Growth Analysis of Pumpkin (*Cucurbita pepo* L.) Under Various Management Practices and Temperature Regimes

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Abstract

Pumpkin (*Cucurbita pepo* L.) is an economically important plant and is cultivated throughout the world for oil and medicinal purposes. Optimum management practices to improve the growth and production of this forgotten crop require detailed growth data and analysis. This study was conducted to investigate the impacts of different management practices (including sowing date, plant density and nitrogen application) and temperature regimes on growth parameters of pumpkin, including shoot dry weight (DW), radiation use efficiency (RUE) and intercepted PAR (PARi). The required data of pumpkin were collected from a four-year experiment (2010, 2012, 2013 and 2014) which performed at research farm of Ferdowsi University of Mashhad, Iran. Results showed that sowing date between 1-11 May, plant density of 2.5 plants m\(^{-2}\) and nitrogen rate of 250kgha\(^{-1}\) resulted in highest possible yield of pumpkin. Increasing of both radiation use efficiency and intercepted PAR increased the pumpkin dry weight. Temperature stress induced by delaying sowing date resulted in lower pumpkin growth, however negative impact of temperature stress can be alleviated through selecting the optimum sowing date. Different temperature regimes during various phases of pumpkin growth cycle also led to the intra and inter annual variation of pumpkin dry weight among different sowing dates and years. Under optimum nitrogen rate, pumpkin showed improved resistance to higher air temperature. The study revealed the role of optimum nitrogen rate on decreasing impacts of temperature stress on crop growth.

Keywords: Sowing date; Plant density; Nitrogen rate; Temperature stress

Introduction

Agricultural systems are characterized by the interdependency and complexity of their components, by variability in surrounding environment and risk involved in their management [1]. In an agricultural system, plant growth and development are dependent upon the integrated responses of various interacting variables (temperature, CO\(_2\), nutrients, water, and agronomic management) through various eco-physiological processes [2]. Increasing environmental degradation in agricultural fields, in the form of declining soil fertility, lowering water tables, rising salinity, increasing resistance to pesticides, and degradation of irrigation water quality [3], rising temperatures and carbon dioxide, and uncertainties in rainfall associated with global climatic change may impact food production [4] and farmers income [1].

Recent climate trends had negative impacts on global yield levels of widely grown crops [5]. Therefore, one of the main topics in agronomic research is to find management strategies that maximize crop production and minimize environmental degradation [6]. To abate the negative impacts of climatic change, the adaptation of agricultural practices will play a decisive role [7]. Agricultural production can benefit already from small changes at the tactical level such as adjustments in sowing date, fertilization intensity [5] and plant density. Sowing date is one of the most important management factor affecting crop production and quality [8]. In a given region, the optimum sowing date depends mainly upon the timing of rainfall [9]. In most cases, delaying sowing beyond the optimum period reduces crop growth and yield [10,11] due to increasing temperatures and diminishing moisture conditions [12,13]. Therefore, selecting the optimum planting date can be considered as an adaptation response to climate change [14].

Nitrogen plays an important role in plant growth [15]. This nutrient is a component of protein and nucleic acid and when N amount in soil is not optimal, growth is reduced [15]. Optimum nitrogen rate enhances crop growth by increasing leaf area
Pumpkin (*Cucurbita pepo L.*) is an economically important plant and is cultivated throughout the world for oil and medicinal products [39] 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 17Kcal/100g of fresh pumpkin) and has large amount of fiber [40]. It has various medicinal effects comprising anti diabetic, antihypertensive, antitumor, antimutagenic, immune modulating, antibacterial, anti-hyper cholesterolemic, intestinal anti-parasitic, antalgic, and anti inflammation effects [41]. However, there has been relatively little research to systematically describe pumpkin growth [42]. Thus, it is tried in this study to analysis the influence of some management practices and climate variables (including temperature, solar radiation and precipitation) on growth of pumpkin under field conditions using the data of four years experiment.

**Materials and Methods**

**Growth data**

The growth data of pumpkin were collected from four years experiments which have been conducted in 2010, 2012, 2013 and 2014 at the research farm of Ferdowsi university of Mashhad, Iran (with latitude 36°16′ N, longitude 59° 38′ E, elevation 999m, annual average of minimum temperature 8.3 °C, annual average of maximum temperature 21.6 °C and total precipitation of 256.5mm [43]. The study location is showed in Figure 1. Furthermore, details of the treatments employed in each experiment are presented in Table 1.
In the first year of experiment (2010), treatments (including nitrogen application and plant density) were arranged using a split plot design in the form of completely randomized block with three replications. Nitrogen application as the main plot was carried out in three levels including 150, 250 and 350 kg N ha\(^{-1}\) (using urea containing 46% Nitrogen) and plant density as the sub-plot was performed in three levels including 2.5, 1.25 and 0.625 plant m\(^{-2}\). For the plant densities of 2.5, 1.25 and 0.625 plant m\(^{-2}\), within row space was 20, 32 and 64 cm, respectively. The size of each plot was 10 m\(^{\times}\)6 m and between rows distance was considered 2 m with a 50 cm furrow for each row. The seedbed preparation was carried out using the common practices (including plow, disk and leveler) and sowing was performed at May 1. The furrow irrigation was employed in order to supply the water requirement of plants and first irrigation was carried out immediately after sowing and other irrigations were performed on weekly basis. During the growing season no fertilizer was applied and weed control was performed by hand weeding. Similar to 2010 experiment, the destructive samplings during the growing season were performed at different dates in order to cover the various developmental stages of pumpkin. Accordingly, six destructive samplings were carried out six times at different dates during the growing season in order to cover the various developmental stages of this crop. The first sampling was performed 27 days after planting and other samplings were accomplished with an interval of 15 days. In each sampling, three plants were randomly harvested from each plot and after measuring the green leaf area using a leaf area meter (LI-3100), the shoot of each plant were separately dried at 75 °C for 72 h. The average of shoot dry weight obtained from three plants of each plot was considered for that plot and the average of dry weight obtained from three plots of each treatment was considered for that treatment.

In the second experiment (2012), treatments (including sowing date and plant density) were arranged using a split plot design in the form of completely randomized blocks with three replications. Sowing date as the main plot was employed in three levels including May 1, May 11 and May 21 and plant density as the sub-plot was performed in two levels including 2.5 and 4 plant m\(^{-2}\). The size of each plot was 10 m\(^{\times}\)5 m and between rows distance was considered 2 m with a 0.5 m furrow for each row. The seedbed was prepared using the common practices (including plow, disk and leveler) and seeds were sown on 1, 11 and 21 of May. For the plant densities of 2.5 and 4 plant m\(^{-2}\), the between row space was 20 and 10 cm, respectively. The furrow irrigation was employed in order to supply the water requirement of plants and first irrigation was carried out immediately after sowing and other irrigations were performed on weekly basis. During the growing season no fertilizer was applied and weed control was performed by hand weeding. Similar to 2010 experiment, the destructive samplings during the growing season were performed at different dates in order to cover the various developmental stages of pumpkin. Accordingly, six destructive samplings were carried out six times at different dates during the growing season in order to cover the various developmental stages of this crop. The first sampling was performed 27 days after planting and other samplings were accomplished with an interval of 15 days. In each sampling, three plants were randomly harvested from each plot and after measuring the green leaf area using a leaf area meter (LI-3100), the shoot of each plant were separately dried at 75 °C for 72 h. The average of shoot dry weight obtained from three plants of each plot was considered for that plot and the average of dry weight obtained from three plots of each treatment was considered for that treatment.

| Experiment | Sowing date | Treatments | Identification Code |
|------------|-------------|------------|---------------------|
| 2010       | May 1       | 150 kg N ha\(^{-1}\) and 0.625 plant m\(^{-2}\) | T1-2010             |
|            |             | 150 kg N ha\(^{-1}\) and 1.25 plant m\(^{-2}\) | T2-2010             |
|            |             | 150 kg N ha\(^{-1}\) and 2.5 plant m\(^{-2}\)  | T3-2010             |
|            |             | 250 kg N ha\(^{-1}\) and 0.625 plant m\(^{-2}\) | T4-2010             |
|            |             | 250 kg N ha\(^{-1}\) and 1.25 plant m\(^{-2}\)  | T5-2010             |
|            |             | 250 kg N ha\(^{-1}\) and 2.5 plant m\(^{-2}\)  | T6-2010             |
|            |             | 350 kg N ha\(^{-1}\) and 0.625 plant m\(^{-2}\) | T7-2010             |
|            |             | 350 kg N ha\(^{-1}\) and 1.25 plant m\(^{-2}\)  | T8-2010             |
|            |             | 350 kg N ha\(^{-1}\) and 2.5 plant m\(^{-2}\)  | T9-2010             |
| 2012       | May 1, May 11 and May 21 | Sowing date May 1 and 2.5 plant m\(^{-2}\) | T1-2012             |
|            |             | Sowing date May 1 and 4 plant m\(^{-2}\)         | T2-2012             |
|            |             | Sowing date May 11 and 2.5 plant m\(^{-2}\)      | T3-2012             |
|            |             | Sowing date May 11 and 4 plant m\(^{-2}\)        | T4-2012             |
|            |             | Sowing date May 21 and 2.5 plant m\(^{-2}\)      | T5-2012             |
|            |             | Sowing date May 21 and 4 plant m\(^{-2}\)        | T6-2012             |
| 2013       | May 6       | 50 kg N ha\(^{-1}\) with plant density of 2.5 plant m\(^{-2}\) | T1-2013             |
|            |             | 150 kg N ha\(^{-1}\) with plant density of 2.5 plant m\(^{-2}\) | T2-2013             |
|            |             | 250 kg N ha\(^{-1}\) with plant density of 2.5 plant m\(^{-2}\) | T3-2013             |
| 2014       | May 6       | 50 kg N ha\(^{-1}\) with plant density of 2.5 plant m\(^{-2}\) | T1-2014             |
|            |             | 150 kg N ha\(^{-1}\) with plant density of 2.5 plant m\(^{-2}\) | T2-2014             |
|            |             | 250 kg N ha\(^{-1}\) with plant density of 2.5 plant m\(^{-2}\) | T3-2014             |
samplings were carried out during the growth of pumpkin. Initial sampling for the first (May 1), second (May 11) and third (May 21) sowing dates was conducted 20, 25 and 29 days after sowing, respectively, and other samplings were performed with an interval of 14 days. In each sampling, three plants were randomly harvested from each plot and after measuring the green leaf area using a leaf area meter (VM-900), the shoot of each plant were separately dried at 75 °C for 72h.

In 2013 and 2014 experiments, the seedbed preparation was carried out using the common practices (including plow, disk and leveler) and pumpkin plants were seeded at 6-May with density equal to 2.5 plant m⁻². The plot size was 15m×5m and in each plot, 6 planting lines with a 2m row spacing and 50cm furrow between each line were considered. 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 were included three levels of nitrogen application (including 50, 150 and 250kg ha⁻¹ using urea fertilizer containing 46% Nitrogen), which were arranged according to the design of completely randomized blocks with four replications. In both years, the first portion of urea fertilizer (half of the total) was applied four weeks after sowing (coinciding with 4-6 leaf stage) and the second fertilization (the second half) was used 6 weeks after sowing (coinciding with flowering stage). In order to apply nitrogen after irrigation, the urea fertilizer was banded 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 were arranged in order to coincide the sampling 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-3100), the shoot of each plant were separately dried at 75 °C for 72h. After drying, the shoot samples were weighted using a digital balance with accuracy of 0.001g.

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.

Leaf Area Duration (LAD)

The leaf area duration (LAD) was calculated using Eq. (1).

\[
LAD (m^2 \cdot \text{day}) = \left( \frac{L_{A1} + L_{A2}}{2} \right) \times (t_2 - t_1) \quad (1)
\]

Where LA1 and LA2 are the leaf area (m²) attimes of t1 and t2, respectively.

Radiation Use Efficiency (RUE)

The radiation use efficiency was calculated by the following equation:

\[
RUE (g MJ^{-1}) = \frac{\text{Shoot dry matter (g m}^{-2}\text{)}}{\text{Cumulative intercepted PAR (MJ m}^{-2}\text{)}} \quad (2)
\]

The Angstrom model (Eq.(3)) was employed in order to calculate the global solar radiation (Rs) [45] from sunshine hours:

\[
R_s = R_s \left( A + B \left( \frac{D}{N} \right) \right) \quad (3)
\]

Where Rs is daily global radiation (MJ m⁻² d⁻¹), RA 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, [46]), n is sunshine duration (h) and N is the astronomical daylength (h) [45]. Global solar radiation was multiplied by 0.45 to obtain global PAR (PARg) [47]. Finally, the intercepted PAR (PARI) was determined according to Eq.(4) [48].

\[
PAR_i = (1 - \rho)PAR_g \left( 1 - e^{-kLAI} \right) \quad (4)
\]

Where \(\rho\) is canopy reflection coefficient (\(\rho=0.07, [49]\)), \(k\) is light extinction coefficient of canopy (for pumpkin=0.72, [44]) and LAI is leaf area index. On days where LAI was not measured, the PAR was estimated by linear interpolation between measured values.

| Year | Month | \(T_{avg}\) (°C) | \(T_{max}\) (°C) | \(T_{min}\) (°C) | P (mm) | Rs (MJ m⁻² d⁻¹) |
|------|-------|-----------------|-----------------|-----------------|-------|-----------------|
| 2010 | May   | 21.9            | 28.8            | 14.9            | 39.2  | 22.3            |
|      | June  | 27.4            | 35.5            | 19.3            | 4.5   | 26.8            |
|      | July  | 28.6            | 36.3            | 20.9            | 0.0   | 27.3            |
|      | August| 26.4            | 34.5            | 18.2            | 0.0   | 25.5            |
| 2012 | May   | 20.9            | 28.0            | 13.9            | 18.4  | 23.1            |
|      | June  | 26.0            | 33.3            | 18.7            | 9.5   | 26.4            |
|      | July  | 28.8            | 36.2            | 21.5            | 0.0   | 26.7            |
|      | August| 27.3            | 35.4            | 19.2            | 0.0   | 25.4            |
| 2013 | May   | 20.9            | 28.0            | 13.6            | 26.8  | 24.3            |
|      | June  | 26.7            | 33.9            | 19.5            | 0.4   | 25.9            |
|      | July  | 28.7            | 36.1            | 21.3            | 0.0   | 26.8            |
|      | August| 25.9            | 33.0            | 18.8            | 2.4   | 24.0            |

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| Source of Variation | Degree of Freedom | Sum of Squares | LSD |
|---------------------|------------------|----------------|-----|
| Nitrogen rate (N)   | 2                | 45490.83**     | 0.12** |
| Plant density (D)   | 2                | 527259.07**    | 2.67** |
| N×D                | 4                | 11950.70**     | 0.09* |
| Error              | 12               | 2739.98        | 0.09 |
| CV (%)             |                  | 4.61           | 6.16 |

* and ** are significant at probability level of 0.05 and 0.01, respectively.

Nitrogen rate had a quadratic effect on all growth traits of pumpkin (Figure 2). Accordingly, all three growth traits evaluated in this study (including DW<sub>max</sub>, RUE<sub>max</sub>, and PAR) increased as the nitrogen rate increased from 150kg ha<sup>-1</sup> to 250kg ha<sup>-1</sup> (Figure 2). Whereas, with increase in nitrogen rate from 250kg ha<sup>-1</sup> to 350kg ha<sup>-1</sup>, the amount of all traits were decreased (Figure 2). Thus, the highest amount of pumpkin’s DW<sub>max</sub>, RUE<sub>max</sub>, and PAR, was obtained by applying 250kg N ha<sup>-1</sup> (Figure 2). These results clearly showed that optimum nitrogen rate (250kg ha<sup>-1</sup>) can increase the pumpkin growth through increasing the radiation use efficiency and intercepted PAR, while nitrogen deficiency (150kg ha<sup>-1</sup>) or excess (350kg ha<sup>-1</sup>) can be resulted in growth suppression of pumpkin due to reduction of the crop RUE and PAR. Previous studies also found that RUE was significantly reduced by application of non-optimum rate of nitrogen, such as maize, rice, and winter oilseed rape [52,53]. The reduction
in biomass production in response to non-optimum N rate is associated with either a reduction in total radiation intercepted by the canopy, or by a decrease in the efficiency with which the intercepted radiation is used to produce dry matter (i.e. RUE), or a combination of both [54].

Figure 2: Effect of nitrogen rate on (a) maximum dry weight (DW\text{max}), (b) maximum radiation use efficiency (RUE\text{max}) and (c) intercepted PAR (PAR\text{i}) of pumpkin in 2010 experiment.

High rate of nitrogen application is required for obtaining the optimum growth and yield of pumpkin [55]. Gholipoori et al. [56] reported that maximum growth and yield of pumpkin was obtained at nitrogen rate of 200kg ha\textsuperscript{-1}. Swiader and Moor [57] also were evaluated the effect of different nitrogen rates (i.e. 0, 84, 168, 252 and 336kg ha\textsuperscript{-1}) on growth and yield of pumpkin (C. pepovarmachuat) under dry-land and irrigated conditions. These authors concluded that under irrigated conditions, increasing nitrogen rate to 252kg ha\textsuperscript{-1} was led to increase in pumpkin growth and yield compared to control. Furthermore, by increasing nitrogen rate to 336kg ha\textsuperscript{-1}, the pumpkin growth and yield was decreased compared to the optimum treatment (i.e. 252kg N ha\textsuperscript{-1}).

Under conditions of optimal nitrogen supply, nitrogen concentration in the plant tissue reaches an optimal value and the plant attains its maximum growth [6]. Whereas, nitrogen-deficiency limits crop growth [58] and nitrogen excess adversely affects crop growth through excessive accumulation of toxic levels of N metabolites in the plant [18]. Similar to the results obtained in this study, a numerous studies conducted with different crop species showed that optimum N application increases crop growth, radiation use efficiency (RUE) and intercepted radiation [9,59,60-62]. For example, Justes et al. [59] reported that maximum growth, RUE and absorbed PAR of winter oilseed rape was obtained by application of 270kg N ha\textsuperscript{-1}, where nitrogen was non-limiting [60,61]. Furthermore, these authors also reported that N deficiencies significantly reduced the aerial dry matter, green leaf area index (LAI), radiation use efficiency and absorbed PAR of winter oilseed rape. Similarly, Fletcher et al. [62] found that shoot dry weight, RUE, LAI and PAR capture of wheat, forage rape and forage sorghum were reduced in response to N shortage. Furthermore, accumulation of nitrates, amides and free amino acids which excessive levels of them are considered to be toxic for crop growth [18] was reported in corn and wheat as a result of excess use of nitrogen [63,64].

All growth traits of pumpkin (including DW\text{max}, RUE\text{max} and PAR) were responded to the different plant densities in a sigmoidal manner (Figure 3). This sigmoidal trend shows that maximum DW (DW\text{max}), maximum RUE (RUE\text{max}) and intercepted PAR (PAR\text{i}) of pumpkin were increased as the plant density increased and the highest amount of all pumpkin growth traits was obtained using the plant density of 2.5 plant m\textsuperscript{-2} (Figure 3). Since crop growth is dependent on light interception and also on radiation use efficiency (RUE) [65], the higher shoot dry weight of pumpkin observed at plant density of 2.5 plant m\textsuperscript{-2} was related to its effect on increasing pumpkin RUE and PAR (Figure 3b & 3c). Whereas, at plant densities lower than 2.5 plant m\textsuperscript{-2} (i.e. 0.625 and 1.25 plant m\textsuperscript{-2}), decreased RUE and PAR was led to decline in pumpkin dry weight (Figure 3b & 3c). Similarly, Mao et al. [66] studied the effect of plant density on light interception and light use efficiency of intercropped cotton. They reported that both light interception and light use efficiency of intercropped cotton were significantly increased by higher plant density. However, the effect of higher plant densities on pumpkin growth

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was less than lower plant densities (Figure 3). For example, with increasing plant density from 0.625 to 1.25 plant m$^{-2}$, the $DW_{\text{max}}$ of pumpkin was increased by 217.3 g m$^{-2}$, while increasing plant density from 1.25 to 2.5 plant m$^{-2}$ was caused to an increase in $DW_{\text{max}}$ of pumpkin by 120.4 g m$^{-2}$ (Figure 3a). At higher plant densities, overlapping of leaves makes that photosynthesis is no longer linearly proportional to the plant population [67].

In accordance with the results obtained in this experiment, Shabahang et al. [51] which evaluated the effect of two intra row spaces (including 20 and 40 cm) and also two inter row spaces (including 100 and 200 cm) on growth and yield of pumpkin concluded that highest growth and yield of pumpkin was obtained by applying 200 × 20 cm inter and intra row spaces, respectively (i.e. plant density of 2.5 plant m$^{-2}$). Ebadi et al. [68] also studied the effect of three levels of plant density (including 1.85, 0.93 and 0.62 plant m$^{-2}$) on growth and seed and fruit yield of pumpkin. These authors reported that dry weight and seed and fruit yield of pumpkin were increased as the plant density increased and highest growth and yield of pumpkin were obtained at plant density of 1.85 plant m$^{-2}$. Douglas et al. [69] compared different plant densities between 0.2 and 6.2 plant m$^{-2}$ for squash (Cucurbita maxima). In their study, total fruit yield increased with increasing plant density to 3.0 plant m$^{-2}$ and then declined. Buwalda and Freeman [70] recorded growth and development of an F1 hybrid kabocha squash at a density of 2 plant per m$^2$. This plant density produced high growth and yield at different sowing dates. In Broderick's study [71], fruit yield of a bush cultivar of C. maxima squash increased as plant density increased from 0.54 to 2.2 plants per m$^2$. Maximum fruit yield was achieved at the highest plant density (2.2 plant m$^{-2}$), which produced a maximum above-ground dry weight.

The interaction between nitrogen rate and plant density showed that for all three nitrogen levels (i.e. 150, 250 and 350 kg ha$^{-1}$), $DW_{\text{max}}$, $RUE_{\text{max}}$ and PAR of pumpkin were responded to the plant density in a sigmoidal manner and 100% of changes in pumpkin $DW_{\text{max}}$ and $RUE_{\text{max}}$ can be explained by the functions obtained (Figure 4). For all levels of plant density (including 0.625, 1.5 and 2.5 plant m$^{-2}$), amount of $DW_{\text{max}}$, $RUE_{\text{max}}$ and PAR was increased by increasing the nitrogen rate to 250 kg ha$^{-1}$ and then, with higher application of nitrogen (350 kg N ha$^{-1}$), both traits were decreased (Figure 4). Furthermore, for all nitrogen rates, with increasing the plant density, all growth parameters of pumpkin were increased non-linearly and maximum amount of dry weight, radiation use efficiency and intercepted PAR was obtained at plant density of 2.5 plant m$^{-2}$ (Figure 4). Therefore, the highest amount of pumpkin $DW_{\text{max}}$, $RUE_{\text{max}}$ and PAR was achieved by using the nitrogen rate of 250 kg ha$^{-1}$ and plant density of 2.5 plant m$^{-2}$. Accordingly, the amount of $DW_{\text{max}}$, $RUE_{\text{max}}$ and PAR, obtained by applying the optimum growth conditions (i.e. nitrogen rate of 250 kg ha$^{-1}$ and plant density of 2.5 plant m$^{-2}$) was 575.60 g m$^{-2}$, 1.91 g MJ$^{-1}$ and 393.30 MJ m$^{-2}$, respectively.

![Figure 3: Effect of plant density on (a) maximum dry weight ($DW_{\text{max}}$), (b) maximum radiation use efficiency ($RUE_{\text{max}}$) and (c) intercepted PAR (PAR) of pumpkin in 2010 experiment.](image-url)
There was a linear relationship between maximum dry weight ($DW_{\text{max}}$) of pumpkin and its maximum radiation use efficiency ($RUE_{\text{max}}$) (Figure 5a) and intercepted PAR ($PAR_i$) (Figure 5b). This linear relationship indicates that pumpkin dry weight was increased with increasing its radiation use efficiency and intercepted PAR (Figure 5). Therefore, under conditions of optimum nitrogen rate and plant density (i.e. nitrogen rate of 250 kg ha$^{-1}$ and plant density of 2.5 plants m$^{-2}$, T6-2010 treatment), increased radiation use efficiency and intercepted PAR caused to the production of highest shoot dry weight of pumpkin compared to other treatments. Previous studies also showed that a higher dry matter production resulted from optimum growth conditions is related to the more solar radiation being intercepted, higher RUE, or a combination of the two [72,73]. In return, for treatments which their nitrogen rate, plant density or both of them was lower or higher than optimum ones, the fewer dry weight was related to the lower RUE and $PAR_i$ (Figure 5).

2012 experiment: In 2012 experiment, the effect of three sowing dates (including May 1, May 11 and May 21) and two plant densities (including 2.5 and 4 plants m$^{-2}$) on pumpkin growth was evaluated. In this experiment, all treatments did not receive any amount of nitrogen fertilizer [74,75]. The analysis of variance showed that sowing date had a highly significant ($P \leq 0.01$) effect on both $DW_{\text{max}}$ and $RUE_{\text{max}}$ and a significant effect ($P \leq 0.05$) on $PAR_i$ of pumpkin (Table 4). There was no significant difference between two plant densities (including 2.5 and 4 plants m$^{-2}$) regarding maximum dry weight ($DW_{\text{max}}$) and maximum radiation
use efficiency (RUE\textsubscript{max}) of pumpkin (Table 4). However, plant density had a significant effect on intercepted PAR of pumpkin (Table 4). Furthermore, for all three pumpkin traits (including \(D_{W_{\text{max}}},\) RUE\textsubscript{max}, and PAR) the effect of sowing date was higher than plant density, i.e. sum of squares obtained for the effect of sowing date on pumpkin traits were higher than those obtained for plant density (Table 4).

**Table 4:** Analysis of variance for the effect of experimental treatments and their interaction on pumpkin’s maximum dry weight (\(D_{W_{\text{max}}}),\) maximum radiation use efficiency (RUE\textsubscript{max}) and intercepted PAR (PAR\textsubscript{i}) in 2012 experiment.

| Source of Variation | Degree of Freedom | Sum of Squares |
|---------------------|-------------------|----------------|
|                     |                   | \(D_{W_{\text{max}}}) | RUE\textsubscript{max} | PAR\textsubscript{i} |
| Sowing date (S)     | 2                 | 22025.01**       | 0.277**        | 2593.89*      |
| Plant density (D)   | 1                 | 129.60NS         | 0.001NS        | 1838.20*      |
| S×D                 | 2                 | 62.41NS          | 0.009NS        | 454.83NS      |
| Error               | 6                 | 315.38           | 0.032          | 1565.10       |
| CV (%)              |                   | 3.75            | 8.95           | 4.89          |

*, ** and NS are significant at probability level of 0.05, 0.01 and non-significant, respectively.

The highest amount of pumpkin’s \(D_{W_{\text{max}}},\) RUE\textsubscript{max} and PAR\textsubscript{i} was obtained from sowing date of May 1 (Table 5). However, there was no significant difference between sowing dates of May 1 and May 11 regarding all growth parameters of pumpkin (Table 5). Whereas, with delaying the sowing date to May 21, all growth parameters of pumpkin were significantly decreased (Table 5). Therefore, sowing date of 1-11 May can be considered as the optimum sowing date for pumpkin growth under climatic conditions of Mashhad.

**Table 5:** Effect of sowing date on maximum dry weight (\(D_{W_{\text{max}}})\), maximum radiation use efficiency (RUE\textsubscript{max}) and intercepted PAR (PAR\textsubscript{i}) of pumpkin in 2012 experiment.

| Sowing date | \(D_{W_{\text{max}}}) (g \ m^{-2}) | RUE\textsubscript{max} (g MJ^{-1}) | PAR\textsubscript{i} (MJ m^{-2}) |
|-------------|-----------------------------------|---------------------------------|----------------------------------|
| May 1       | 221.00a                            | 0.92a                           | 339.38a                          |
| May 11      | 215.05a                            | 0.89a                           | 337.73a                          |
| May 21      | 144.00b                            | 0.64b                           | 313.13b                          |

Values with the same letter do not have a significant difference according to the LSD test at probability level of 0.05.

For three sowing dates evaluated in 2012 experiment, there was a linear association between maximum dry weight (\(D_{W_{\text{max}}})\) of pumpkin and its maximum radiation use efficiency (RUE\textsubscript{max}) (Figure 6a) and intercepted PAR (PAR\textsubscript{i}) (Figure 6b). Accordingly, the highest amount of pumpkin growth (\(D_{W_{\text{max}}})\) obtained from optimum sowing dates (May 1 and May 11) was attributed to their effect on increasing radiation use efficiency (RUE\textsubscript{max}) and intercepted PAR(PAR\textsubscript{i}) of pumpkin compared to the non-optimum sowing date (May 21) (Table 5). In accordance with the results obtained from this experiment, numerous publications [11,74,75, 76] have reported an increased crop growth and yield with optimum sowing and a reduction in crop growth when sowing is delayed after the optimum time.

**Figure 6:** Relationship between (a) maximum dry weight (\(D_{W_{\text{max}}})\) and maximum radiation use efficiency (RUE\textsubscript{max}) of pumkin and (b) maximum dry weight (\(D_{W_{\text{max}}})\) and intercepted PAR (PAR\textsubscript{i}) of pumpkin for three sowing dates of 2012 experiment.
For three sowing dates of 2012 experiment, the photo synthetically active radiation (PAR) intercepted by pumpkin had a linear relationship with maximum leaf area index (LAI\text{max}) (Figure 7a) and also with maximum leaf area duration (LAD\text{max}) (Figure 7a) of this crop [76]. The values of 1.73, 1.63 and 1.05m² for LAI\text{max} and values of 21.2, 19.3 and 13.3m² day\(^{-1}\) for LAD\text{max} were obtained for sowing dates of May 1, May 11 and May 21, respectively. Considering the linear association of PAR\(_i\) with LAI\text{max} and LAD\text{max} (Figure 7) and since the values of LAI\text{max} and LAD\text{max} for optimum sowing dates (i.e. May 1 and May 11) were higher than those obtained from non-optimum sowing date (i.e. May 21), the higher PAR intercepted by pumpkin grown under optimum sowing date (1-11 May) was related to the increased leaf area index (LAI) and leaf area duration (LAD) (Figure 7).

![Figure 7: Relationship between (a) intercepted PAR (PAR\(_i\)) and maximum leaf area index (LAI\text{max}) of pumpkin and (b) intercepted PAR (PAR\(_i\)) and maximum leaf area duration (LAD\text{max}) of pumpkin for three sowing dates of 2012 experiment.](image)

![Figure 8: Relationship between (a) maximum leaf area index (LAI\text{max}) of pumpkin and number of days with Tmax > 32 °C, (b) maximum leaf area duration (LAD\text{max}) of pumpkin and number of days with Tmax > 32 °C and (c) maximum radiation use efficiency (RUE\text{max}) of pumpkin and number of days with Tmax > 32 °C for three sowing dates of 2012 experiment.](image)

The ceiling temperature for pumpkin growth is 32 °C [77,78] and pumpkin growth is decreased by increasing the number of days with maximum temperature higher than 32 °C (T\(_{\text{max}}\) > 32 °C). The association between maximum leaf area index (LAI\text{max}), maximum leaf area duration (LAD\text{max}) and maximum radiation use efficiency (RUE\text{max}) as dependent variables and number of days with T\(_{\text{max}}\) > 32 °C for three sowing dates of 2012 experiment is showed in Figure 8. These sigmoidal associations (Figure 8)
indicate that all growth parameters of pumpkin (including LAI_{max}, LAD_{max} and RUE_{max}) were decreased as the number of days with T_{max} > 32 °C increased (Figure 8). The number of days with T_{max} > 32 °C increased by delaying the sowing date, i.e. the number of days with T_{max} > 32 °C for sowing dates of May 1, May 11 and May 21 was 54, 69 and 80 days, respectively. However, considering that there was no significant difference between sowing dates of May 1 and May 11 regarding pumpkin growth (Table 5), the optimum number of days with T_{max} > 32 °C for pumpkin was between 54 to 69 days and higher increase of this number can be resulted in significant decrease of pumpkin growth as observed for sowing date of May 21. Therefore, the higher LAI_{max}, LAD_{max} and RUE_{max} observed under optimum sowing date (1-11 May) was dependent on the more suitable temperature conditions, while the lower values of these growth parameters obtained from non-optimum sowing date (May 21) was related to the temperature stress.

These results showed that negative impacts of weather extremes such as high temperatures on crop growth can be decreased by choosing the optimum sowing date. In contrast, delaying sowing date can cause significant differences of environmental conditions during crop growth, usually causing crops to grow with increasing temperatures and diminishing moisture conditions [12,13], which can be resulted in growth suppression of crop. The significant increase (P ≤ 0.05) in PAR intercepted by pumpkin grown under plant density of 4 plants m^{-2} compared to the plant density of 2.5 plants m^{-2} (Table 4) was related to the higher leaf area index and leaf area duration obtained from plant density of 4 plants m^{-2} (Figure 9). However, this increased interception of PAR did not lead to the significant increase in pumpkin dry weight due to non-significant difference between two plant densities regarding radiation use efficiency (Table 4). Therefore, considering the results of 2010 experiment which showed that among plant densities of 0.625, 1.25 and 2.5 plants m^{-2}, the highest growth of pumpkin was obtained using plant density of 2.5 plants m^{-2} and also in light of the results of 2012 experiment which indicated a non-significant difference between plant densities of 2.5 and 4 plants m^{-2} regarding pumpkin growth, the plant density of 2.5 plants m^{-2} can be considered as the optimum plant density for pumpkin growth.

**2013 and 2014 experiments:** The combined analysis of variance for 2013 and 2014 experiments showed that year had only a highly significant effect (P≤0.01) on maximum dry weight of pumpkin (DW_{max}) (Table 6), while effect of nitrogen rate for all growth parameters of pumpkin (including DW_{max}, RUE_{max} and PAR_i) was significant at probability level of 0.01 (Table 6). Furthermore, the effect of interaction between year and nitrogen rate (Y × N) was not significant for all growth parameters of pumpkin (Table 6). The higher sum of squares obtained for the effect of nitrogen rate on maximum dry weight of pumpkin (DW_{max}) (Table 6) indicates that impact of nitrogen rate on pumpkin growth was more than the influence of year. In addition, the non-significant difference between two years (2013 and 2014) regarding maximum radiation use efficiency (RUE_{max}) of pumpkin (Table 6) shows that radiation use efficiency of pumpkin is approximately stable across the years and thus, can effectively be used for simulation its dry weight through multiplying by intercepted PAR. Similarly, Sinclair & Muchow [79] reported that RUE is stable across environments.

**Table 6:** Analysis of variance for the effect of year, nitrogen rate and their interaction on pumpkin’s maximum dry weight (DW_{max}), maximum radiation use efficiency (RUE_{max}) and intercepted PAR (PAR_i) in 2013 and 2014 experiments.

| Source of Variation | Degree of Freedom | Sum of Squares | DW_{max} | RUE_{max} | PAR_i |
|---------------------|-------------------|----------------|---------|----------|-------|
| Year (Y)            | 1                 | 9126.00**      |         | 0.00NS   | 1443.36NS |

Figure 9: Relationship between (a) intercepted PAR (PAR_i) and maximum leaf area index (LAI_{max}) of pumpkin and (b) intercepted PAR (PAR_i) and maximum leaf area duration (LAD_{max}) of pumpkin for plant densities of 2.5 and 4 plants m^{-2} in 2012 experiment.
Effect of year on maximum dry weight of pumpkin (DW$_{\text{max}}$) showed that DW$_{\text{max}}$ obtained in 2014 year was significantly higher than that obtained in 2013 (Table 7). This was due to a more suitable temperature conditions observed at 2014 growing season which is described in next section. Nitrogen rate had a linear effect on all growth parameters of pumpkin and all of them linearly increased as the nitrogen rate increased (Figure 10). The highest amount of DW$_{\text{max}}$, RUE$_{\text{max}}$ and PARi which was obtained from application of 250kg N ha$^{-1}$ was 641g m$^{-2}$, 2gMJ$^{-1}$ and 375MJ m$^{-2}$, respectively (Figure 10). Since there was a positive strong correlation between DW$_{\text{max}}$ with RUE$_{\text{max}}$ and PARi of pumpkin (i.e. R$^2$ = 0.98 for DW$_{\text{max}}$ vs. RUE$_{\text{max}}$ and R$^2$= 0.99 for DW$_{\text{max}}$ vs. PARi), the increase in pumpkin growth due to increased nitrogen rate was related to the effect of higher rate of nitrogen on increment of the pumpkin RUE and PARi. N affects production through different mechanisms. Increases in crop growth are largely produced through an increase in leaf area index [80,81], intercepted photo synthetically active radiation [16] and also by an increase in radiation use efficiency (RUE, dry matter produced per unit of either incident radiation or intercepted radiation) [80,81].

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|}
\hline
Nitrogen rate (N) & 2 & 362489.33** & 0.78** & 68040.42** \\
\hline
Y × N & 2 & 172.00NS & 0.00NS & 87.23NS \\
\hline
Error & 12 & 746.13 & 0.20 & 3598.58 \\
\hline
CV (%) & 5.07 & 7.24 & 5.47 & \\
\hline
\end{tabular}
\end{table}

Table 7: Effect of year on maximum dry weight (DW$_{\text{max}}$) of pumpkin.

Finally, from results of 2010, 2013 and 2014 experiments, it was showed that highest pumpkin growth is obtained through application of 250kg Nha$^{-1}$. Furthermore, results of 2010 and 2012 experiments showed that optimum plant density for pumpkin growth was 2.5 plantm$^{-2}$, and in 2012 experiment it was indicated that sowing date of 1-11 May was the optimum sowing date for pumpkin growth. Therefore, it can be concluded that optimum conditions for pumpkin growth was: sowing date between 1-11 May, plant density of 2.5 plant m$^{-2}$ and nitrogen rate of 250kg ha$^{-1}$. Among all treatments evaluated in this study only three treatments (including T6-2010, T3-2013 and T3-2014) had the optimum growth conditions (Table 1).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure10.png}
\caption{Effect of nitrogen rate on (a) maximum dry weight (DW$_{\text{max}}$) of pumpkin (b) maximum radiation use efficiency (RUE$_{\text{max}}$) of pumpkin and (c) intercepted PAR (PARi) of pumpkin across 2013 and 2014 experiments.}
\end{figure}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Year & DW$_{\text{max}}$ (g m$^{-2}$) \\
\hline
2013 & 511.33a \\
2014 & 472.33b \\
\hline
\end{tabular}
\end{table}

Table 7: Effect of year on maximum dry weight (DW$_{\text{max}}$) of pumpkin.

Effect of air temperature

Temperature is the most important climate variable during pumpkin growth life [82], which shows a strong relationship with leaf emergence and number of this crop [83]. Moreover,
flowering and pollination stages, and duration of development of pumpkin also are very sensitive to air temperature [83]. There is no specific definition and established phenological scale for pumpkin. However, in temperate climates, semi-determinate Cucurbita plants can reach the end of their exponential growth phase within 6 to 7 weeks after sowing [42]. Hence, for evaluating the effect of air temperature on shoot dry weight (DW) of pumpkin, the growth cycle of this crop was divided into three phases based on the growth pattern obtained from experimental data. These growth phases included exponential phase, linear phase and senescent phase.

In 2012 experiment which three sowing dates were employed, the duration of exponential and linear growth phases of pumpkin was linearly decreased (Figure 11a & 11b), while the duration of senescent phase was linearly increased (Figure 11c) as the sowing date moved forward (i.e. air temperature increased). Some processes, e.g. photosynthesis, show continuous and mainly nonlinear changes in their rates if temperature changes. Other processes, such as phonological development, show a much more linear change with variation in temperature [84]. For sowing dates of May 1, May 11 and May 21 (with mean temperature of 25.4, 26.3 and 27.1 °C, respectively) the duration of 42, 40 and 36 days for exponential phase, 31, 30 and 29 days for linear phase and 16, 22 and 30 days for senescent phase. In fact, the duration of all phases of pumpkin growth was decreased with increasing the air temperature (Figure 11) and air temperature during exponential and linear phase for sowing dates of May 1 and May 11 was higher than sowing date of May 21, while during senescent phase, sowing date of May 1 had the highest air temperature (Figure 11). Accordingly, in sowing dates of May 1, May 11 and May 21, the air temperature of 22.6, 24.3 and 25.2 °C for exponential phase, 27.6, 28.0 and 29.0 °C for linear phase and 27.7 and 27.1 °C for senescent phase was obtained (Figure 11). Since the shoot dry weight of pumpkin in sowing dates of May 1 and May 11 was significantly higher than dry weight obtained in sowing date of May 21, it seems that decrease in duration of exponential and linear phase can be resulted in reduction of pumpkin growth.

For 2012 experiment, the dry weight of pumpkin in both exponential and linear phase was decreased with increasing the air temperature (Figure 12). However, there was no significant difference between pumpkin dry weight obtained from sowing dates of May 1 and May 11 at both phase. Therefore, in this experiment, the highest dry weight of pumpkin was obtained at temperatures between 22.6-24.3 °C for exponential phase and 27.6-29.0 °C for linear phase (Figure 12). Bannayan et al. [78] reported that Rapid vegetative growth of pumpkin requires 22-27 °C thermal environment. Whereas by delaying the sowing date to May 21 or by increasing the air temperature to 25.2 °C for exponential phase and 29.0 °C for linear phase, pumpkin dry weight was significantly decreased in both phase (Figure 12). As previously showed (Figure 8), this significant growth reduction
was due to temperature stress. However, in senescent phase there was a positive relationship between air temperature and pumpkin dry weight (Figure 12). This positive relationship was related to the higher dry weight produced in previous phases (i.e. exponential and linear) of optimum sowing date (1-11 May). Therefore, earlier planting of pumpkin in Mashhad can be resulted in higher pumpkin growth due to a cooler temperature during exponential and linear phases of its growth cycle. Bannayan et al. [78] studied climatic suitability of pumpkin in different regions of Iran. They reported that Azerbaijan region which had a cooler temperature during flowering and pollination period of growth cycle indicated more favorable climatic suitability for cultivation of pumpkin than other regions. In conclusion, results of 2012 experiment showed that intra-annual temperature variations which are resulted from different sowing dates can be led to the variation in pumpkin growth and by adopting the optimum sowing date, the various growth stages of this crop are coincided with the optimum temperature and this causes to obtaining higher crop growth in comparison with non-optimum sowing dates. Therefore, one of the promising methods for mitigating the impact of global warming on crop growth is the re-establishment of sowing date in order to coinciding growth phases of crop with their optimum temperature. Similarly, Delgado et al. [14] reported that changing the planting date can be considered as an adaptation response to climate change. Matching crop development to the available soil moisture supply, as well as avoiding other environmental constraints such as cool or hot temperatures [85], is a key determinant of adaptation today and will continue to be important in future climates [86].

The effect of air temperature on shoot dry weight of three treatments with optimum growth conditions (i.e. treatments with sowing date between 1-11 May; plant density of 2.5 plants m⁻² and nitrogen rate of 250kg ha⁻¹) also was evaluated. These treatments were included T6-2010, T3-2013 and T3-2014 which were belonged to the 2010, 2013 and 2014 experiments, respectively (Table 1). In exponential phase, pumpkin dry weight (DW) were increased as the air temperature increased and highest DW in this phase was obtained from 2014 year which had the maximum air temperature (i.e. 24 °C) in comparison with two other treatments (Figure 13a). Furthermore, the shoot dry weight of pumpkin in exponential phase of 2013 experiment was higher than 2010, which this was due to higher temperature during exponential phase of 2013 growing season compared to 2010, i.e. 23.5 °C for 2013 vs. 22.8 °C for 2010 (Figure 13a). However, these results were in contrast to 2012 experiment which showed that in exponential phase, pumpkin dry weight was decreased with increasing air temperature (Figure 12). In contrast to 2012 experiment which all treatments did not receive any amount of nitrogen, the positive relationship between pumpkin dry weight and air temperature observed in exponential phase of three treatments with optimum growth conditions.
may be due to interaction between nitrogen and temperature. N deficiency increases sensitivity of plant photosynthesis to heat stress and nitrogen nutrition plays an important role in the protective adaptation of the crop photosynthesis to higher temperatures [87].

In linear phase, pumpkin dry weight was increased by increasing air temperature from 27.5 °C (i.e. 2013 year) to 28.3 °C (i.e. 2014 year) and with higher increase in air temperature, the pumpkin dry weight was decreased (Figure 13b). Therefore, the highest pumpkin dry weight in this phase was obtained from 2014 experiment which air temperature during its linear phase was 28.3 °C (Figure 13b). Pumpkin dry weight during linear phase of 2013 experiment was also higher than 2010 which this was because of cooler air temperature observed during linear phase of 2013 compared to 2010, i.e. 27.5 °C for 2013 versus 29.2 °C for 2010 (Figure 13b). Therefore, the greater pumpkin dry weight in 2014 growing season compared to 2013 was related to the higher air temperature observed during both exponential and linear phase of 2014 (Figure 13), while higher pumpkin dry weight of 2013 growing season in comparison with 2010 was due to warmer air temperature during exponential phase and cooler temperature during linear phase of 2013 year (Figure 13). In conclusion, these results showed that inter-annual weather variations also can affect pumpkin growth and optimum nitrogen application may increase pumpkin resistance to higher air temperature.

Conclusion

A number of management practices including different sowing dates, plant densities and nitrogen rates were evaluated in four experimental years (2010, 2012, 2013 and 2014) in order to determining the optimum growth conditions of pumpkin. Results showed that in 2010, 2013 and 2014 experiments, highest pumpkin growth was obtained using application of 250kgNha-1. In 2010 experiment, maximum growth of pumpkin produced under plant density of 2.5 plants m² and in 2012, there was no significant difference between plant densities of 2.5 and 4 plants m² regarding pumpkin growth. Furthermore, the significant difference did not observe between pumpkin dry weight obtained from sowing dates of May 1 and May 11 in 2012 experiment. Therefore, according to these results, it was concluded that optimum growth conditions for pumpkin regarding sowing date, plant density and nitrogen rate is 1-11 May, 2.5 plants m² and 250kg ha⁻¹, respectively. Results also showed that delaying the sowing date to late May can be resulted in significant reduction of pumpkin growth due to temperature stress. Thus, by selecting the optimum planting date, it is possible to mitigate the negative impacts of temperature stress pumpkin on crop growth. Furthermore, fluctuations of air temperature which was related to different sowing dates and different experimental years caused to the variation in pumpkin growth. For three sowing dates of 2012 experiment, pumpkin dry weight was decreased with increasing the air temperature in both exponential and linear phases of pumpkin growth cycle, while for treatments with optimum growth conditions in 2010, 2013 and 2014 years (i.e. T6-2010, T3-2013 and T3-2014 treatments), pumpkin dry weight (DW) in exponential phase was consistently increased as the air temperature increased and in linear phase, pumpkin DW increased to the temperature of 28.3 °C and thereafter dry weight decreased. Since in 2012 experiment no amount of nitrogen was applied, the higher temperature resistance of pumpkin grown under T6-2010, T3-2013 and T3-2014 treatments compared to the 2012 experiment was probably due to applying the optimum rate of nitrogen in these treatments. Therefore, optimum nitrogen rate not only can increase crop growth but also can enhance its resistance to the higher temperatures.

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