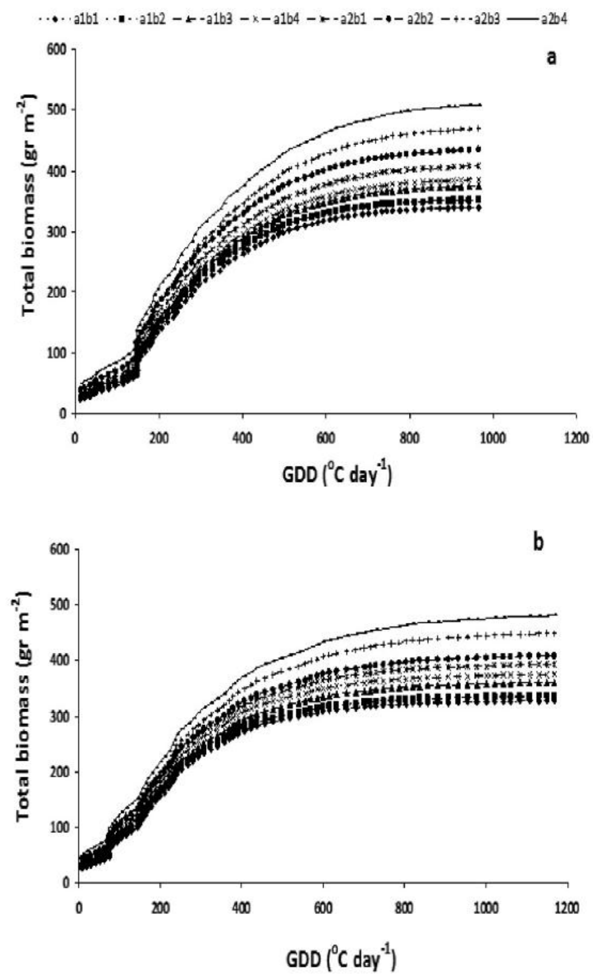

Fig. 6. Trend of total biomass fluctuations under different nitrogen application rates and cultivated bulb weight across 2010 (a) and 2011 (b) growing. (a: cultivated bulb weight, a1: 10-20 g and a2: 20-30 g. b: nitrogen application rate, b1: control, b2: 200 kg ha^{-1}, b3: 250 kg ha^{-1} and b4: 300 kg ha^{-1})

study but it was not significant ($P > 0.05$). The range of RUE was between 1.06 to 1.27 gr MJ^{-1} across applied treatments (Figs. 7a and 7b). The highest RUE values obtained under 250 and 300 kg ha^{-1} nitrogen application and 20 - 30 g cultivated bulbs weight in both years of the study (Figs. 7a and 7b).

Nitrogen-use efficiency

In general, increasing the cultivated bulb weight and decreasing the applied nitrogen rate raised the NUE in both years of the study (Fig. 8). The range of NUE values was between 0.87 to 2.7 g bulb per g nitrogen across different treatments and years. Highest and lowest values of NUE obtained under control (100 kg N ha^{-1}) + 20 - 30 g cultivated bulb weight and 300 kg N ha^{-1} + 10 - 20 g cultivated bulb weight (Fig. 8).

Partitioning coefficients

Partitioning coefficients of Persian shallot was calculated for high (300 kg ha^{-1} nitrogen application + 20 - 30 g cultivated bulbs) and low (100 kg ha^{-1} nitrogen application + 10 - 20 g cultivated bulbs) source conditions which refers to nitrogen availability for the whole growing season and carbon availability during the early growth season. The highest carbon was allocated (at least 50%) to bulbs in both high and low availability of resources in both years of the study (Fig. 9). The allocation of carbon to bulbs declined under both unlimited and limited conditions until 400°C day^{-1}, although the carbon allocated to bulbs increased during the remainder of the growth season, particularly under limited conditions (Fig. 9).

There was no significant difference in carbon allocation to aboveground organs such as stems and leaves until the late growth season between unlimited and limited conditions. However, carbon allocation to aboveground organs significantly decreased to negative values under limited conditions in both years (Fig. 9). Carbon allocation to reproductive organs showed a flat trend until 650°C day^{-1} and increased to 0.4 during the end of the growth season (Fig. 9).

Discussion

The Persian shallot production showed a positive response to increasing application of nitrogen and cultivated bulb weight in this study. In addition, increasing the applied nitro-

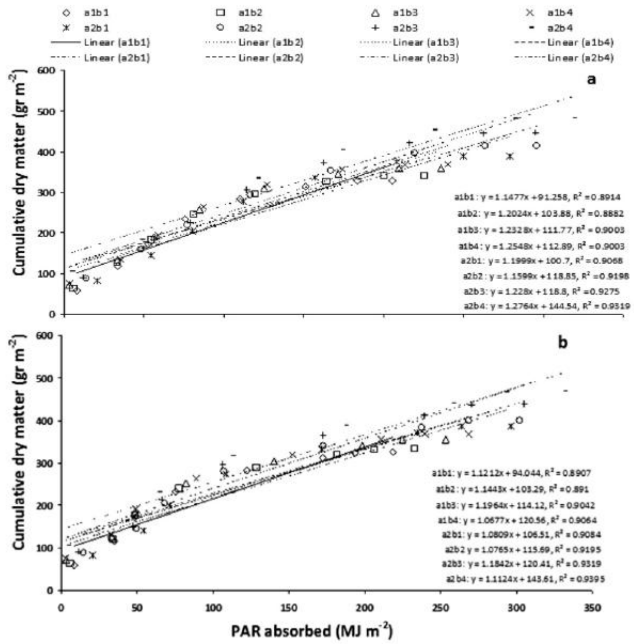

Fig. 7. Relationships between cumulative dry matter (gr m^{-2}) and absorbed PAR by the crop canopy (MJ m^{-2}) across 2010 (a) and 2011 (b) growing seasons. (a: cultivated bulb weight, a1: 10-20 g and a2: 20-30 g. b: nitrogen application rate, b1: control, b2: 200 kg ha^{-1}, b3: 250 kg ha^{-1} and b4: 300 kg ha^{-1})

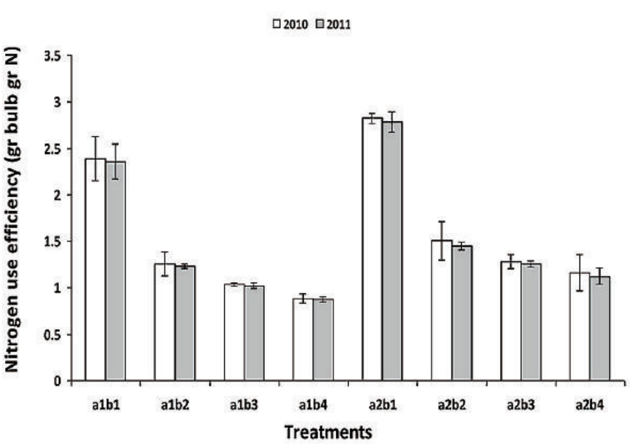

Fig. 8. ersian shallot nitrogen-use efficiency as affected by different nitrogen application rate and cultivated bulb weight (There are no significant differences between averages with similar overlap range according to standard division). (a: cultivated bulb weight, a1: 10-20 g and a2: 20-30 gr. b: nitrogen application rate, b1: control, b2: 200 kg ha^{-1}, b3: 250 kg ha^{-1} and b4: 300 kg ha^{-1}).

gen significantly enhanced the leaf area expansion, crop growth rate, and radiation-use efficiency (19% increase) while reducing nitrogen-use efficiency. Most of the medicinal and/or new crops did not indicate a direct response to increasing nitrogen application (Aroiee and Omidbaigi 2004; Csizinszky 2000). Such response to high nitrogen application as declining the production of wild species or landraces of new crops is due to imbalance on vegetative and reproductive stages duration and changes in carbon allocation to reproductive organs (Csizinszky 2000; Omer 1999). It should be also considered that the response of the plant to nitrogen application is often evaluated by the economic organ and utilization

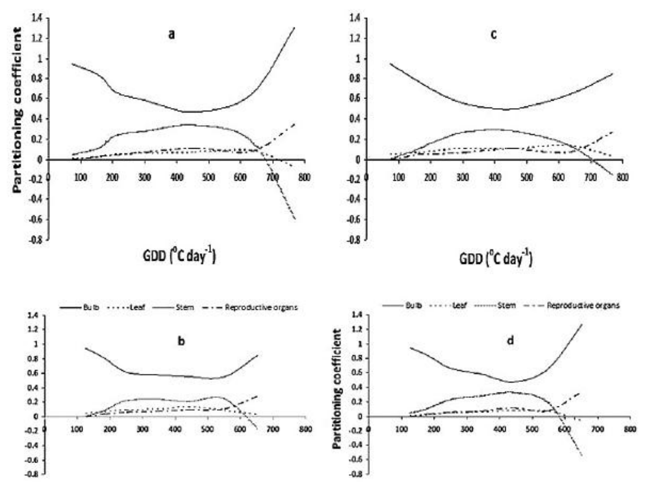

Fig. 9. Time trend of partitioning coefficients of the different organs of Persian shallot under nitrogen limited (a: 2010 and b: 2011) and unlimited conditions (c: 2010 and d: 2011)

of the plant product. In addition, response of new crops or wild species of medicinal plants is species-specific. For instance, increasing nitrogen application from 100 to 225 kg ha^{-1} showed positive effects on fresh weight and oil content of Japanese mint (*Mentha arvensis* L.), peppermint (*Mentha piperita* L.), and spearmint (*Mentha spicata* L.) (Singh et al. 1989). Very high (up to 150 kg ha^{-1}) application of nitrogen decreased the oil production though it increased the fresh weight of all mint species (Singh et al. 1989). On the other hand, Sreevalli et al. (2004) found that increasing nitrogen application from 0 to 150 kg ha^{-1} showed a 160 and 49% increase in leaf yield and leaf alkaloid content, respectively, in Periwinkle (*Catharanthus roseus* L.). Increasing nitrogen fertilizer application showed 27% enhancement of growth rate of thyme (*Thymus vulgaris* L.) plants (Shams et al. 2012). Some reports showed that increasing nitrogen application consequently enhanced the radiation-use efficiency in different crops (Sinclair and Muchow 1999). In addition, Muurinen and Peltonen-Sainio (2006) found a positive correlation between nitrogen application and radiation-use efficiency, especially in old spring cereals varieties in northern growing conditions.

A negative relationship between nitrogen application rate and nitrogen-use efficiency is well documented under different conditions due to volatilization, denitrification, and leaching of nitrogen (Cassman et al. 2002). Prakasa et al. (1998) showed that increasing the nitrogen application rate from 80 kg ha^{-1} decreased the nitrogen-use efficiency in davana (*Artemisia pallens*) plants. Furthermore, increasing nitrogen application from 40 to 80 kg ha^{-1} caused a 67% decrease in nitrogen-use efficiency of palmarosa (*Cymbopogon martinii* (Roxb.) Wats) (Rajeswara Rao 2001).

Increasing cultivated bulb weight increased the yield and growth parameters of Persian shallot in both years of this study. It seems that the application of heavier bulbs increased the carbon availability during early growth and allowed the plant to produce more leaves and consequently, a higher rate of photosynthesis. Increasing the cultivated bulb weight from 10 to 20 g showed a 50% increase in bulb yield of onion due to an increase in the crop's growth rate and growing season duration of onion (Mosleh-Deen 2008).

Generally, limited nitrogen availability during the growth season and carbon availability of Persian shallot increased the carbon allocation to underground organs (bulbs) especially during the end of the growth season due to remobilization of carbon from aboveground organs (stem and leaves). Increasing of applied nitrogen to more than 200 kg ha^{-1} improved the carbon partitioning to vegetative organs by 207 and 27% in contrast to applications of 0 and 112 kg ha^{-1} in switchgrass (*Panicum virgatum* L.) (Ma et al. 2001).

In conclusion, high nitrogen application (300 kg ha^{-1}) and cultivated bulb weight (20 - 30 g) would be a suitable management practice for enhancing Persian shallot bulb yield and plant growth for utilization in food industries. However, more studies are necessary to evaluate the effects of nitrogen application on essential oil and medicinal characteristics of Persian shallot. In addition, assessing the nitrate concentration amount in plant tissues and nitrogen partitioning to different organs may give a better overview from Persian shallot response to nitrogen application rate.

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