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Effect of nitrogen application on growth and yield of pumpkin

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ABSTRACT

Evaluation of any crop response to different nitrogen amounts is important for determining the amount that can be considered as optimum from economical and environmental point of view. This study was conducted to (1) evaluate the growth and yield of pumpkin (*Cucurbita pepo* L.) under different nitrogen rates and (2) determine the nitrogen use efficiency (NUE) of pumpkin in two growing seasons (2013 and 2014). In both growing seasons, nitrogen fertilizer (at three rates including 50, 150, and 250 kg ha^{-1}) was band-dressed on the planted side of each furrow, coinciding with 4–6 leaves stage and flowering. Crop performance over 2 years was evaluated by measuring shoot dry matter, crop growth rate (CGR), leaf area index (LAI), leaf area duration (LAD), intercepted PAR (PAR_i), radiation use efficiency (RUE), shoot nitrogen uptake, water use efficiency (WUE), NUE, and fruit and seed yield. The results showed that in both growing seasons, the highest growth and yield of pumpkin were obtained by applying 250 kg N ha^{-1} (using urea fertilizer containing 46% nitrogen). Increased nitrogen rate from 50 to 250 kg ha^{-1} resulted in 87.3%, 27.0%, 62.1%, 87.5%, and 84.5% increase in shoot dry weight, RUE, WUE, fruit yield, and seed yield of pumpkin, respectively, across both growing seasons. However, higher application nitrogen rate decreased the NUE of pumpkin, i.e., the NUE decreased by 62.5% when the nitrogen rate increased from 50 to 250 kg ha^{-1}. The effect of nitrogen applied in 2014 growing season on growth and yield of pumpkin was higher than that in 2013 growing season, which might be due to more suitable weather condition. In conclusion, the nitrogen rate of 250 kg ha^{-1} produced the highest amount of fruit and seed yield in pumpkin.

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radiation use efficiency; water use efficiency; nitrogen use efficiency; weather variation

Introduction

Medicinal plants are in use by many people in developing countries, considering their low costs, effectiveness, the frequently inadequate provision of modern medicine, and cultural and religious preferences (Bannayan, Eyshi Rezaei, and Alizadeh 2011). Pumpkin (*Cucurbita pepo* L.) is an economically important medicinal plant and is cultivated throughout the world for oil and medicinal purposes (Fu, Shi, and Li 2006), and its importance as an economical and medicinal plant is becoming increasingly apparent. It is rich in nutrients and bioactive compounds such as phenolics, flavonoids, vitamins, amino acids, carbohydrates, and minerals (especially potassium), and it is low in energy content (about 17 Kcal/100 g of fresh pumpkin) and has large amount of fiber (Tamer et al. 2010). It has various medicinal effects comprising antidiabetic, antihypertensive, antitumor, antimutagenic, immunemodulating, antibacterial, antihypercholesterolemic, intestinal antiparasitic, antalgic, and anti-inflammation effects (Kostalova, Hromadkova, and Ebringerova 2009). Young and mature fruits and seed of pumpkin are edible and utilized as vegetables (Oloyede, Adebooye, and Obuotor 2014). Pumpkin fruits are

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extensively used as vegetable, at both immature and mature stages. The immature fruits, called courgettes, are eaten as a vegetable, boiled, fried, or stuffed. Mature fruits, called pumpkin, are used peeled and cooked or prepared as pumpkin pie (Oloyede et al. 2012). Seeds of pumpkin have long been used as a medicine for various ailments, particularly, as a treatment against worms (Bannayan, Eyshi Rezaei, and Alizadeh 2011). In Eritrea, Sudan, and Ethiopia, pumpkin seeds are used to treat tapeworm, when the dried seeds are eaten on an empty stomach. For many years, particularly in Europe, extracts from pumpkin seeds have been used in folk medicine as a remedy for micturition caused by Benign Prostatic Hyperplasia. Pumpkin is used for treating helminth and as a medicine to reduce the bad cholesterol (Bannayan, Eyshi Rezaei, and Alizadeh 2011).

Crop yield is the result of the interactions between genotype (cultivar characteristics), environment (climate and soil conditions), and management (Jing et al. 2008). The growth and yield of food and feed crops in a given habitat are controlled by the soil and weather conditions as the main environmental factors (Mathe-Gaspar et al. 2005). Among the 17 plant nutrients, nitrogen (N) plays the most important role in augmenting agricultural production (Aulakh and Malhi 2005). Since nitrogen is consumed in the largest quantity of all the minerals during growth and development of most crops (Zhang et al. 2012) and is a component of protein and nucleic acid, when lower than optimal level, it reduces the plant growth (Sepaskhah and Barzegar 2010). Therefore, adequate N availability during crop growth and development must be ensured to obtain high yields and maximum profits (Elia and Conversa 2012). Nitrogen affects production through different mechanisms. High crop growth rates (CGRs) are largely due to high leaf area index (LAI) and/or high radiation use efficiency (RUE, dry matter produced per unit of either incident radiation or intercepted radiation) (Lawlor 1995). A sufficient application of nitrogen results in a rapid expanse of leaf canopy, enabling plants to intercept more solar radiation and thus resulting in higher photosynthesis and RUE (Mokhtassi-Bidgoli et al. 2013). Elia and Conversa (2012) studied the agronomic and physiological responses of a tomato crop to nitrogen input. These authors concluded that N supply positively affected LAI and RUE of tomato. Similarly, Justes et al. (2000) found that the maximum possible RUE (RUE_{max}) in winter oilseed rape was obtained by applying 270 kg N ha^{-1} (N_{270}), where N was non-limiting. They also reported that N deficiencies that occurred for N_0 and N_{135} significantly reduced the green LAI, and consequently $\sum PAR_i$.

N fertilization may also increase water use efficiency (WUE) by stimulating dry matter production (Latiri-Souki, Nortcliff, and Lawlor 1998), through a more rapid growth and improved transpiration efficiency (Morell et al. 2011). An increase in LAI may reduce soil evaporation, thus offsetting the increased water loss through the plant transpiration, and depending on the relative importance of these processes, the WUE may be improved (Latiri-Souki, Nortcliff, and Lawlor 1998). The increase in WUE, as consequence of N fertilization, has been reported by several studies for different crops (Latiri-Souki, Nortcliff, and Lawlor 1998; Albrizio et al. 2010; Morell et al. 2011). However, the nitrogen use efficiency (NUE) typically decreases with progressively greater application rates of nitrogen fertilizer (Hamzei and Soltani 2012). The decrease in NUE as consequence of N fertilization was reported by several authors (Latiri-Souki, Nortcliff, and Lawlor 1998; Albrizio et al. 2010), and it is attributed to the fact that crop yield rises less than the N supply in soil and fertilizer (Lopez-Bellido and Lopez-Bellido 2001).

The goals of this study are (i) to measure the growth and yield of pumpkin under different nitrogen treatments and (ii) to determine the NUE along an array of nitrogen application.

Materials and methods

Field experiments

Field experiments, were carried out in two years (2013 and 2014) at research farm of Ferdowsi university of Mashhad, Iran (latitude 36° 16′ N, longitude 59° 38′ E, elevation 999 m, annual average of minimum temperature 8.3°C, annual average of maximum temperature 21.6°C, and total precipitation of 256.5 mm; Bannayan and Sanjani 2011). The monthly weather data during the pumpkin growth season for 2 years are presented in Table 1.

Table 1. Monthly weather data during 2013 and 2014 growing seasons, Mashhad, Iran.

Year	Month	T_{avg} (°C)[a]	T_{max} (°C)	T_{min} (°C)	$P_{(mm)}$	RH_{avg} (%)	R_s (MJ m^{-2} d^{-1})
2013	May	20.9	28	13.6	26.8	31.5	24.3
	June	26.7	33.9	19.5	0.4	22.1	25.9
	July	28.7	36.1	21.3	0	22	26.8
	August	25.9	33	18.8	2.4	25.4	24
2014	May	22.9	30.2	15.5	27.1	27.4	23.5
	June	27.1	34.8	19.3	4	20.3	26.5
	July	28	35.6	20.3	0	15	27.2
	August	27.4	35.5	19.3	0	15.3	25.1

[a]T_{avg}, T_{max}, and T_{min} are average, maximum, and minimum temperatures, respectively, P is monthly total precipitation, RH_{avg} is monthly average of relative humidity, and R_s is monthly average of solar radiation.

Table 2. The physicochemical properties of the experimental soil for 2013 and 2014 growing seasons.

Soil parameters	2013	2014
Texture	Silty-loam	Silty-loam
Bulk density (g cm^{-3})	1.40	1.40
pH	8.11	7.43
EC (dS m^{-1})	1.34	1.66
Organic C (%)	0.67	0.62
Total N (%)	0.065	0.080
Available P (mg kg^{-1})	12	22
Available K (mg kg^{-1})	224	185

In both years, before preparation of the seed bed, six soil samples were taken randomly from 0 to 20 cm depth by a 4-cm diameter auger, and the mixed sample was used for soil analysis. The results of soil analysis for 2 years are showed in Table 2. The seed bed preparation was carried out using the common practices (including plow, disk and leveler), and pumpkin plants were sown on 6 May at a density of 2.5 plant m^{-2}. The plot size was 15 m × 5 m, and in each plot, six planting lines with a 2-m row spacing and 0.5-m furrow between each line were considered. The first and sixth lines were considered as border rows, the second and fifth lines were used for destructive samplings during the growth cycle of pumpkin, and third and fourth lines were left without any changes for yield determination at harvest (Figure 1).

The furrow irrigation was employed in order to supply the water requirements of pumpkin plants, and first irrigation was carried out immediately after sowing and other irrigations were performed on weekly basis. During the growing season of pumpkin, weed control was performed by hand weeding. Treatments included three levels of nitrogen application (including 50, 150, and 250 kg ha^{-1} using urea fertilizer containing 46% nitrogen), which were arranged according to the design of completely

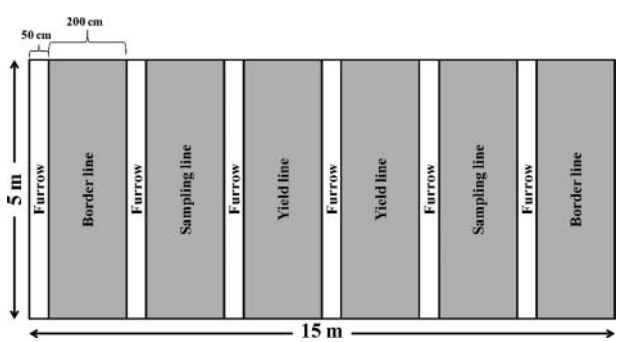

Figure 1. The arrangement of planting lines in each plot.

randomized blocks with four replications. In both years, the first portion of urea fertilizer (half of the total) was applied 4 weeks after sowing (coinciding with 4–6 leaf stage), and the second fertilization (the second half) was applied 6 weeks after sowing (coinciding with flowering stage). In order to apply nitrogen after irrigation, the urea fertilizer was band-dressed on the planted side of each furrow.

Five destructive samplings were carried out during the crop growth cycle, starting from 30 days after planting, and others were taken 42, 56, 70, and 77 days after planting. Sampling was arranged to coincide with developmental stages of pumpkin. In each sampling, three plants were randomly harvested from second and fifth lines of each plot, and after measuring the green leaf area by a leaf area meter (LI-3100C; LI-COR, USA), the shoot of each plant was dried at 75°C for 72 hr. After drying, the shoot samples were weighed using a digital balance with accuracy of 0.001 g. Then, the average of three plants harvested from each plot was considered for that plot, and the average of four replications of each treatment was recorded for corresponding treatment. At each sampling, the CGR, LAI, and leaf area duration (LAD) were determined using Eqs. (1)–(3), respectively:

$$CGR\ (\mathrm{g\ m^{-2}\ day^{-1}}) = \frac{DM_2 - DM_1}{t_2 - t_1} \tag{1}$$

$$LAI = \frac{LA}{GA} \tag{2}$$

$$LAD\ (\mathrm{m^2.day}) = \left(\frac{LA_1 + LA_2}{2}\right) \times (t_2 - t_1) \tag{3}$$

where DM_2 and DM_1 are primary and secondary shoot dry matter (g m^{-2}), t_2 and t_1 are primary and secondary sampling time (day), LA and GA are leaf area (m^2) and ground surface area (m^2), and LA_1 and LA_2 are primary and secondary leaf area (m^2), respectively. Furthermore, the growing degree day (GDD) during the growth cycle of pumpkin was calculated by the following equation:

$$GDD = \sum \left(\frac{T_{\max} + T_{\min}}{2}\right) - T_b \tag{4}$$

where T_{max} and T_{min} are daily maximum and minimum air temperature, and T_b is base temperature of pumpkin (T_b=10°C; Smith 1997). If $[(T_{max}+T_{min})/2] < T_b$, then $[(T_{max}+T_{min})/2] = T_b$ (McMaster and Wilhelm 1997).

At the end of pumpkin growth cycle, when fruits become dark orange-colored, the shoot of all plants reserved for final harvest were completely removed, and fruit yield and seed yield were measured.

Radiation use efficiency (RUE)

During the growth season of pumpkin from 30 to 77 days after sowing (DAS) and coinciding with destructive samplings, photosynthetically active radiation (PAR) above and below the canopy was measured at the rows devoted for final harvest yield using a ceptometer with 90-cm line probe (AccuPAR LP-80; Pullman, Washington, USA). The measurements were taken on clear days between 10:30 AM and 1:30 PM with three replications per plot. The fraction of photosynthetically active radiation intercepted by the canopy ($f_{i\text{-}PAR}$) for a particular day was calculated with the following equation:

$$f_{i-PAR} = 1 - \left(\frac{PAR_t}{PAR_0}\right) \tag{5}$$

where PAR_t is the PAR measured at ground level (μmol m^{-2} s^{-1}) and PAR_0 is the PAR at the top of the canopy (μmol m^{-2} s^{-1}) (Hamzei and Soltani 2012).On days when $f_{i\text{-}PAR}$ was not directly measured, it was estimated by linear interpolation between measured values (Fletcher et al. 2013). The Angstrom model [Eq. (6)] was employed in order to calculate the global solar radiation (R_s) (Pohlert 2004) for a

particular day using daily sunshine hours.

$$R_s = R_a\left(A + B\left(\frac{n}{N}\right)\right) \tag{6}$$

where R_s is daily global solar radiation (MJ m^{-2} d^{-1}), R_a is daily extra-terrestrial radiation (MJ m^{-2} d^{-1}), A and B are empirical coefficients (for Mashhad, A = 0.3 and B = 0.37; Ameri and Nassiri-Mahallati 2009), n is sunshine duration (hr), and N is the daylength (hr) (Pohlert 2004). Global solar radiation was multiplied by 0.45 to obtain global PAR. Then, daily global PAR values were multiplied by corresponding daily $f_{i\text{-PAR}}$ values to compute daily intercepted PAR (PAR_i) (Pradhan et al. 2014). Finally, RUE for each treatment was calculated as the ratio between shoot dry matter and cumulative intercepted PAR [Eq. (7)] (Sadras et al. 2012).

$$RUE = \frac{\text{Shoot dry matter (g m}^{-2})}{\text{Cumulative intercepted } PAR \text{ (MJ m}^{-2})} \tag{7}$$

Nitrogen uptake and nitrogen use efficiency (NUE)

In order to determine the nitrogen content of plant shoots, the dried samples were ground finely to less than 1 mm and digested in a mixture of concentrated sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2) (Zhou, Wang, and Fei 2011). The nitrogen content of digests was measured based on the Kjeldahl method in four samples per treatment. The nitrogen content of shoots was expressed on the basis of dry matter (%). Furthermore, the nitrogen uptake of plant samples (g m^{-2}) was estimated by multiplying dry matter weights in their nitrogen concentrations (%). From pooled experimental data of both growing seasons, power N dilution curves (%N= a × DW^{-b}) were fitted between shoot dry weight (DW, g m^{-2}) and shoot N concentration (%) as independent and dependent variables, respectively (Elia and Conversa 2012). NUE was calculated for each treatment by the ratio of pumpkin fruit yield to nitrogen fertilizer supply (50, 150, and 250 kg N ha^{-1}) (Gholamhoseini et al. 2013).

Water use efficiency (WUE)

Crop evapotranspiration (ET_c) was measured weekly using the water balance approach, based on the following equation (Gallardo et al. 2011):

$$ET_c = (SWC_{t0} - SWC_{t1}) + I + P \tag{8}$$

where (SWC_{t0}-SWC_{t1}) is the change in volumetric soil water content between two measurement dates (t0 and t1), I and P are the total volume of applied irrigation and precipitation for the weekly period (Gallardo et al. 2011). Water losses due to runoff and leaching were assumed to be negligible (Cantero-Martinez, Angas, and Lampurlanes 2003). For measuring the volumetric soil water content (SWC), the soil samples were taken using a 4-cm diameter soil auger, before and after each irrigation. At each sampling, two samples per plot were taken from 0 to 20 cm depth. Soil samples were dried in an oven at 105°C for 48 hr, and gravimetric water content (GWC) in a % basis was calculated by the following equation:

$$GWC = \left(\frac{MWS - MDS}{MDS}\right) \times 100 \tag{9}$$

where MWS and MDS are the mass of wet soil (g) and the mass of dry soil (g), respectively. Then, SWC was computed from GWC and bulk density (BD) of soil, assuming a 200-mm (20 cm) sampling depth

[Eq. (10)] (Morell et al. 2011).

$$SWC = GWC \times BD \times 200 \tag{10}$$

The WUE, in g mm^{-1} m^{-2}, was calculated as the amount of shoot dry matter per mm of water used (ET_c) (Morell et al. 2011), based on the following equation:

$$WUE\ (\text{g mm}^{-1}\ \text{m}^{-2}) = \frac{\text{Shoot dry matter (g m}^{-2})}{\text{Cumulative } ET_c\ (\text{mm})} \tag{11}$$

Statistical analysis of data

Analysis of variance (ANOVA) was performed using the GLM Procedure of SAS 9.0 software (SAS, Cary, NC). The mean comparison of main and interaction effects was carried out using the least significant difference (LSD) test by considering $p \leq 0.05$ as the significant level. The regression analysis was carried out by SigmaPlot 11.0 software. The parameter estimation of the non-linear power N dilution equations was obtained with the NLIN Procedure of SAS software using the Gauss-Newton method (Elia and Conversa 2012), and the quality of the regressions was assessed by the determination coefficient (R^2) of linear regression between observed and simulated values.

Results and discussion

Leaf area index (LAI) and duration (LAD)

In both growing seasons, nitrogen affected LAI and also, LAD. Increasing the nitrogen rate resulted in higher LAI and LAD (Figure 2 and 3). Nitrogen application significantly increased the maximum leaf area index (LAI_{max}) of pumpkin in both growing seasons (Figure 4). However, the relationship between nitrogen rate and LAI_{max} was quadratic (Figure 4), and maximum LAI of pumpkin increased up to a certain level of nitrogen application, and thereafter, more nitrogen application had no effect on LAI_{max} or even decreased it. The maximum LAI obtained from nitrogen treatments of 50, 150, and 250 kg ha^{-1} was 1.6, 2.5, and 3.1 for 2013 experiment and 1.7, 2.6, and 3.2 for 2014 experiment, respectively (Figure 2). The 2-year average of the maximum LAI for nitrogen rates of 50, 150, and 250 kg ha^{-1} also was 1.65, 2.55, and 3.15, respectively. Furthermore, the growing season average of LAD in nitrogen treatments of 50, 150, and 250 kg ha^{-1} was 8.3, 13.7, and 18.1 m^2 day^{-1} for 2013 experiment and 9.2, 14.6, and 19 m^2 day^{-1} for 2014 experiment, respectively (Figure 3). In addition, the 2-year average of LAD for treatments of 50, 150, and 250 kg N ha^{-1} was 8.75, 14.15, and 18.55 m^2 day^{-1}, respectively.

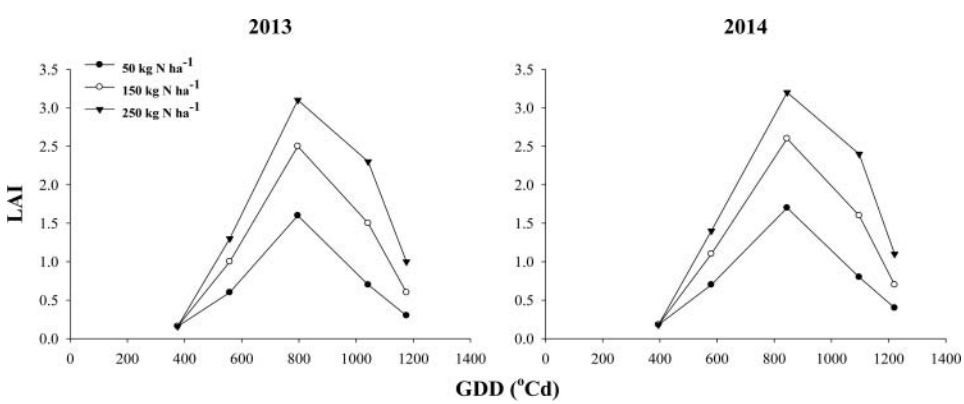

Figure 2. Effect of nitrogen application on leaf area index (LAI) of pumpkin during the growth period (GDD).

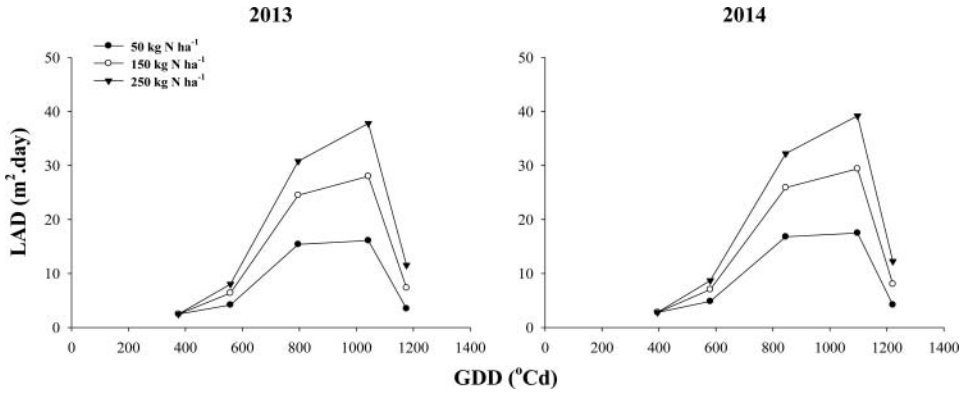

Figure 3. Effect of nitrogen application on leaf area duration (LAD) of pumpkin during the growth period (GDD).

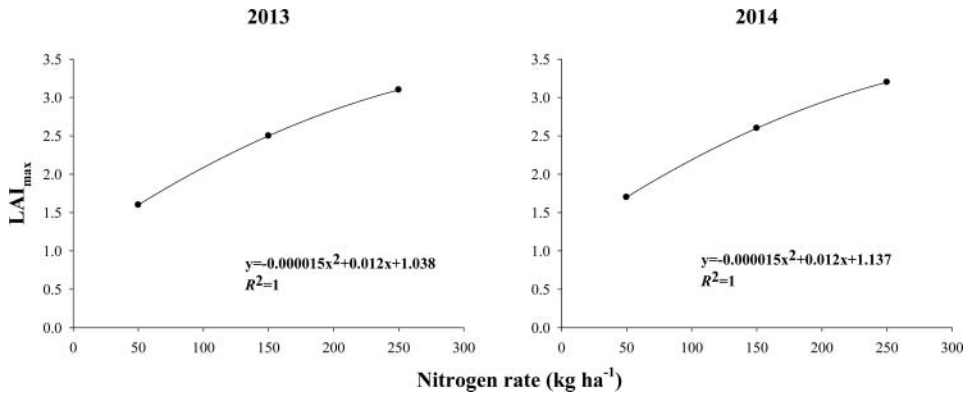

Figure 4. Relationship between nitrogen rate and maximum leaf area index (LAI_{max}) of pumpkin.

Similar to the results of Bourke (1985), the pattern of LAI development for both experiments was very similar to that of CGR, and LAI was highly correlated with CGR in both trials ($r = 0.92$, $p \leq 0.01$ for 2013 experiment and $r = 0.90$, $p \leq 0.01$ for 2014 experiment).

Regression analysis showed a strong linear relationship between LAI of pumpkin and its shoot dry matter during vegetative phase of pumpkin growth life cycle in both growing seasons ($R^2 = 0.97$, $p \leq 0.01$ for 2013 trial and $R^2 = 0.96$, $p \leq 0.01$ for 2014 trial) (Figure 5). This means that increased LAI during vegetative phase of pumpkin growth cycle resulted in increasing the shoot dry weight of this

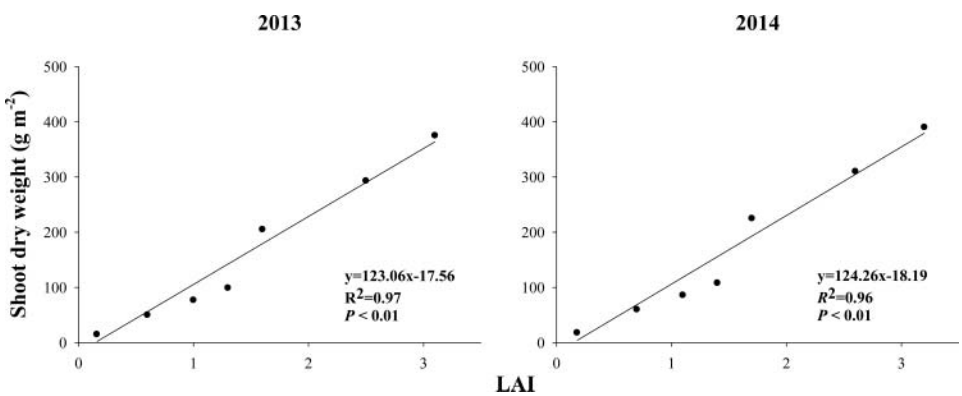

Figure 5. Relationship between leaf area index (LAI) and shoot dry weight during vegetative phase of pumpkin growth.

crop. LAI is the main physiological determinant of crop growth and yield (Hamzei and Soltani 2012). Thus, to increase biomass, a larger LAI and a longer duration for which LAI is maintained are required, which can be obtained by adding N fertilizer (Latiri-Souki, Nortcliff, and Lawlor 1998). Under nitrogen (N) shortage, leaf area expansion decreases and senescence increases (Massignam et al. 2011). This results in a reduction of crop LAI and LAD (Fletcher et al. 2013). Latiri-Souki, Nortcliff, and Lawlor (1998) reported that the nitrogen application increased LAI and green crop duration of durum wheat, thus increasing total dry matter, which resulted in improved radiation and WUE (Latiri-Souki, Nortcliff, and Lawlor 1998). Hamzei and Soltani (2012) reported that compared to low dose of N (8 g N m^{-2}), high (16 g N m^{-2}) and optimum (12 g m^{-2}) doses of N preserved green leaf tissues of rapeseed for a more extended period of time.

The maximum LAI and the growing season average of LAD for all treatments of 2014 experiment were higher than their corresponding treatments in 2013. By increasing the nitrogen rate from 50 to 150 kg ha^{-1} and from 150 to 250 kg ha^{-1}, the maximum LAI increased 56.2% and 24% for 2013 growing season and 52.9% and 23.1% for 2014 growing season, respectively. Furthermore, increasing the nitrogen rate from 50 to 150 kg ha^{-1} and from 150 to 250 kg ha^{-1} increased the maximum LAD by 73.9% and 35.0% for 2013 growing season and 68.0% and 33.3% for 2014 growing season, respectively. However, despite the equal increase in nitrogen rate (100 kg ha^{-1}), the slope of LAI and LAD increment by increasing the nitrogen level from 50 to 150 kg ha^{-1} was higher than the slope of LAI and LAD increment obtained by increase of nitrogen rate from 150 to 250 kg ha^{-1}. In other words, by increasing the nitrogen rate from 150 to 250 kg ha^{-1}, the impact intensity of nitrogen application decreased in comparison with increment of nitrogen rate from 50 to 150 kg ha^{-1}.

Intercepted PAR (Par_i) and radiation use efficiency (RUE)

In both growing seasons, the fraction of intercepted PAR_i ($f_{i\text{-}PAR}$) (Figure 6) and the RUE (Figure 8) of pumpkin showed an increasing trend up to 796°Cd in 2013 experiment and up to 845°Cd in 2014. The pattern of changes in $f_{i\text{-}PAR}$ and RUE was similar to that of LAI, and these two traits ($f_{i\text{-}PAR}$ and RUE) were highly correlated with LAI in both growing seasons ($r = 0.95$, $p \leq 0.01$ for $f_{i\text{-}PAR}$ vs. LAI and $r = 0.86$, $p \leq 0.01$ for RUE vs. LAI in 2013 trial; $r = 0.96$, $p \leq 0.01$ for $f_{i\text{-}PAR}$ vs. LAI and $r = 0.89$, $p \leq 0.01$ for RUE vs. LAI in 2014 trial). Previous studies also showed that the fraction of intercepted PAR is highly correlated with LAI (Williams et al. 2003; de Medeiros et al. 2001). The maximum $f_{i\text{-}PAR}$ and the maximum RUE during both growing seasons were obtained at flowering stage and then, both traits decreased. However, across all treatments and in both years, the $f_{i\text{-}PAR}$ and RUE during reproductive phase were higher than those of vegetative phase. For example, in 2014, the average of $f_{i\text{-}PAR}$ and RUE for nitrogen treatment of 250 kg ha^{-1}during 21 days before flowering was 1.68 g MJ^{-1} and 0.61 versus 1.94 g MJ^{-1} and 0.73 during 21 days after flowering, respectively. This study showed that there was a difference between various developmental stages of pumpkin regarding their fraction of intercepted

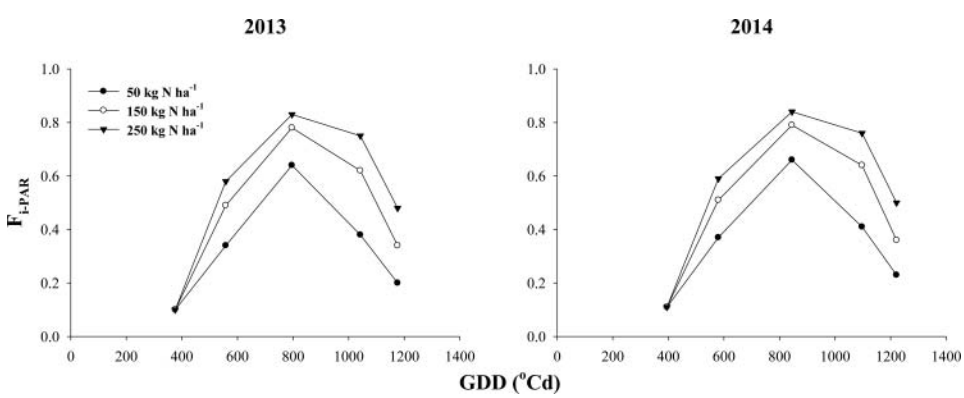

Figure 6. Effect of nitrogen application on fraction of intercepted PAR ($f_{i\text{-}PAR}$) by pumpkin during the growth period (GDD).

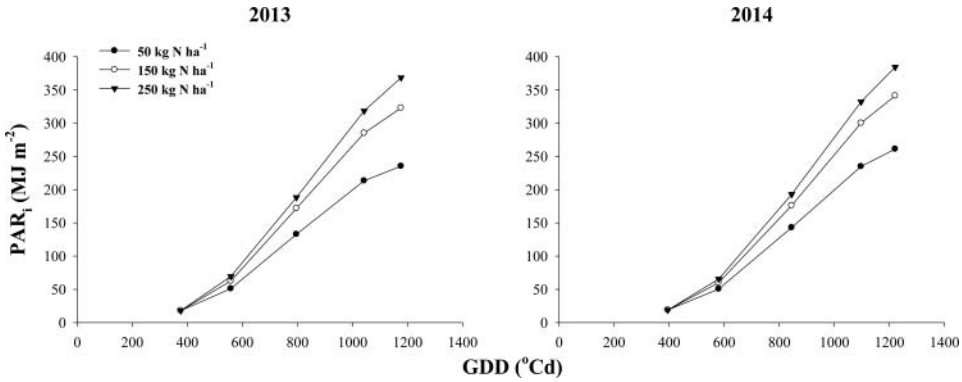

Figure 7. Effect of nitrogen application on PAR intercepted (PAR_i) by pumpkin during the growth period (GDD).

PAR ($f_{i\text{-}PAR}$) and RUE. Hence, considering a constant value for pumpkin RUE during its whole growth cycle seems not to be true, especially for modeling purposes. Similarly, Rouphael and Colla (2005) reported values of RUE for greenhouse-grown pumpkin (*C. pepo* L.) that changed depending on crop development and cropping season. These authors reported higher values of RUE for reproductive growth (2.5 and 4.2 g MJ^{-1} PAR for the summer and autumn crops, respectively) than for vegetative growth (2.0 and 2.2 g MJ^{-1} PAR for the summer and autumn crops, respectively).

Nitrogen application affected the fraction of intercepted PAR ($f_{i\text{-}PAR}$) (Figure 6), cumulative intercepted PAR (PAR_i) (Figure 7), and RUE (Figure 8) of pumpkin in both growing seasons. At all samplings performed after the nitrogen application, increased N rate has resulted in increasing the $f_{i\text{-}PAR}$ (Figure 6), PAR_i (Figure 7) and RUE (Figure 8), in both years. Accordingly, the maximum $f_{i\text{-}PAR}$ and the maximum RUE in 2013 growing season were 0.64 and 1.54 g MJ^{-1} for treatment of 50 kg N ha^{-1}, 0.78 and 1.70 g MJ^{-1} for treatment of 150 kg N ha^{-1}, and 0.83 and 1.99 g MJ^{-1} for treatment of 250 kg N ha^{-1}, respectively, and the maximum $f_{i\text{-}PAR}$ and RUE in 2014 growing season were 0.66 and 1.57 g MJ^{-1} for treatment of 50 kg N ha^{-1}, 0.79 and 1.76 g MJ^{-1} for treatment of 150 kg N ha^{-1}, and 0.84 and 2.02 g MJ^{-1} for treatment of 250 kg N ha^{-1}, respectively. Furthermore, the cumulative intercepted PAR at 77 DAS for treatments of 50, 150, and 250 kg N ha^{-1} was 235.4, 322.9 and 368.5 MJ m^{-2}, respectively, in 2013 growing season versus 261.1, 341.2, and 384.4 MJ m^{-2}, respectively, in 2014 growing season (Figure 7). Thus, in both growing seasons, the maximum amount of $f_{i\text{-}PAR}$, PAR_i and RUE in treatment of 250 kg N ha^{-1} was higher than that of the two other treatments. The 2-year average of maximum $f_{i\text{-}PAR}$ and RUE was 0.650 and 1.550 g MJ^{-1} for nitrogen rate of 50 kg ha^{-1}, 0.785 and 1.730 g MJ^{-1} for nitrogen rate of 150 kg ha^{-1}, and 0.835 and 2.005 g MJ^{-1} for treatment of 250 kg N ha^{-1}, respectively.

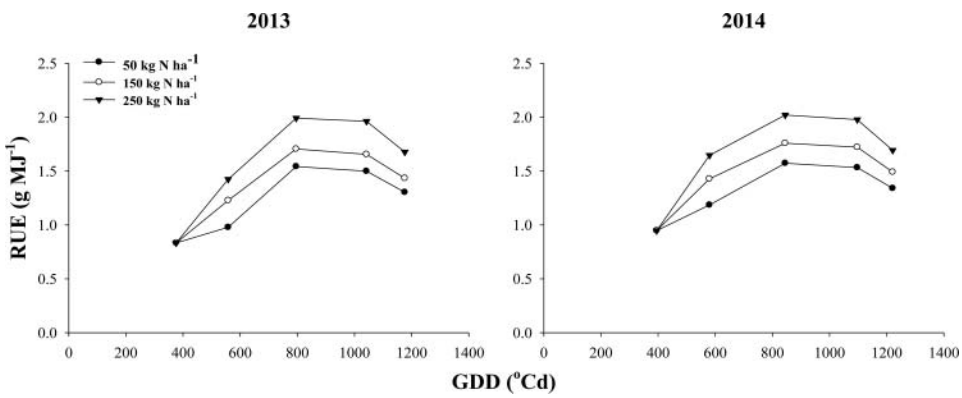

Figure 8. Effect of nitrogen application on radiation use efficiency (RUE) of pumpkin during the growth period (GDD).

Variation in dry matter production in response to N availability could rise from differences in the amount of cumulative intercepted radiation by the canopy, the RUE, and the partitioning between different organs (Hamzei and Soltani 2012). A large number of studies reported the positive effect of nitrogen application on LAI development, PAR interception, and RUE. Di-qin et al. (2012) found a positive linear relationship between RUE of rice and amount of applied N with a certain N applying range. Elia and Conversa (2012) reported that N supply positively affected LAI, RUE, aboveground dry weight, and N accumulation in tomato. Hamzei and Soltani (2012) found that $\sum PAR_i$ of rapeseed was significantly affected by N treatment, averaging 1897 μmol m^{-2} under LN treatment (8 g N m^{-2}) compared with 2179 μmol m^{-2} under HN treatment (16 g N m^{-2}).

Higher LAI and cumulative solar radiation during 2014 growing season resulted in greater PAR interception compared to 2013 (Figure 7). Shoot dry matter produced in both growing seasons was highly correlated with intercepted PAR ($r = 0.98$, $p \leq 0.01$ for 2013 trial and $r = 0.98$, $p < 0.01$ for 2014 experiment). There is a close linkage between the amount of radiation received by a crop and its growth (Bonhomme 2000). Crop growth under field conditions depends on the ability of the canopy to intercept the incoming radiation, which is a function of LAI and canopy architecture, and on its conversion into biomass (Gifford et al. 1984). The total intercepted PAR over the crop season is an important determinant of production of any crop (Monteith 1981). Increased interception of radiation is the main driving force for the increased crop biomass (Monteith 1981; Latiri-Souki, Nortcliff, and Lawlor 1998). Thus, a greater shoot dry matter produced in 2014 growing season was due to its higher intercepted PAR and also, its greater RUE compared to 2013 growing season. Previous studies also showed that a higher dry matter production thus results from more solar radiation being intercepted, higher RUE, or a combination of the two (Willey 1990).

Water use efficiency (WUE)

WUE of pumpkin was strongly correlated with pumpkin shoot dry matter ($r = 0.97$, $p \leq 0.01$ for both trials). In both growing seasons, the WUE of pumpkin increased by increasing nitrogen application (Figure 9). Accordingly, the maximum WUE during pumpkin growth cycle for treatments of 50, 150, and 250 kg N ha^{-1} was 0.89, 1.23, and 1.51 g m^{-2} mm^{-1} in 2014, respectively. In 2013, the respective values were 0.93, 1.26, and 1.49 g m^{-2} mm^{-1} (Figure 9). Thus, the 2-year average of the maximum WUE for nitrogen rates of 50, 150, and 250 kg ha^{-1} was 0.910, 1.245, and 1.500 g m^{-2} mm^{-1}, respectively. There was a strong and significant correlation between pumpkin WUE with RUE and intercepted PAR (PAR_i) in both growing seasons ($r = 0.93$, $p \leq 0.01$ for RUE and $r = 0.94$, $p \leq 0.01$ for PAR_i, in 2013 growing season, $r = 0.88$, $p \leq 0.01$ for RUE and $r = 0.93$, $p \leq 0.01$ for PAR_i, in 2014 growing season). Thus, higher WUE due to increased nitrogen application can be associated to an increase in shoot dry matter production through greater PAR interception and higher RUE. Adamtey et al. (2010) reported that WUE of maize crop increased as N application rate increased. They

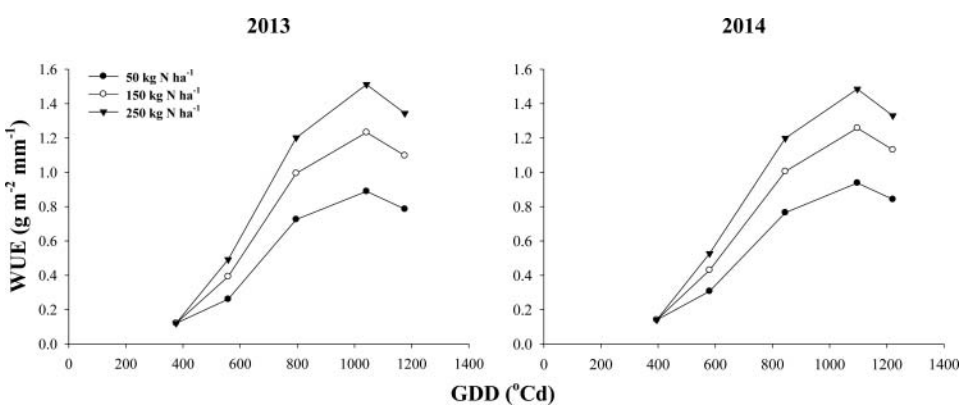

Figure 9. Effect of nitrogen application on water use efficiency (WUE) of pumpkin during the growth period (GDD).

concluded that higher water use efficiency, at higher application of N can be attributed to high nutrient uptake, transpiration efficiency, and low leaf senescence.

Dry matter accumulation

In both years, the shoot dry weight of pumpkin increased with increase in the rate of nitrogen application (Figure 10). Similarly, in both growing seasons, the highest shoot dry weight of pumpkin in all samplings performed after the nitrogen application (from 358° Cd thereafter for 2013 and from 382°Cd thereafter for 2014) obtained from treatment of 250 kg N ha^{-1}. A great number of studies have reported the positive and linear association between shoot dry weight of crops and vegetables such as sweet potato (Bourke 1985), winter oilseed rape (Justes et al. 2000), wheat (Albrizio et al. 2010), tomato (Elia and Conversa 2012), flixweed (Mokhtassi-Bidgoli et al. 2013), onion (Buckland et al. 2013), and maize (Wang, Li, and Li 2014) with nitrogen supply. Swiader, Sipp, and Brown (1994) studied the effect of various nitrogen-potassium (N-K) fertilizer treatments on pumpkin (*Cucurbita moschata* Poir.) growth and yield and concluded that in both years, the pumpkin dry-matter production increased as the amount of N application increased.

The maximum dry weight produced in treatments of 50, 150, and 250 kg N ha^{-1} was 320, 472, and 625 g m^{-2} for 2013 growing season and 360, 517, and 657 g m^{-2} for 2014 growing season, respectively (Figure 10), which was obtained at the mid-stage of fruit development. Therefore, the maximum shoot dry matter obtained from each nitrogen treatment in 2014 growing season was more than the maximum shoot dry weight produced in corresponding treatments of 2013 growing season. However, the 2-year average of pumpkin shoot dry weight for nitrogen rates of 50, 150, and 250 kg ha^{-1} was 340, 494 and 641 g m^{-2}, respectively. The shoot dry weight of pumpkin was increased up to 1042° cadmium (Cd) in 2013 growing season and up to 1097°Cd in 2014 growing season, and then, the shoot dry weight in both years was decreased due to leaves abscission (Figure 10). Thus, the duration of dry matter accumulation in 2014 experiment was 55°Cd higher than 2013 experiment, and this can be considered as one of the results for a greater shoot dry matter produced in 2014 growing season compared to 2013 growing season.

In both years, the CGR was also increased as the nitrogen application increased. At all samplings carried out after the nitrogen application (from 358°Cd thereafter for 2013 and from 382°Cd thereafter for 2014), the CGR of pumpkin in the nitrogen level of 250 kg ha^{-1} was maximum for both growing seasons. The growth rate of pumpkin was increased up to 796°Cd in 2013 growing season and up to 845°Cd in 2014 growing season, and then, the CGR decreased in both years at the late stages of pumpkin growth cycle. The maximum CGR during the growth cycle of pumpkin at nitrogen rates of 50, 150, and 250 kg ha^{-1} was 11.07, 15.43, and 19.71 g m^{-2} day^{-1} for year 2013 and 11.78, 16, and 20.14 g m^{-2} day^{-1} for year 2014, respectively. These high values were obtained at flowering stage. Furthermore, the

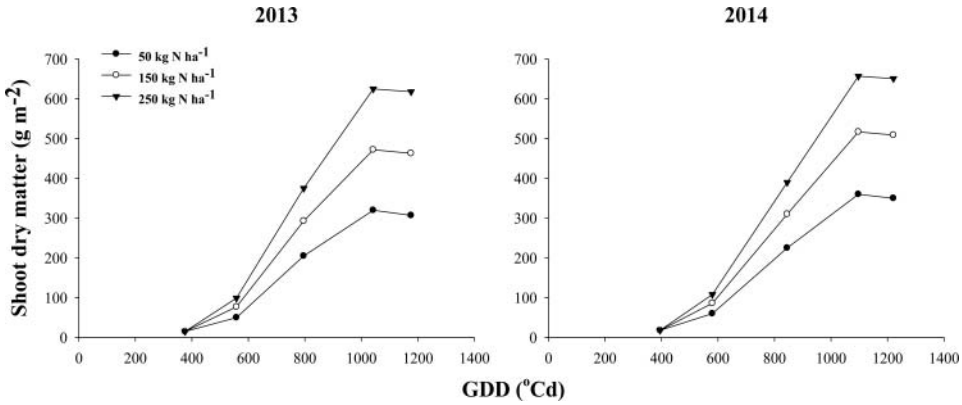

Figure 10. Effect of nitrogen application on shoot dry matter of pumpkin during the growth period (GDD).

growing season average of pumpkin growth rate for treatments of 50, 150, and 250 kg N ha^{-1} was 4.22, 6.61, and 8.94 g m^{-2} day^{-1} in 2013 experiment and 4.88, 7.28, and 9.42 g m^{-2} day^{-1} in 2014 trial, respectively. As shown, the maximum CGR and the growing season average of CGR for all treatments of 2014 experiment were greater than those of their corresponding treatments in 2013 experiment.

Increasing nitrogen availability in the root environment may increase the CGR (Bot, Adamowicz, and Robin 1998). Bourke (1985) by studying the influence of nitrogen and potassium fertilizer on growth of sweet potato (*Ipomoea batatas*) has concluded that N fertilizer increased CGR. The results of the current study also showed that nitrogen application has an important role in increasing the CGR and thus can increase the dry matter accumulation of shoot.

Biological yield is the product of growth rate and duration of the growing period (Diepenbrock 2000). The regression analysis showed that there was a positive and linear relationship between pumpkin growth rate and its shoot dry matter accumulation during vegetative phase of pumpkin growth cycle in both growing seasons ($R^2 = 0.98$, $p \leq 0.01$ for 2013 trial; $R^2 = 0.97$, $p \leq 0.01$ for 2014 trial) (Figure 11). Thus, a higher CGR can result in a higher shoot dry matter. Hence, a greater shoot dry weight observed in 2014 growing season can be due to a higher CGR and as shown previously, because of a longer duration of dry matter accumulation during this growing season compared to 2013 experiment.

Two factors can be considered for a higher CGR and also, a longer duration of dry matter accumulation during 2014 experiment compared to 2013. The first factor is that the background concentration of soil nitrogen in 2014 was higher than that in 2013 (Table 2). The total nitrogen of soil in 2014 was 0.08% compared to 0.06% in 2013 (Table 2). Nitrogen-deficient plants grow slowly, and their leaves are small. Nitrogen deficiency also decreases LAI, lowers RUE, and lowers photosynthesis activity in plants (Fageria 2009).

The second factor that can result in a greater CGR and a longer duration of dry matter accumulation in 2014 is the slightly higher temperature and solar radiation during this growing season. As shown in Table 1, the growing season average of mean temperature and solar radiation were 26.3°C and 25.6 MJ m^{-2} day^{-1}, respectively, in 2014 experiment, and 25.5°C and 25.2 MJ m^{-2} day^{-1}, respectively, in 2013 experiment. According to the regional field experiments, temperature, water requirement, and sunshine hours showed the highest influence on pumpkin growth, respectively (Bannayan, Eyshi Rezaei, and Alizadeh 2011). All developmental stages of pumpkin require high level of sunshine (Bannayan, Eyshi Rezaei, and Alizadeh 2011). The higher solar radiation due to the high level of natural light and long photoperiod was presumably responsible for the increased photosynthesis in the spring-summer with respect to the summer-fall growing season. The global radiation and temperature ranged from 12.2 to 22.5 MJ m^{-2} d^{-1} and 10.8 to 28.8°C, respectively, in the spring-summer versus 3.0 to 17.1 MJ m^{-2} d^{-1} and from 6.0 to 24.8°C, respectively, in the summer-fall growing season (Amer 2011).

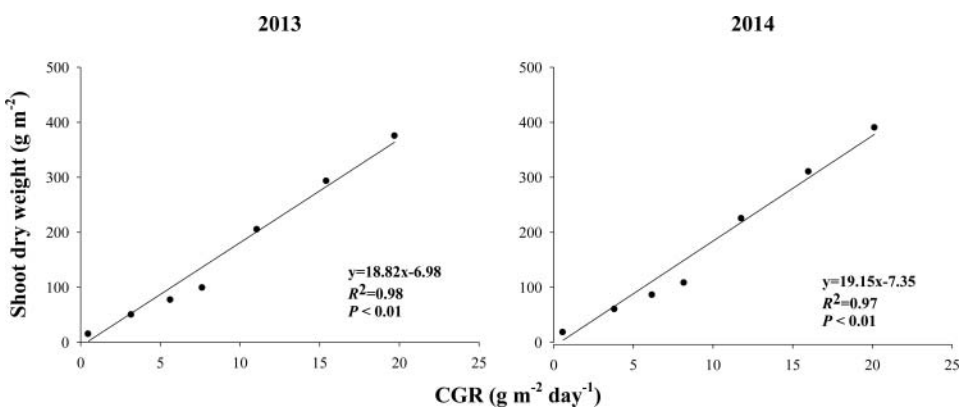

Figure 11. Relationship between crop growth rate (CGR) and shoot dry weight during vegetative phase of pumpkin growth cycle.

It is noteworthy that the impact intensity of nitrogen treatments on both maximum shoot dry weight and maximum CGR was diminishing, i.e., the increment in maximum shoot dry matter due to increase in the nitrogen rate from 50 to 150 kg ha^{-1} and from 150 to 250 kg ha^{-1} was 47.5% and 32.4% for 2013 and 43.6% and 27.1% for 2014, respectively. The impact intensity resulted from increase in the nitrogen rate from 50 to 150 kg ha^{-1} on maximum growth rate of pumpkin was higher than the impact intensity resulted from increment of nitrogen level from 150 to 250 kg ha^{-1}; i.e. 39.3% vs. 27.8% for 2013 trial and 35.8% vs. 25.9% for 2014.

Nitrogen concentration and uptake

By increasing the nitrogen application in both growing seasons, nitrogen concentration and uptake increased (Figures 12 and 13). Accordingly, the growing season average of nitrogen concentration for treatments of 50, 150, and 250 kg N ha^{-1} was 1.33%, 1.65%, and 1.86%, respectively, in 2013 growing season compared to 1.40%, 1.71%, and 1.92%, respectively, in 2014 growing season. Among three N levels in both growing seasons, highest nitrogen uptake (g m^{-2}) that was calculated as the product of nitrogen concentration (%) and shoot dry weight (g m^{-2}) was obtained in treatment of 250 kg N ha^{-1} (Figure 13).

In both growing seasons, nitrogen concentration during pumpkin growth cycle decreased by increasing the plant shoot dry weight (Figure 12). The actual plant N concentration in a crop stand declines even under favorable N supply as the crop mass increases (Greenwood, Neeteson, and

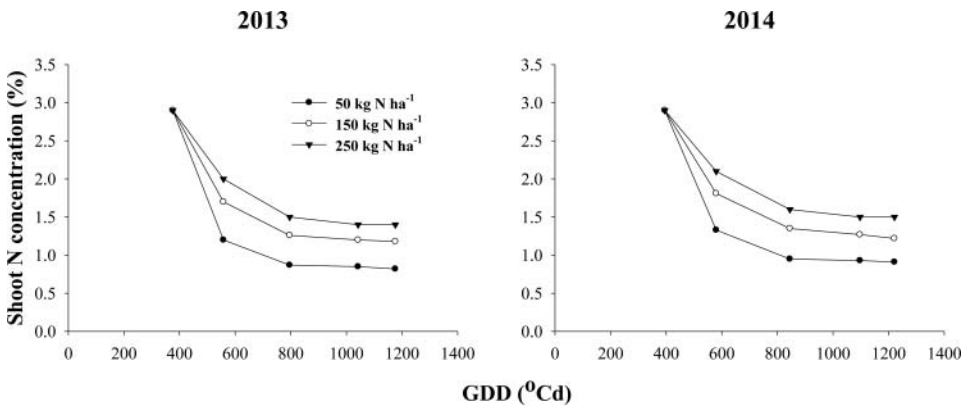

Figure 12. Effect of nitrogen application on shoot nitrogen concentration of pumpkin during the growth period (GDD).

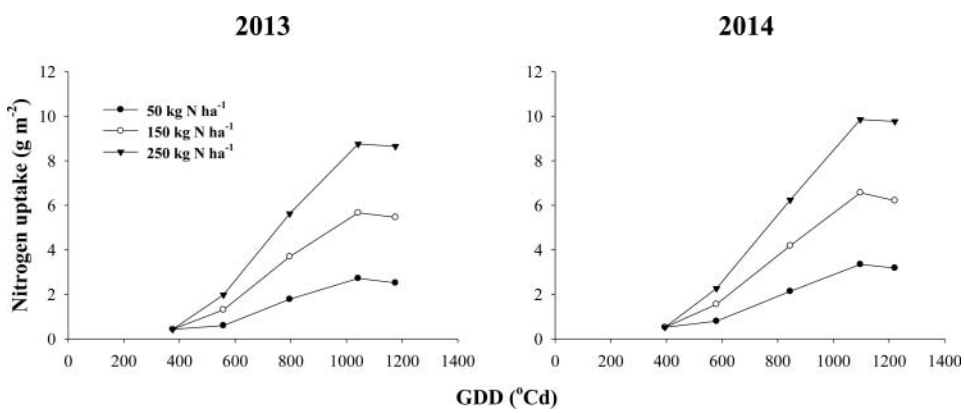

Figure 13. Effect of nitrogen application on shoot nitrogen uptake of pumpkin during the growth period (GDD).

Table 3. Estimated parameters (a and b) and regression coefficients (R^2) after fitting the dilution power function model ($\%N = a \times DW^{-b}$) to the decrease in N concentration using dry weight as an independent variable for each nitrogen fertilizer rate and pooling data from 2013 and 2014 field trials.

Applied N (kg ha^{-1})	a	b	R^2 (%)
50	7.08	0.37	91**
150	5.68	0.25	98**
250	4.96	0.19	99**

**Significant at $p \leq 0.01$.

Draycott 1986). This decline can be described empirically by a negative power function ($\%N = a \times DW^{-b}$) (Lemaire et al. 2008) relating plant N concentration (%N) to crop mass. Estimated parameters of power N dilution functions for each nitrogen rate are presented in Table 3. As shown in Table 3, value of both a and b parameters was decreased as a result of increase in the nitrogen rate. Elia and Conversa (2012) found that in tomato, the b parameter linearly decreased with increase in N supply. However, value of a parameter (4.96) obtained for treatment with 250 kg N ha^{-1} was higher than the average reported for C_3 crops (4.8) (Bot, Adamowicz, and Robin 1998), while the value of b parameter (~0.19) in this treatment was lower than the average reported for C_3 crops (0.34) (Bot, Adamowicz, and Robin 1998).

Nitrogen concentration and nitrogen uptake across all N levels in 2014 were higher than those in 2013. This may be due to higher growth of plants in 2014. Evaluation of the relationship between growth parameters of pumpkin and weather features of 2 years confirmed better growth condition (weather) in 2014 (Table 4). Solar radiation (R_s) did not show a significant effect on all growth parameters of pumpkin in 2013 trial, while in 2014 growing season, all growth parameters were positively correlated to the solar radiation (R_s) (Table 4). The growing season average of sunshine hours in 2013 and 2014 was 11.2 and 11.5 hr, respectively.

Final yield and nitrogen use efficiency (NUE)

ANOVA across data of two growing seasons (combined analysis) showed that among sources of variation, nitrogen rate had significant ($p \leq 0.05$) or highly significant ($p \leq 0.01$) effects on yield components and NUE (Table 5).

Mean comparison for the effect of growing season on fruit number, fruit yield, and NUE of pumpkin showed that in 2014 growing season, all these features were significantly higher than those in 2013 growing season (Table 6). The average of fruit number, fruit yield, and NUE of pumpkin across three nitrogen levels in 2014 growing season were 10518.7 fruit ha^{-1}, 14981.5 kg ha^{-1}, and 129.4 kg kg^{-1}, respectively compared to 9902.5 fruit ha^{-1}, 13818.8 kg ha^{-1}, and 117.7 kg kg^{-1}, respectively, in 2013

Table 4. The correlation between weather features and pumpkin growth parameters.

		LAI	LAD	CGR	$f_{i\text{-}PAR}$	PAR_i	RUE	DM
2013 growing season	T_{min}	0.43	0.45	0.26	0.58*	0.83**	0.76**	0.78**
	T_{max}	0.29	0.33	0.09	0.43	0.86**	0.67**	0.78**
	T_{ave}	0.36	0.39	0.17	0.51*	0.85**	0.72**	0.79**
	R_s	−0.02	0.07	−0.04	0.2	0.44	0.27	0.38
2014 growing season	T_{min}	0.7**	0.63*	0.57*	0.81**	0.67**	0.86**	0.68**
	T_{max}	0.66**	0.56*	0.48	0.77**	0.68**	0.82**	0.67**
	T_{ave}	0.68**	0.60*	0.52*	0.79**	0.68**	0.84**	0.67**
	R_s	0.71**	0.76**	0.62*	0.77**	0.78**	0.85**	0.79**

T_{min}: daily minimum temperature (°C); T_{max}: daily maximum temperature (°C); T_{ave}: daily mean temperature (°C); R_s: daily solar radiation (MJ m^{-2}); LAI: leaf area index; LAD: leaf area duration (m^2 day); CGR: crop growth rate (g m^{-2} day^{-1}); $f_{i\text{-}PAR}$: fraction of intercepted PAR; PAR_i: cumulative intercepted PAR (MJ m^{-2}); RUE: radiation use efficiency (g MJ^{-1}); DM: shoot dry matter (g m^{-2}).
*Significant at $p \leq 0.05$.
**Significant at $p \leq 0.01$.

Table 5. Analysis of variance (ANOVA) for combined data of two growing seasons.

		Mean square					
Source of variation	df	NF[a]	FY	FW	SY	SW	NUE
Year	1	2277968.2*	8110762.7**	6432.1 NS	1488.4 NS	0.17 NS	844.9**
Block (year)	6	71014.9 NS	261552.0 NS	4231.1 NS	320.3 NS	2.6 NS	51.4 NS
Nitrogen	2	16586593.0**	151520033.2**	504789.8**	41081.2**	121.9**	34996.4**
Nitrogen × year	2	16288.0 NS	115161.2 NS	768.2 NS	1.5 NS	0.0 NS	181.1 NS
Error	12	268170	316542.7	3004.3	388.9	3.5	61.1
CV (%)		5.07	3.90	3.94	8.20	8.10	6.30

[a]NF, number of fruits; FY, fruit yield; FW, fruit weight; SY, seed yield; SW, seed weight; NUE, nitrogen use efficiency.
*, **and NS are significant at probability level of 0.05, 0.01 and non-significant, respectively.

Table 6. The effect of growing season on fruit number, fruit yield, and nitrogen use efficiency of pumpkin.

Growing season	NF[a] (ha^{-1})	FY (kg ha^{-1})	NUE (kg kg^{-1})
2013	9902.5b	13818.8b	117.7b
2014	10518.7a	14981.5a	129.4a

Means within each column followed by the same letter do not have significant difference ($p \leq 0.05$) according to LSD test.
[a]NF, number of fruits; FY, fruit yield; NUE, nitrogen use efficiency.

Table 7. The effect of nitrogen application on yield components and nitrogen use efficiency of pumpkin.

Applied nitrogen (kg ha^{-1})	NF[a] (ha^{-1})	FY (kg ha^{-1})	FW (g $fruit^{-1}$)	SY (kg ha^{-1})	SW (g $fruit^{-1}$)	NUE (kg kg^{-1})
50	8985.5c	9941.3c	1106.2c	169.6c	18.9c	198.8a
150	9849.6b	14622.5b	1484.0b	237.4b	24.1b	97.5b
250	11796.6a	18636.8a	1581.8a	312.9a	26.6a	74.5c

Means within each column followed by the same letter do not have significant difference ($p \leq 0.05$) according to LSD test.
[a]NF, number of fruits; FY, fruit yield; FW, fruit weight; SY, seed yield; SW, seed weight; NUE, nitrogen use efficiency.

(Table 6). However, there was no significant difference between two growing season regarding fruit weight, seed yield, and seed weight (Table 5).

There was a significant difference between nitrogen levels regarding all yield components of pumpkin (Table 7). By increasing the nitrogen rate from 50 to 150 kg ha^{-1} and from 150 to 250 kg ha^{-1}, all yield components of pumpkin (including fruit number, fruit yield, fruit weight, seed yield, and seed weight) were significantly increased (Table 7). Thus, the maximum amount of all yield components of pumpkin was obtained from nitrogen rate of 250 kg ha^{-1} (Table 7). Increased nitrogen rate from 50 to 250 kg ha^{-1} caused to 31.3%, 87.5%, 43.0%, 84.5%, and 40.7% increment in fruit number, fruit yield, fruit weight, seed yield, and seed weight of pumpkin, respectively (Table 7). The results of previous studies also are in accordance with the results of the current study. Gholipoori et al. (2006) reported that with increase in the nitrogen rate from 0 to 200 kg ha^{-1}, the fresh fruit weight, 1000 seeds weight, fruit yield, and seed yield of pumpkin increased significantly. Swiader and Moor (2002) evaluated the effect of different nitrogen rates (i.e. 0, 84, 168, 252, and 336 kg ha^{-1}) on yield of pumpkin (*C. pepo* var machuata) under dry-land and irrigated conditions. These authors concluded that under dry-land condition, with increase in the nitrogen rate up to 84 kg ha^{-1}, the pumpkin yield significantly increased by 29% compared to control (0 kg N ha^{-1}). They also reported that under irrigated condition, the increased nitrogen rate up to 252 kg ha^{-1} resulted in increase in the pumpkin yield by 200% compared to control. However, by increasing the nitrogen rate up to 336 kg ha^{-1}, the pumpkin yield was decreased in comparison with 250 kg N ha^{-1}.

However, the NUE of pumpkin decreased with increase in the nitrogen rate, i.e., the maximum NUE was obtained from nitrogen rate of 50 kg ha^{-1} (Table 7). Increase in the nitrogen rate from 50 to 250 kg ha^{-1} resulted in 62.5% decrease in NUE of pumpkin (Table 7).

Conclusion

The results of this study showed that increase in nitrogen rate can increase both growth and yield of pumpkin. The maximum growth and yield of pumpkin in both growing seasons were obtained from application of nitrogen rate of 250 kg ha^{-1}. Application of nitrogen caused a higher PAR interception through increasing the LAI and LAD. Increased PAR interception should have resulted in increment of crop photosynthesis and thus higher shoot dry matter accumulation, which have finally led to higher crop yield. The results of the current study showed that annual climate variation can affect the pumpkin growth and yield. For example, better coincidence of weather condition (especially solar radiation) with pumpkin growth in 2014 growing season resulted in higher growth and yield of pumpkin compared to 2013.

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