Late nitrogen application and late season irrigation increased bulb yield but negatively affected quality and storability of onion.

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One of the common mistakes during onion (Allium cepa L.) production committed by some Egyptian farmers is adding late nitrogen (N) dose and/or delaying irrigation withholding before bulb lifting which has a subsequent negative effect on both onion bulb quality and storability. To address the importance of ensuring the accurate timing of N application and ceasing irrigation before bulb lifting, two field experiments were conducted during winter seasons of 2014/2015 and 2015/2016 in the Experimental farm of the National Research Centre at El-Nubaria, Northern Egypt. Onion plants cv. Giza 20 were evaluated for late N application (last N dose 30 days before lifting) compared with normal N application time (last N dose 60 days before lifting) and late season irrigation before lifting where irrigation was ceased at three irrigation withholding periods (IWP) which were 7, 14, and 21 days before lifting. The obtained results indicated that late N application with short IWP (7 days) increased bulb fresh weight, neck diameter, bulb length, bulb width and bulb N content (%) but it reduced dry matter (%), and total soluble solids (TSS %). Late N application combined with short IWP increased all yield components (total, marketable and cull; kg/m²), but negatively affected bulb storability as it increased total bulb loss either as total weight loss (%) or deteriorated weight loss percentage (sprouted or rotten bulbs). The best treatment was normal N application with moderate IWP (14 days) which resulted in satisfactory bulb characteristics with moderate yield but markedly increased onion bulb storability and positively reduced both bulb total and deteriorated weight loss during storage.

Keywords: Neck diameter; Bulb fresh weight; TSS; Bulb N content; Decay; Postharvest loss.

INTRODUCTION

Onion (Allium cepa L.) is ranked the third most important vegetable crop after tomato and potato in Egypt which is the 9th onion producer in the world and in 2014 onion production area was 68487 ha with a total production of 2'505'289 tons with an average yield of about 36 t.ha⁻¹ (FAOSTAT, 2014). In addition, Egyptian onion varieties characterized with high quality characters due to its high nutritional value and pungency thus it has a high potential for exportation. Onion is considered one of the major sources of hard currency due to the early maturity and the possibility of the early exports to European markets. Production of onion bulb with high quality and low storage loss (either by weight loss or as decay loss during storage) is an important target for Egyptian onion growers. High quality onion bulbs are free of diseases, unblemished, and not doubled or have loose skin (flacked bulbs), with a color represent the cultivar (Ghoname et al. 2007;
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Tucker and Drew, 1982). One of the major challenges for exportation of Egyptian onion is short storability and postharvest decay during shipping. One reason of postharvest loss might be the high softness and succulence of harvested bulbs and bulb water content. Bulb water content was found to be greatly affected by both irrigation and nitrogen fertilization (Chung, 1989; Kebede, 2003; Kumar et al. 2007; Tsegaye et al. 2016; Yaso et al. 2007).

Nitrogen (N) is one of the most important nutrients for high yield and quality of vegetable crops especially under sandy soil conditions (Ahmed et al. 2009; Ghoname et al. 2009; Riad et al. 2009) and optimum nitrogen is essential for the maximum economic yield of onions. Nitrogen not only affects bulb yield but also, bulb maturity, disease resistance, quality and storability (Nasreen et al. 2007). Shortage of N reduces both total bulb yield, size and/or marketable yield (Jiliani et al. 2004). However, excessive N rates were found to produce succulent plants and bulbs that are more susceptible to mechanical damage and disease attack (Tekalign et al. 2012; Woldetsadik and Workneh, 2010; Wright 1993).

Nitrogen application normally is distributed throughout the growing season and the last N dose should be around bulb maturity to reduce water accumulation in the tissue and promote ripening (Saimbhi and Randhawa, 1983; Salo, 1996). Despite that late N application improve onion yield, but it oppositely delayed maturity, cause double bulbs, and reduce bulbs storability as a result of increased water content and high bulb storage rots. Moreover, late N application developed more thick-necked bulbs, which are susceptible to wounding when topped and thus easily attacked by soft-rotting bacteria (Corgan et al. 2000; Wright 1993).

Onion is sensitive to water stress and requires frequent irrigation to avoid water deficiency and to recharge the rhizosphere with optimum soil moisture (Koriem et al. 1994). Maximum yield of onion was found to be obtained when soil adequately moist throughout the bulb development time (Kadayifci et al. 2005; Martín de Santa Olalla et al. 2004). Water deficiency on onion plants caused a significant reduction in bulb weight and size and reduced total yield (Rattin et al. 2011).

Although excessive irrigation during the vegetative period increases foliage growth, increases bulb size, and total and marketable yield, it delays and reduces bulb development, reduces nutritional values, reduce dry matter content, and also has a negative impact on storability (Bekele and Tilahun 2007; Biswas et al. 2003; Biswas et al. 2010; Chung, 1989; Kemal, 2013; Neeraja et al. 1999; Pérez-Ortólá and Knox, 2015; Shock et al. 1998; Tsegaye et al. 2016). However, Soujala et al. (1998) reported that irrigation had only a minor effect on the storage performance and shelf life of onion while Nandi et al. (2002) reported that growth and yield of onion were significantly affected by irrigation, but not postharvest life.

Even though late irrigation at the end of the growing season simulates plant vegetative growth and increased bulb yield (Attallah, 2012; Brewster, 1990), it has an undesirable effect on storability of onion due to the significant increase in bulbs moisture content (Chung, 1989). Other negative effects of late season irrigation are the delayed maturity, reduced bulb quality, promoting bulb skin flacking and increase bulb rotting (Brewster, 1990). Also, late irrigation increases sprouted bulb percentage during storage (Sorensen and Grevesen, 2001). On the other hand, long water withholding period significantly reduce storage losses compared with later irrigation before lifting (Bhonde et al. 1996; Biswas et al. 2010; Shock et al. 1998).

There is limited available work on the effect of both N application timing and irrigation withholding period before lifting thus, the target of the current study was to figure out the optimum N application schedule and ideal irrigation withholding period under Egyptian sandy soil conditions in order to have highest bulb yield and quality while maintaining bulb storability.

**MATERIALS AND METHODS**

**Location, plant material, and growth conditions**

Two field experiments were conducted during 2014/2015 and 2015/2016 growing seasons in the National Research Centre Experimental farm at El-Nubaria, El-Beihira Governorate, north of Egypt (30°29'50"N 30°19'16"E). The experimental soil had a sandy texture (87.4% sand, 7.9% silt, and 4.7% clay) with pH of 7.8, EC of 1.68 dS/m and organic matter content of 0.41% in the upper 30cm of the soil. Available soil N, P, and K contents were 17.1, 4.4, 26.0 mg/kg soil, respectively and extractable-Fe, Mn and Zn were 2.98, 1.74, 0.66 mg/kg soil, respectively. The experimental site has a prevailing arid climate with cool winters and hot dry summer.
Table (1) Monthly climatic data in the experimental site during the onion planting seasons of 2014/2015 and 2015/2016.

<table>
<thead>
<tr>
<th>Month</th>
<th>Season</th>
<th>Air temperature (°C)</th>
<th>Humidity (%)</th>
<th>Precipitation (mm)</th>
<th>Wind speed (m/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>December</td>
<td>2014/2015</td>
<td>16.1</td>
<td>7.9</td>
<td>22.7</td>
<td>63</td>
</tr>
<tr>
<td>January</td>
<td>14.2</td>
<td>8.1</td>
<td>21.2</td>
<td>60</td>
<td>1.4</td>
</tr>
<tr>
<td>February</td>
<td>16.4</td>
<td>9.4</td>
<td>24.3</td>
<td>58</td>
<td>0.1</td>
</tr>
<tr>
<td>March</td>
<td>18.6</td>
<td>10.7</td>
<td>25.2</td>
<td>63</td>
<td>12.6</td>
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<tr>
<td>April</td>
<td>20.3</td>
<td>12.4</td>
<td>28.8</td>
<td>52</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>21.2</td>
<td>12.9</td>
<td>28.6</td>
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<tr>
<td>December</td>
<td>2015/2016</td>
<td>19.4</td>
<td>8.0</td>
<td>23.3</td>
<td>64</td>
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<tr>
<td>January</td>
<td>15.5</td>
<td>7.1</td>
<td>24.8</td>
<td>62</td>
<td>1.2</td>
</tr>
<tr>
<td>February</td>
<td>16.3</td>
<td>7.7</td>
<td>26.9</td>
<td>57</td>
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<tr>
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<td>11.1</td>
<td>30.5</td>
<td>50</td>
<td>0.1</td>
</tr>
<tr>
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<td>24.8</td>
<td>14.2</td>
<td>31.8</td>
<td>48</td>
<td>0</td>
</tr>
</tbody>
</table>

Table (1) summarizes the monthly climatic data for the two growing seasons. The climatic variables were obtained from Nubaria meteorological station according to the official data of The Central Laboratory of Meteorology, Ministry of Agriculture and Land Reclamation, Egypt. Since the climate at the experimental site was usually dry with ineffective rainfall amount, rainfall water was not taken into consideration in the irrigation water calculation.

Onion seedlings cv. Giza 20 was transplanted at the second week of December in the two seasons. Seedlings were planted on drip irrigated laterals that were 1 m apart and 25 m long with 25 cm between drippers (standard 4 L/h discharge @ 1.5 bar drippers). Three irrigation lines were used as a border between treatments and were not included in the experiment to prevent the interaction between treatment plots. Four seedlings were planted around each dripper with 10 cm apart. Onion plants were supplied with the recommended dose of nitrogen (20 g N/m²), phosphorus (12 g P₂O₅/m²), and potassium (25 g K₂O/m²). Other agricultural cultural practices for growing onion were conducted as recommended for onion production at North Delta region.

**Experimental design and treatments**

This experiment evaluated the effect of N application time: normal N application (last N dose was 90 days after transplanting; about 60 days before lifting) and late N application (last N dose was 120 days after transplanting; about 30 days before lifting). Also, this study investigated three irrigation withholding periods (IWP): 7, 14, and 21 days before bulb lifting. Irrigation withholding was done manually by switching off water from the drip irrigation lines. The treatments were arranged in a split plot design with three replicates where N application time treatments were the main plots, while irrigation withholding period (IWP) the subplot.

**Measurements of crop parameters:**

**Bulb characteristics.**

At harvesting time (when bulbs reach the variety normal bulb size and skin color which is about 150 DAT), onions were lifted by hand. Immediately after lifting, onions were subjected to field curing on the ground under shaded area for 10 days. After curing period bulbs were sorted and the
followed variables were measured: Average bulb weight (g); by dividing the total yield of the plot area on the number of bulbs. Dry matter percentage (D.M. %): Bulb tissue was oven dried at 70°C for 72 hours and weighed then attributed to the initial fresh weight. Neck diameter (cm). Bulb diameter (cm). Bulb length (cm).

Yield and yield components. The following variables were measured: Total yield (kg/m²). It was calculated on basis of total yield for the experimental plot. Cull yield (kg/m²): It includes bulbs of less than 3 cm diameter, doubles, bolters, off-colored and damaged bulbs. Marketable yield (kg/m²): After removing the cull bulbs, the remaining sound bulbs were considered as marketable yield.

Bulb chemical quality parameters. Another sample was taken to the lab in Vegetable Research Department, NRC, to measure bulb quality characteristics. Bulb quality was evaluated by measuring total soluble solids (TSS %; determined by Hanna Digital Refractometer Model HI96801). Bulb dried samples were wet digested and total nitrogen content (%) was determined using the modified micro-Kjeldahl method according to the procedure described by Cottenie et al. (1982).

Bulbs storability
After harvesting and bulb curing, marketable bulbs uniform in size and shape were then cleaned, their roots removed and their tops cut off 2 cm above the bulbs. For the storage study, bulbs from each treatment were placed in 2-kg plastic netted bags (subsamples) and stored for 5 months in a shaded well-ventilated area at room condition. During storage period, three subsamples from each treatment were taken out every month and weighed then sorted to discard deteriorated bulbs (sprouted, damaged, and rotten bulbs). In each subsampling time, total weight loss percentage (total weight after storage attributed to the initial weight before storage) and deteriorated weight loss percentage (deteriorated bulbs weight attributed to the initial weight before storage) were measured.

2.4. Statistical analysis
The data were statistically analyzed and means separation done using LSD test according to the method described by Gomez and Gomez (1984). Due to the close proximity between the two studied seasons, data for the both seasons were combined.

RESULTS AND DISCUSSION

Bulb characteristics
Both late N application and short irrigation withholding period significantly affected onion bulb characteristics, i.e., bulb fresh and dry weight, neck diameter and bulb length and width (Table 2). The obtained data clearly indicate that there is a strong interaction between N application timing and the irrigation withholding period in all of the measured parameters.

Average bulb fresh weight (g) statistically increased with the late N application and with shorter irrigation withholding period (IWP) as shown in Table (2). The highest values were obtained from late N application treatment with either 7 or 14 days IWP. The lowest average bulb fresh weight was recorded when onion plants received the last N dose at normal application time with longer irrigation withholding (21 days IWP). The obtained results were in agreement with those obtained by (Geries et al. 2012; Kebede, 2003; Woldetsadik and Workneh, 2010) who observed that onion bulb fresh weight increased with more applied N. These results confirmed the findings of Tsegaye et al. (2016) who mentioned that using the optimum level of irrigation increased bulb fresh weight.

Dry matter content is among the most important quality traits of onion bulbs (Ombódi et al. 2016). Bulb dry matter was significantly affected by both N application timing and irrigation withholding period (Table 2). Normal N application with longer irrigation withholding period (21 or 14 days IWP) significantly resulted in the highest bulb dry matter with no significant difference between them followed by late N application combined with 21 days IWP and then followed by normal N application with 7 days IWP. However, lowest bulb dry matter was with late N application and wet soil conditions (7 and 14 days IWP) with no significant difference between them. These results were supported by several other researchers who revealed that increasing N application increased bulb dry matter (Abdissa et al. 2011; Geries et al. 2012). Meanwhile, other investigations stated that dry matter in onion bulbs tended to increase with less frequent irrigation and the correlation between the amount of supplied water and dry matter was negative (Chung, 1989; Ombódi et al. 2013; Riekels, 1977).
As for neck diameter, Data shown in Table (2) showed that normal N application time with longer IWP (21 days) produced bulbs with smaller, tighter and more closed neck, which is more desired onion quality parameter. While late N application with shorter IWP (7 days) led to the most thick-necked onion bulbs. The thickest neck was obtained when onion plants received late N application with short irrigation withholding period (7 days) followed by late N application with 14 days IWP and normal N application with 7 days IWP with no significant difference between them. The smallest neck diameter was achieved when normal N application treatment was combined with longer IWP (21 days).

Previous studies showed an increment of neck diameter with high N fertilization and/or more irrigation frequency. High N application has been associated with thick necks in onions (Brewster et al. 1987; Gamieli et al. 1991; Geries et al. 2012; Messele, 2016; Muhammad et al., 2016; Syed et al. 2000). While Chung (1989) and Gessesew et al. (2015) mentioned that N rate had no effect on onion bulb neck thickness. On the other hand, Al-Moshileh, (2007) and Bolandnazar (2009) mentioned that thick-necked onion bulbs were markedly increased with increasing of soil moisture The wider or thicker neck diameter bulbs is an undesirable character which expected to be more easily damaged and susceptible to be pathogen infected and consequently had higher storability loss (Muhammad et al. 2016).

Bulb length and width were significantly affected by N application time and irrigation withholding period before lifting (Table 2). Late N application with shorter IW period (7 or 14 days) produced bulbs with the highest length and width with no significant difference between these two
The results suggested that delaying N application combined with shorter IW period clearly increased bulb growth which is might be attributed to the more translocation and accumulation of water in the bulb hence increasing fresh weight while decreasing dry matter content and also increasing bulb length and width. The results of Chung (1989) demonstrated that increasing irrigation withholding before harvesting reduced bulb size (expressed as a reduction in size grade). Furthermore, bulb diameter of onion was found to be increased with increasing irrigation regime and N level (Kemal, 2013; Neeraja et al. 1999; Tsegaye et al. 2016) who stated that the improved bulb diameter with increasing N and irrigation resulted in more large sized bulbs, which have high market demand.

Yield and yield component
Late nitrogen application combined with either 7 or 14 days IWP statistically increased bulb total, marketable, and cull yield (Fig. 1). Regarding total and marketable yield (kg/m²), there was no significant difference between late nitrogen application combined with either 7 or 14 days IWP treatments and normal N application with 7 days of IWP. In addition, there was no significant difference between normal N application with 7 days of IWP and normal N application with 14 days IWP. The lowest total yield was obtained with either normal N or late N application combined with 21d IWP with no significant difference between them. On the other hand, cull yield was significantly higher with late N application in all irrigation withholding periods with no significant difference among them followed by normal N application combined with either 14 or 7 days IWP with no significant difference between them. The lowest cull yield was obtained with normal N application with 21 days IWP. These results are in agreement with those of (Geries et al., 2012; Kebede, 2003; Woldetsadik and Workneh, 2010) who found that increasing N dose increased total bulb yield.

Similarly, the obtained results were in harmony with those of Chung (1989) who mentioned that shorter irrigation withholding period increased the total bulb yield but it reduced the cull yield (small size bulbs) and also with Bekele and Tilahun (2007) who stated that the maximum yield was obtained with full irrigation treatment. Generally, onion is more sensitive to water stress because of its shallow roots and this might be the reason for the reported increase in vegetative growth and bulb yield with increasing irrigation.

In regard to the interaction between N fertilization and irrigation, the results of Tsegaye et al. (2016) indicated that marketable bulb yield of onion is positively influenced by increasing N and irrigation regime. However, further increase of N can adversely affect marketable bulb yield due to the development of physiological disorders such as thick-necked bulbs. Our results are in conformity with many authors (Enciso et al. 2009; Kandil et al. 2011; Kemal, 2013; Neeraja et al. 1999; Pejić et al. 2011).

The positive response of bulb yield to high amounts of water and N application could be attributed to the enhancement in the availability of water and nutrients to the plants root, which in turn improves the vegetative growth of the onion plants and hence increases photosynthetic area and total plant assimilation. The increase in assimilates resulted in larger bulbs and consequently higher total and marketable bulb yield.

Bulb chemical quality parameters
Regarding total soluble solids (TSS %), there was a statistically positive interaction between N application and irrigation withholding period (Fig. 2). The highest TSS value was obtained when normal N application with 21 days IWP were applied and the lowest TSS obtained when onion plants received late N application combined with 7 days IWP. Similar results were recorded by other investigators and they demonstrated that the highest TSS values were obtained in onion bulbs of plants that had less irrigation before bulb harvesting (El-Tabbakh et al. 1979; Kandil et al. 2011). However, different findings were obtained by Abdalla (1992) who found that the irrigation regime had no significant effect on the TSS values.

Our findings were in agreement with Moursy et al. (2007) who showed that increasing of N-level resulted in an increment in the measured TSS value. Oppositely, the results of Haggag et al. (1986) and Hanna-alla et al. (1991) detected lower TSS content with increasing N dose.

As for onion bulb N content (%), late N application with 7 days IWP had significantly the highest N content. The lowest N content was recorded by plants that received normal N application with 21 days water withholding (Fig. 2).
Figure. (1) Onion bulbs yield component (Total, Marketable, and Cull; kg/m²) as affected by nitrogen application time and different irrigating withholding periods. Means with the same letter within each yield component are not significantly different at P ≤ 5% (combined data set of 2014/2015 and 2015/2016 seasons).

Fig. (2) Onion bulbs TSS (%) and N content (%) as affected by nitrogen application time and different irrigating withholding periods. Means with the same letter are not significantly different at P ≤ 5% (combined data set of 2014/2015 and 2015/2016 seasons).
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Figure. (3) Onion bulbs total weight loss (%) and deteriorated weight loss (%) during storage for 5 months as affected by nitrogen application time and different irrigating withholding periods (combined data set of 2014/2015 and 2015/2016 seasons).
Kebede (2003) and Kemal (2013) found a similar trend and mentioned that N uptake of shallot bulbs was higher with increased irrigation and/or N fertilization. In addition, Mayer and Marcum (1998) indicated that the total potato tuber N content increased as the amount of applied water increased. The positive impact of late N application and longer IWP could be due to the more availability and utilization of N because of the higher soil moisture content during the last stage of bulb development.

**Bulbs storability**

Onion bulb both total weight loss and deteriorated weight loss increased gradually with increased storage period. After 5 months of storage, the total weight loss was highest in bulbs treated with late N application and received 7 days IWP. The highest quality preservation and best bulb storability expressed as lowest the total weight loss was obtained by onion bulbs that had normal N application with long irrigation withholding period (21 days) (Fig. 3).

Regarding deteriorated weight loss, analogous trend to the total weight loss was found (Fig. 3) except that after 4 months of storage there was a higher deteriorated weight loss in the bulbs with Late N application and 21 days IWP than bulbs of normal N application with 14 days IWP.

Generally, both late N application and shorter water withholding period negatively affected bulb storability throughout the storage period. The higher weight loss during storage in treatments with late N and or short IWP may be attributed to that onion plants received N late in the season usually store high water content, had more succulent soft tissues and had higher percentage of thick-necked bulbs. Thick neck bulbs had higher susceptibility rate to pathogen infections and a higher total and deterioration weight loss during storage. These results are in harmony with several researchers who demonstrated the negative effect of high N on onion bulbs storage and that adding more nitrogen especially in the late season delays maturity and gave soft bulbs, causing poor handling qualities (Kumar et al. 2007; Muhammad et al. 2016; Shock et al. 1998; Tucker and Morris, 1984). Additionally, increasing irrigation before bulb lifting had a negative impact on bulb storability which could be due to that more irrigation in the late season gave more succulent bulbs and more susceptible to be attacked by bacteria and fungi during storage. (Biswa et al. 2010; Chung, 1989; Shock et al. 1998).

**CONCLUSION**

This investigation affirmed the significance of both nitrogen application timing and irrigation withholding period on onion bulb growth, yield, quality, and storability. It could be recommended to onion growers under sandy soil conditions to add last nitrogen dose two months before bulb lifting and to avoid nitrogen application during the last month before lifting. Furthermore, this study stresses the importance of the drought period at the end onion bulb growing. The optimum irrigation withholding period under these conditions is two weeks before bulb lifting for maximum bulb yield with best bulb quality and store ability.

**CONFLICT OF INTEREST**

The authors declared that present study was performed in absence of any conflict of interest.

**AUTHOR CONTRIBUTIONS**

All authors contributed equally in all parts of this study.

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