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Research Article

Effect of nitrogen fertilization levels and plant density on dry weight, yield components and bulb quality of onion plant

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Abstract

A field experiment was carried out during the two successive winter seasons of 2020/2021 and 2021/2022 to study the effect of mineral nitrogen levels and plant density on dry weight, yield and its components, as well as bulb quality of onions (cv. 'Ahmar Tanawy'). This experiment included 12 treatments, which were combinations between four levels of mineral nitrogen (0, 192, 240 and 288 kg N/ha) and three plant densities (4, 5 and 6 rows/ridge equal 33.33, 41.67 and 50 plants/m^2, respectively). These treatments were arranged in a split-plot design with three replications. Nitrogen levels were randomly arranged in the main plots, and plant densities were randomly distributed in the subplots. Nitrogen application at 192,244 and 288 kg N/ha led to increase dry weight/plant compared to control (zero N) and 288 kg N/ha gave the highest values of dry weight of leaves, dry weight of bulbs, and total dry weight per plant at 100 days in both seasons. The increases in total dry weight per plant were about 4.84 and 4.80 g per plant for 192 kg N/ha, 4.76 and 3.87 g per plant for 244 kg N/ha, and 6.86 and 5.74 g per plant for 288 kg N/ha over the control at 100 days in the 1st and 2nd seasons, respectively. The interaction between N at 288 kg/ha and low plant density (4 rows/ridge) gave the highest values of dry weight of leaves, bulb, and total dry weight/plant and increased yield of grade 1, exportable yield, average bulb weight, as well as nitrate and sulphur contents in bulbs, whereas the interaction between N at 244 kg/ha and high plant density (6 rows/ridge) increased grades 2, 3, and 4, marketable yield, and total yield/ha.

Keywords: bulb quality; mineral nitrogen levels; onion; plant density; yield

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Introduction

Onion (*Allium cepa* L.) belongs to the family *Amaryllidaceae* (Alliaceae). It is one of the most important commercial vegetable crops and is widely grown in almost all countries in the world (Gebretsadik and Dechassa, 2018). In addition to its medicinal value, it contains carbohydrates, protein, vitamin A, thiamine, riboflavin, niacin, and ascorbic acid (Yahaya *et al*., 2010). Over 85.5 million tons of onions were harvested from over 4.3 million hectares of land, with Africa accounting for about 0.57 million hectares of the total (Charrondière *et al*., 2013). Egypt occupies fifth place in the world of growing area onions and ranked ninth in terms of productivity. In Egypt, the production of onions reached in season 2013, approximately two million tons of the cultivated area (150 thousand faddan) (Aboukhadrah *et al*., 2017; Ragab *et al*., 2019). The medicinal and health benefits of onion are due to flavonoids, anthocyanins, fructo-oligosaccharides, and organosulfur compounds (Omar *et al*., 2020; Ketter and Randle, 1998). Onion is a versatile vegetable that may be used in a wide variety of warm recipes. It is most prepared by culinary methods such as baking, boiling, braising, grilling, frying, roasting, sautéing, or steaming. It can be used as a spice, a pickle, a juice, or even raw in salads *(Zhao et al*., 2021). Onion is a popular herbal remedy for a variety of ailments, including atherosclerosis, asthma, bronchitis, and coughs, it has many bioactive components, including organosulfur compounds, phenolic compounds, polysaccharides, and saponins, are responsible for their beneficial effects on human health (Priyadarshini *et al*., 2019; Omar *et al*., 2020). The antioxidant, antimicrobial, anti-inflammatory, anti-obesity, anti-diabetic, anticancer, cardiovascular, neuroprotective, hepatorenal, respiratory, digestive, reproductive, and immunomodulatory properties of onion and its bioactive compounds have recently been demonstrated by accumulated studies (Loredana *et al*., 2019; Zhao *et al*., 2021). Due to their short, unbranched roots, onions are more susceptible to nutritional deficiencies than other plants and so benefit greatly from supplemental fertilization (Brewster, 2008). Primary macronutrients include nitrogen (N), potassium (K), and phosphorus (P) due to the high uptake rates of these three elements from the soil by plants. Most crops are more likely to lack enough of these nutrients. Nitrogen, which makes up about 7% of a plant's dry matter, is the primary structural element in its cells. As a mineral nutrient, it is particularly convoluted due to its several forms in soil, air, and water. As a result, it's tough to make a firm recommendation on the ideal dosage and frequency of administration. Nitrogen (N) is a necessary nutrient, yet its scarcity is a common factor in reducing agricultural output. There is a considerable danger of nitrate leaching losses and a low N fertilizer usage efficiency in onion (*Allium cepa* L.) production because of the plants' shallow and sparse root systems (Geisseler *et al*., 2022). Nitrogen is an essential elementary constituent of numerous important substances such as amino acids, protein, and nucleic acids (Alharbi *et al*., 2022; Mohamed *et al*., 2022; Omar *et al*., 2022; Galal *et al*., 2023). There are two benefits to using the optimal amount of space between plants or plant populations, this reduces the likelihood of plants having to compete for scarce resources like water, nutrients, and sunlight. Furthermore, with the right number of plants in each plot, farmers may make the most of their harvesting space (Aboukhadrah *et al*., 2017).

An attempt has been made by several workers to find out the optimum plant spacing and nitrogen fertiliser for onion plants to maximise total yield with the best quality and improve storability, especially under old land conditions. The plants grown under wider spacing received more nutrients, light, and moisture around each plant compared to plants with closer spacing. Which is probably the cause of the better performance and yield of individual onions in wider spacing. Also, these plants with wider spacing produced the highest percentage of multiplier bulbs that were not better for storage or consumer demand. Whereas the plants grown under the closest spacing gave the maximum total yield of onions due to the presence of more plants, resulting in the highest total yield. But the size of the bulb under the closest spacing was so small that they were not suitable for marketing due to consumer choice (Khan *et al*., 2003). Aliyu *et al*. (2008) found that the optimum yield of onion bulbs (30.83 t/ha) was obtained from 15 cm intra-row spacing combined with 100 kg N/ha. However, for large bulb sizes, the application of 150 kg N/ha in plants spaced at 25 cm intra-row spacing may be recommended. Therefore, the aim of this study was to determine the suitable nitrogen fertiliser rate and plant density and to obtain maximum onion yield with high bulb quality.

Materials and Methods

Experimental design

A field experiment was carried out during the two successive winter seasons of 2020/2021 and 2021/2022 on the private farm at Diarb Negm District, Sharkia Governorate, Egypt, to study the effect of mineral nitrogen levels and plant density on dry weight, yield, and its components, as well as bulb quality of onions onion (cv. 'Ahmar Tanawy'). The physical and chemical properties of the experimental soil in 2020/2021 and 2021/2022 seasons are presented in Table 1.

Table 1. The physical and chemical properties of the experimental soil in 2020/2021 and 2021/2022 seasons

Soil properties	1st season	2nd season
Physical properties		
Sand (%)	90.24	90.69
Silt (%)	7.40	6.18
Clay (%)	2.36	3.13
O.M (%)	0.04	0.06
Texture	Sandy	Sandy
Chemical properties		
pH	8.19	8.16
E.C. (mmhos/cm)	2.08	1.99
Total N (%)	0.02	0.03
Available N (ppm)	4.07	3.98
Available P (ppm)	3.17	3.36
Available K (ppm)	10.24	9.91

O.M.; Organic matter and E.C: Electric conductivity. Soil samples were taken from 25 cm soil surface.

This experiment included 12 treatments, which were combinations between four levels of mineral nitrogen (0, 192, 240 and 288 kg N/ha), and three plant densities (4, 5 and 6 rows/ridge equal 33.33, 41.67 and 50 plants/m^2, respectively). These treatments were arranged in a split-plot design with three replications. Nitrogen levels were randomly arranged in the main plots, and plant densities were randomly distributed in the subplots. Nitrogen levels were in the form of ammonium sulphate (20.6% N) and added as a soil application (three doses) every month, beginning one month after transplanting. Seeds of onion were sown in the nursery on November 5th and 10th in the 2020/2021 and 2021/2022 seasons, respectively. Onion transplants were transplanted on December 25th and 28th in the first and second seasons, respectively, at 10 cm apart. All experimental units had an area of 21.6 m^2, and they contained three ridges with a length of 6 m and a width of 120 cm. One ridge was used for the samples to measure vegetative growth, and the other two ridges were used for yield determination. Plant densities and the number of plants per m^2 and hectare are presented in Table 2.

Table 2. Plant densities and number of plants per m² and hectare

Plant densities	Wide (cm)		Plant spacing (cm)	Area/ plant (m^2)	Number of plants per	
	ridge	row			m^2	ha
4 rows / ridge	120	30	10	0.03	33.33	333300
5 rows / ridge	120	24	10	0.024	41.67	417700
6 rows / ridge	120	20	10	0.02	50	500000

Phosphorus and potassium were added at a rate of 144 and 204 kg/ha in the form of calcium superphosphate (16-18% P_2O_5) and potassium sulphate (48-52% K_2O), respectively. All the amounts of phosphorus fertilizer and one fourth of the amounts of K mineral fertilizer were added during soil preparation. The rest of the K fertilizers were divided into three portions and added to the soil every month, beginning at 30 days from transplanting.

Sampling and measurements

Dry weight: The different parts of the onion plant, i.e., bulb and leaves, were oven dried at 70 °C till constant weight, and then bulb dry weight, leaf dry weight, and dry weight (bulb + leaves)/plant were recorded at 100 days after transplanting.

Yield and its components

At the proper maturity stage of the bulbs, bulbs from each plot were harvested and graded into four categories according to specifications laid down by the Ministry of Economic Affairs for onion exportation (1963) as follows: Grade 1: bulbs with a diameter above 5.5 cm; Grade 2: bulbs with a diameter between 4.5 and 5.5 cm; Grade 3: bulbs with a diameter between 3.5 and 4.4 cm; and Grade 4: bulbs with a diameter less than 3.5 cm. Each grade was weighed separately on the same day, and the following data were recorded: Exportable yield (grade 1+ grade 2) tonne/ha, marketable yield (grade 1+ grade 2+ grade 3) tonne/ha, and total yield (grade 1+ grade 2 + grade 3 + grade 4) ton/ha as well as average bulb fresh weight = yield of bulbs per plot or total number of bulbs per plot.

Bulbs quality

At harvest time, five bulbs were randomly taken from each treatment and oven dried at 70 °C until constant weight, and the chemical constituents of onion bulbs during the two seasons were determined as follows: Nitrate content in bulbs (mg/kg FW) was determined according to the methods described by Cafado *et al*. (1975), and Sulphur content (%) was estimated according to Novozamsky and Van Eck (1977).

Statistical analyses

Collected data were subjected to proper statistical analysis of variance according to Snedecor and Cochran (1980), and the differences among treatments were compared using Duncan's multiple range test (Duncan, 1958).

Results

The effect of nitrogen fertilizer at different levels (192, 240 and 288 kg /ha) on dry weight of leaves/plant (g), and on dry weight of bulb (g) at 100 days after transplanting of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions are presented in Tables 3, 4 and 5. Fertilising onion plants with 192,244 and 288 kg N/ha increased dry weight weight/ plant compared to control (zero N), and 288 kg N/ha gave the highest values of dry weight of leaves, dry weight of bulbs, and total dry weight per plant at 100 days in both seasons (Tables 3-5). The increases in total dry weight per plant were about 4.84 and 4.80 g per plant for 192 kg N/ha, 4.76 and 3.87 g per plant for 244 kg N/ha, and 6.86 and 5.74 g per plant for 288 kg N/ha over the control at 100 days in the 1st and 2nd seasons, respectively.

Table 3. Effect of nitrogen levels, plant density and their interaction on dry weight of leaves/plant (g) at 100 days from transplanting of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	7.25de	6.43e	6.14e	**6.60c**
192	9.70b	9.13bc	8.53bc	**9.12b**
240	9.67b	8.98bc	8.78bc	**9.14ab**
288	12.38a	9.13bc	8.23cd	**9.91a**
Mean (NL)	9.75a	8.4b	7.92b	
2021/2022 season				
0	7.42f	7.28f	6.60g	**7.10c**
192	9.76 a	8.93bc	8.84bc	**9.17a**
240	7.78ef	8.23de	8.43cd	**8.14b**
288	10.03a	9.04b	8.88bc	**9.31a**
Mean (NL)	**8.74a**	**8.37b**	**8.18b**	

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

The effect of plant density (4, 5 and 6 rows/ridge) on dry weight of leaves/plant (g) and on dry weight of bulb (g) at 100 days after transplanting of onion plants during the 2020/2021 and 2021/2022 seasons under clay soil conditions is presented in Tables 3, 4 and 5. Planting onion plants at 4 rows per ridge (low plant density) gave the highest values of dry weight of leaves, dry weight of bulb, and total dry weight per plant at 100 days in both seasons (Tables 3-5). The increases in total dry weight per plant were about 2.88 and 1.55 g per plant for 4 rows/ridge, and 1.29 and 0.54 g for 5 rows/ridge over 6 rows/ridge at 100 days in the 1st and 2nd seasons, respectively.

Table 4. Effect of nitrogen levels, plant density and their interaction on dry weight of bulb (g) at 100 days from transplanting during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	5.41f	5.03f	4.81f	**5.08 c**
192	8.11b	7.80bc	6.31e	**7.40b**
240	7.36cd	7.53bcd	7.02d	**7.30b**
288	9.08a	8.89a	7.92bc	**8.63a**
Mean (NL)	7.49a	7.31a	6.51b	
2021/2022 season				
0	6.01c	5.81c	4.68d	**5.50c**
192	8.87a	7.82b	7.99b	**8.22b**
240	9.04a	8.14b	7.79b	**8.32 b**
288	9.32a	8.94a	8.81a	**9.02a**
Mean (NL)	**8.31a**	**7.67b**	**7.31c**	

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

The effect of interaction between nitrogen fertiliser at different levels (192, 240, and 288 kg/ha) and plant density (4, 5 and 6 rows/ridge) on dry weight of leaves/plant (g) and on dry weight of bulb (g) at 100 days after transplanting of onion plants during the 2020/2021 and 2021/2022 seasons under clay soil conditions are presented in Tables 3, 4 and 5. The interaction between nitrogen levels at 288 kg N/ha and plant density (4 rows/ridge) gave the highest values of dry weight of leaves, bulb, and total dry weight per plant at 100 days in both seasons (Tables 3 and 5). In general, planting with low plant density (4 rows per ridge), dry weight of leaves, bulb, and total dry weight per plant were the highest values with N at 192, 244 and 288 kg/ha as well as control, compared to planting with high plant density (5 or 6 rows per ridge) with the same N level 100 days in both seasons.

Table 5. Effect of nitrogen levels, plant density and their interaction on total dry weight/plant (g) at 100 days after transplanting of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	12.66 g	11.45h	10.95h	**11.68c**
192	17.81bc	16.93cd	14.84f	**16.52b**
240	17.03bcd	16.51de	15.80ef	**16.44b**
288	21.46a	18.02b	16.15de	**18.54a**
Mean (NL)	17.24a	15.72b	14.43c	
2021/2022 season				
0	13.43e	13.09e	11.28f	**12.60d**
192	18.63ab	16.75d	16.83d	**17.40b**
240	16.82d	16.37d	16.22d	**16.47c**
288	19.35a	17.98bc	17.69c	**18.34a**
Mean (NL)	**17.05a**	**16.04b**	**15.50c**	

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

The effect of nitrogen fertilizer at different levels (192, 240, 288 kg /ha) on yield of grade 1, 2, 3 and 4 (ton/ha) and on exportable yield (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions are presented in Tables 6, 7, 8, 9, 10, 11, 12 and 13. Fertilising with N at 288 Kg/ ha significantly increased yields of grade 1, grade 2, exportable yield, marketable yield, and total yield, as well as average bulb weight, with no significant differences with N at 244 kg/ha in marketable yield or total yield (Tables 6 to 13). This means that N at 288 kg/ha increased yield of grade 1 and exportable yield, whereas N at 244 kg/ha increased yield of grade 2, marketable yield, total yield, and average bulb weight in both seasons. As for yield of grade 3 and grade 4, N at 244 kg /ha increased yield of grade 3 in both seasons, whereas N at 288 kg /ha increased yield of grade 4 in the 1st and 2nd seasons, respectively. Nitrogen at 244 kg/ha. increased total yield may be due to 244 kg/ha. increased yield of grades 2 and 3. The increases in total yield were about 5.771 and 5.374 tons/ha for N at 192 kg/ha, 10.375 and 9.041 tons/ha for N at 244 kg/ha, and 10.553 and 9.517 tonnes/ha for N at 288 kg/ha over the control in the 1st and 2nd seasons, respectively.

Table 6. Effect of nitrogen levels, plant density and their interaction on yield of grade 1 (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	4.901f	3.622g	2.928g	**3.816d**
192	8.621cd	7.414de	6.838e	**7.622c**
240	11.489b	7.313de	7.279e	**8.693b**
288	13.097a	11.443b	9.612c	**11.383a**
Mean (NL)	9.526a	7.447b	6.662c	
2021/2022 season				
0	5.306fg	3.835gh	3.072h	**4.070d**
192	9.463c	7.752de	6.480ef	**7.898c**
240	11.729b	8.993cd	7.279e	**9.334b**
288	14.297a	11.923b	9.612c	**11.942a**
Mean (NL)	**10.198a**	**8.124b**	**6.610c**	

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 7. Effect of nitrogen levels, plant density and their interaction on yield of grade 2 (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	5.443g	6.833fg	7.152f	**6.475c**
192	9.041e	11.004d	10.142de	**10.061b**
240	16.054c	18.235ab	18.334ab	**17.539a**
288	16.860bc	17.093abc	18.502a	**17.484a**
Mean (NL)	11.849b	13.291a	13.531a	**0.000**
2021/2022 season				
0	5.443e	7.114de	7.207de	**6.588c**
192	8.856cd	11.352c	9.240cd	**9.816b**
240	15.574b	16.555ab	17.088ab	**16.404a**
288	16.860ab	17.093ab	18.502a	**17.484a**
Mean (NL)	**11.683b**	**13.027a**	**13.008a**	**0.000**

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 8. Effect of nitrogen levels, plant density and their interaction on yield of grade 3 (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	2.153g	3.358f	3.787f	**3.098d**
192	6.550de	6.667de	12.094ab	**8.436b**
240	9.514c	12.391a	11.407b	**11.102a**
288	5.904e	7.320d	9.694c	**7.639c**
Mean (NL)	6.029c	7.433b	9.245a	**0.000**
2021/2022 season				
0	2.153e	2.801e	3.970d	**2.974d**
192	6.998c	6.480c	11.117a	**8.198b**
240	7.354c	9.701b	10.351ab	**9.134a**
288	4.802d	7.320c	9.694b	**7.272c**
Mean (NL)	**5.326c**	**6.574b**	**8.782a**	**0.000**

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 9. Effect of nitrogen levels, plant density and their interaction on yield of grade 4 (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg/ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	1.973ef	2.292e	2.678d	**2.316c**
192	3.146c	3.206c	3.965b	**3.439b**
240	1.795f	3.012cd	4.994a	**3.266b**
288	3.710b	4.942a	4.934a	**4.529a**
Mean (NL)	2.654c	3.362b	4.142a	**0.000**
2021/2022 season				
0	2.244g	2.455f	2.698d	**2.465c**
192	2.693de	2.592def	3.965b	**3.082a**
240	1.250h	2.532f	4.990a	**2.923b**
288	1.150h	2.542ef	3.024c	**2.237d**
Mean (NL)	**1.834c**	**2.530b**	**3.667a**	**0.000**

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

The effect of plant density (4, 5 and 6 rows/ridge) on yield of grade 1, 2, 3, and 4 (ton/ha.) and on exportable yield (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions are presented in Tables 6, 7, 8, 9, 10, 11, 12, and 13. Low plant density (4 rows/ridge) increased yield of grade 1, exportable yield, and average bulb weight in both seasons, whereas high plant density (6 rows/ridge) increased yields of grades 2, 3, and 4 and total yield in both seasons, with no significant differences with 5 rows/ridge in yield of grade 2 in both seasons (Tables 6 to 13). High plant density (6 rows per ridge) increased total yield, which may be due to the increased yield of grades 2, 3, and 4. The increases in total yield per fad were about 0.612 and 0.508 tonnes for 5 rows per ridge and 1.466 and 1.263 tonnes per ha for 6 rows per ridge over 4 rows per ridge in the 1st and 2nd seasons, respectively.

The effect of interaction between nitrogen fertilizer at different levels (192, 240, 288 kg /ha) and plant density (4, 5, and 6 rows/ridge) on yield of grade 1, 2, 3, and 4 (ton/ha.) and on exportable yield (ton/ha.) of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions are presented in Tables 6, 7, 8, 9, 10, 11, 12 and 13. The interaction between N at 288 kg /ha and low plant density (4 rows/ridge) increased yield of grade 1, exportable yield, and average bulb weight, whereas the interaction between N at 244 kg /ha and high plant density (6 rows/ridge) increased grades 2, 3, and 4, marketable yield, and total yield/ha, with no significant differences with the interaction between N at 288 kg /ha and plant density (5 and 6 rows/ridge) as shown in Tables 6 to 13. For all treatments, average bulb weight ranged from 20.28 and 72.32 g in the 1st season and 20.77 to 67.82 g in the 2nd season. In general, planting at 4 rows/ridge (low plant density) with all nitrogen levels (192, 244 and 288 kg/ha) increased average bulb weight compared to planting at 5 and 6 rows/ridge (high plant density) with the same nitrogen levels. Aliyu *et al*. (2008) found that the optimum yield of onion bulbs (30.83 t/ha) was obtained from 15 cm intra-row spacing combined with 100 kg N/ha. However, for large bulb sizes, the application of 150 kg N/ha in plants spaced at 25 cm intra-row spacing may be recommended.

Table 10. Effect of nitrogen levels, plant density and their interaction on exportable yield (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	10.344e	10.457e	10.082e	**10.294d**
192	17.662d	18.418d	16.980d	**17.686c**
240	27.542b	25.548c	25.613c	**26.234b**
288	29.957a	28.536ab	28.114b	**28.870a**
Mean (NL)	21.374a	20.738ab	20.196b	**0.000**
2021/2022 season				
0	10.750g	10.951g	10.282g	**10.661d**
192	18.319e	19.104e	15.720f	**17.714c**
240	27.30bc	25.548cd	24.367d	**25.740b**
288	31.157a	28.886ab	28.114b	**29.386a**
Mean (NL)	**21.881a**	**21.122a**	**19.620b**	**0.000**

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 11. Effect of nitrogen levels, plant density and their interaction on marketable yield (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	12.497d	13.817d	13.872d	**13.394c**
192	24.211c	25.085c	29.074b	**26.124b**
240	37.056a	37.939a	37.020a	**37.339a**
288	35.861a	35.856a	37.807a	**36.509a**
Mean (NL)	27.406b	28.174b	29.443a	**0.000**
2021/2022 season				
0	12.902d	13.752d	14.254d	**13.637c**
192	25.318c	25.584c	26.837c	**25.913b**
240	34.656b	35.249ab	34.718b	**34.874a**
288	35.959ab	36.336ab	37.807a	**36.701a**
Mean (NL)	**27.209a**	**27.730a**	**28.404a**	**0.000**

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 12. Effect of nitrogen levels, plant density and their interaction on total yield (ton/ha) of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	14.470f	16.109f	16.548f	**15.710c**
192	27.358e	28.289e	33.038d	**29.561b**
240	38.868c	40.951abc	42.014ab	**40.610a**
288	39.571bc	40.798abc	42.742a	**41.038a**
Mean (NL)	30.067c	31.536b	33.586a	**0.000**
2021/2022 season				
0	15.144f	16.207f	16.949f	**16.099c**
192	28.010e	28.178de	30.804d	**28.997b**
240	35.906c	37.781bc	39.708ab	**37.798a**
288	37.109bc	38.878ab	40.831a	**38.940a**
Mean (NL)	**29.042b**	**30.262b**	**32.074a**	**0.000**

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Table 13. Effect of nitrogen levels, plant density and their interaction on average bulb weight (g) of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	26.44h	23.63i	20.28j	**23.45d**
192	50.00f	41.51g	40.49g	**44.00c**
240	71.00b	60.08c	52.37e	**61.15b**
288	72.32a	59.86c	56.80d	**62.99a**
Mean (NL)	54.94a	46.27b	42.48c	
2021/2022 season				
0	27.68h	23.77i	20.77j	**24.07d**
192	51.19d	41.34f	37.75g	**43.42c**
240	65.62b	55.43c	48.66e	**56.57b**
288	67.82a	57.04c	50.04de	**58.30a**
Mean (NL)	**53.07a**	**44.39b**	**39.30c**	

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

The effect of nitrogen fertilizer at different levels (192, 240 and 288 kg /ha), and plant density (4, 5 and 6 rows/ridge) on nitrate contents (mg / Kg FW) in bulbs at harvesting time of onion plants during 2020/2021 and 2021/2022 seasons under clay soil conditions are presented in Tables 14 and 15. Nitrate and sulfur contents in the bulb significantly increased with increasing N up to 288 kg N/ha. Planting at low plant density (4 rows per ridge) significantly increased nitrate and sulphur contents in bulbs.

Table 14. Effect of nitrogen levels, plant density and their interaction on nitrate contents (mg/Kg FW), and sulphur content (%) in bulb at harvesting time during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	94.68g	80.21h	78.13h	**84.34d**
192	192.65d	186.28e	180.74f	**186.56c**
240	211.25c	212.41c	192.75d	**205.47b**
288	236.43a	233.08a	222.13b	**230.55a**
Mean (NL)	183.75a	178.00b	168.44c	
2021/2022 season				
0	96.54h	85.17i	81.19j	**87.63d**
192	203.11c	200.08d	182.34g	**195.18b**
240	192.54e	180.79g	186.32f	**186.55c**
288	286.09a	212.53b	192.68e	**230.43a**
Mean (NL)	**194.57a**	**169.64b**	**160.63c**	

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Data in Tables 14 and 15 show that the interaction between N at 288 kg/ha and planting at 4 rows/ridge increased nitrate and sulphur contents. Plant densities (4, 5 and 6 rows/ridge) without nitrogen recorded minimum values of nitrate content in bulbs compared to the other treatments. For all treatments, as an average of the two seasons, nitrate ranged from 79.66 to 261.26 mg/kg FW, and sulphur ranged from 0.242 to 0.345%.

Table 15. Effect of nitrogen levels, plant density and their interaction on sulphur content (%) in bulb at harvesting time of onion plants during 2020/2021 and 2021/2022 seasons

Nitrogen levels kg /ha (NL)	Plant density (PD)			Mean (PD)
	4 rows/ ridge	5 rows/ ridge	6 rows/ ridge	
2020/2021 season				
0	0.251f	0.238fg	0.224g	**0.237c**
192	0.305bcd	0.279e	0.275e	**0.286b**
240	0.311b	0.291cde	0.287de	**0.296b**
288	0.341a	0.308bc	0.293b-e	**0.314a**
Mean (NL)	0.302a	0.279b	0.269b	
2021/2022 season				
0	0.260ef	0.259f	0.277def	**0.265c**
192	0.287cd	0.287cd	0.282def	**0.285b**
240	0.309bc	0.294bcd	0.285de	**0.296b**
288	0.348a	0.312bc	0.317b	**0.325a**
Mean (NL)	**0.301a**	**0.288b**	**0.290ab**	

Values having the same alphabetical letter (s) did not significantly difference at the 0.05 level of significance, according to Duncan's multiple range test.

Discussion

Our results showed that growth characteristics were found to be considerably influenced by nitrogen fertilizer levels. Increases in nitrogen fertilization have been linked to more robust vegetative growth in onions. This may be because nitrogen plays an important role in enhancing the color and vitality of the leaf canopy, a meristematic activity that boosts cell proliferation and cell elongation (Woldetsadik, 2003). These results are in harmony with those recorded by numerous researchers (Abbey and Kanton, 2004; Abdel-Mawgoud *et al.*, 2005; Mutetwa and Mtaita, 2014; Singh and Ram, 2014; Meena *et al.*, 2015). This important role of nitrogen fertilizer was recorded in many plants such as onion (Ragab *et al.*, 2019), rice (Mohamed *et al.*, 2023), sugar beet (Zalat *et al.*, 2021) and wheat (Mosalem *et al.*, 2021). In the current study, nitrogen fertilizer levels were found to have a substantial effect on total, exportable, and marketable yields, as well as bulb weight. The increase in bulb yields and their attributes because of increasing nitrogen fertilizer rates up to 214.2 kg N/ha can be easily ascribed to the role of nitrogen in activating the growth of plants, enhancement yield components and consequently increasing bulb yield per unit area (Jayathilake *et al.*, 2002). Moreover, nitrogen encourages plants to uptake other elements activating, thereby improving yields and their components. These results are incompatible with those found by (Halvorson *et al.*, 2008; Geries, 2013). In the current study, planting onion plants at 4 rows per ridge (low plant density) gave the highest values of the dry weight of leaves, dry weight of the bulb, and total dry weight per plant in both seasons. The same results were reported for total, exportable, and marketable yields, as well as bulb weight. From the abovementioned results, it could be concluded that the plants grown in wider spaces received more nutrients, light, and moisture around each plant compared to plants in closer spaces, which is probably the cause of the better performance of the total dry weight of individual onion plants in wider spaces. The increased results at the wider spacing were probably due to the availability of more nutrients, moisture, light, space, etc. Similar results were also obtained by Atalay *et al.* (2022), Abd El-Wahed (2008), and Bardisi (2013) on onion, who found that the dry weight of onion plant increased with increasing plant spacing within seedlings. The plants grown in wider spaces received more nutrients, light, and moisture around each plant compared to plants in closer spaces, which is probably the cause of the better performance of the total dry weight of individual onions in wider spaces. Bulb size increased with wider space, whereas total bulb yield increased with closer space (Resende and Costa, 2005; El-Sharkawy *et al.*, 2006; Dawar *et al.*, 2007).

Conclusions

Planting onions Ahmar Tanawy in clay soil at 4 rows per ridge (33.33 plants per m^2) with mineral nitrogen fertilisation at 288 kg/ha gave the highest values of total dry weight per plant and increased yield of grade 1, exportable yield, average bulb weight as well as nitrate and sulphur contents in bulbs, whereas planting at 6 rows per ridge (50 plants per m^2) with N at 244 kg/ha increased grades 2, 3 and 4, marketable yield and total yield per hectare.

Authors' Contributions

Conceptualization: E. A., A.B., A.O.,.; Data curation: E. A., A.B., A.O., H.I., K. AL..; Formal analysis: E. A., A.B., A.O., H.I., S.I. and Kh.A.; Funding acquisition: K. AL., W.AL., N.A., S.A.; Investigation: E. A., A.B., A.O., H.I., S.I..; Methodology :E. A., A.B., A.O..; Project administration: E. A., A.B., A.O., H.I.; Resources: E. A., A.B., A.O., H.I., S.I. and Kh.A.; Software: E. A., A.B., A.O., HS.I. S.I.; Supervision: E. A., A.B., H.I., S.I. .; Validation: E. A., A.B., Writing - original draft: E. A., A.B., A.O., H.I., K. AL., W.AL., N.A., S.A, S.I. and Kh.A.; Writing - review and editing: E. A., A.B., A.O., H.I., K. AL., W.AL., N.A., S.A, S.I. and Kh.A.. Please note: Authorship must be. All authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Abbey L, Kanton R (2004). Fertilizer type, but not time of cessation of irrigation, affect onion development and yield in a semi-arid region. Journal of Vegetable Crop Production 9(2):41-48. *https://doi.org/10.1300/J068v09n02_06*

Abd El-Wahed A (2008). Evaluation of growth characters, productivity, quality, and storability of some onion (*Allium cepa* L.) cultivars planted at different densities under Al-Akhdar conditions. M.Sc. Thesis, Hort. Dept., Fac. Agric., Omar Al-Mokhtar University, Libia.

Abdel-Mawgoud AMR, Abou-Hussein SD, Salman SR, El-Nemr MA (2005). Interactive effects of zinc and different nitrogen sources on yield and quality of onion. Arab Universities Journal of Agricultural Sciences 13(3):863-875. *https://doi.org/10.21608/ajs.2005.15325*

Aboukhadrah S, El-Alsayed AWAH, Sobhy L, Abdelmasieh W (2017). Response of onion yield and quality to different planting date, methods and density. Egyptian Journal of Agronomy 39(2):203-219. *https://doi.org/10.21608/agro.2017.1203.1065*

Alharbi K, Haroun SA, Kazamel AM, Abbas MA, Ahmaida SM, AlKahtani M, … Gamel RME (2022). Physiological studies and ultrastructure of *Vigna sinensis* L. and *Helianthus annuus* L. under varying levels of nitrogen supply. Plants 11(14):1884. *https://doi.org/10.3390/plants11141884*

Aliyu U, Dikko A, Magaji M, Singh A (2008). Nitrogen and intra-row spacing effects on growth and yield of onion (*Allium cepa* L.). Journal of Plant Sciences 3(3):188-193.

Atalay D, Alemayehu M, Ayana D (2022). Effects of intra-row spacing and nitrogen fertilizer rates on growth, and yield of onion (*Allium cepa* L.) under irrigation in mecha district of Amhara, Ethiopia. International Journal of Bioorganic Chemistry 7(1):17. *https://doi.org/10.11648/j.ijbc.20220701.13*

Bardisi S (2013). Effect of some agricultural treatments on the productivity, quality and storability of onion grown in sandy soil. M.Sc. Thesis, Fac. Agric., Zagazig University.

Brewster JL (2008). Onions and other vegetable alliums. Vol. 15. CABI. *https://doi.org/10.1079/9781845933999.0000*

Cataldo DA, Haroon M, Sharderand LE, Youn VL (1975). Rapid colorimetric determination of nitrate in plant tissues by nitrification of salicylic acid comm. Soil Science and Plant Analysis 6:71-80. *http://dx.doi.org/10.1080/00103627509366547*

Charrondière UR, Stadlmayr B, Rittenschober D, Mouille B, Nilsson E, Medhammar E, … Ebanks K (2013). FAO/INFOODS food composition database for biodiversity. Food Chemistry 140(3):408-412. *https://doi.org/10.1016/j.foodchem.2012.08.049*

Dawar NM, Wazir FK, Dawar M, Dawar SH (2007). Effect of planting density on growth and yield of onion varieties under climatic conditions of Peshawar. Sarhad Journal of Agriculture 23(4):911.

Duncan DB (1958). Multiple Range and Multiple F-Test. Biometrics 11:1-5. *https://doi.org/10.2307/3001478*

El-Sharkawy AF, Mostafa AK, Maksoad HA (2006). Effect of alternate furrow irrigation and transplanting distance on water utilisation efficiency for onion crop. Misr Journal of Agricultural Engineering 23:137-150. *http://dx.doi.org/10.4067/SO718-58392013000200014*

Galal A, Basahi M, Shabana MT, Abdelaal Kh, Abdel-Hafez AG (2023). Studies on combining ability in triticale under nitrogen levels. Fresenius Environmental Bulletin 32(1):241-249.

Gebretsadik K, Dechassa N (2018). Response of onion (*Allium cepa* L.) to nitrogen fertilizer rates and spacing under rain fed condition at Tahtay Koraro, Ethiopia. Scientific Reports 8(1):9495. *https://doi.org/10.1038/s41598-018-27762-x*

Geisseler D, Ortiz RS, Diaz J (2022). Nitrogen nutrition and fertilization of onions (*Allium cepa* L.)–A literature review. Scientia Horticulturae 291:110591. *https://doi.org/10.1016/j.scienta.2021.110591*

Geries L (2013). Effect of nitrogen fertilizer and foliar spraying with humic acid on growth and yield of onion (*Allium cepa* L.). Egypt Journal of Applied Science 28(4):204-226.

Gessesew WS, Woldetsadik K, Mohammed W (2015). Growth parameters of onion (*Allium cepa* L. var. *cepa*) as affected by nitrogen fertilizer rates and intra-row spacing under irrigation in Gode, South-Eastern Ethiopia. Agriculture, Forestry and Fisheries 4(6):239-245. *http://dx.doi.org/10.11648/j.aff.20150406.11*

Halvorson AD, Bartolo ME, Reule CA, Berrada A (2008). Nitrogen effects on onion yield under drip and furrow irrigation. Agronomy Journal 100(4):1062-1069. *https://doi.org/10.2134/agronj2007.0377*

Jayathilake P, Reddy I, Srihari D, Neeraja G, Reddy R (2002). Effect of nutrient management on growth, yield and yield attributes of rabi onion (*Allium cepa* L.). Vegetable Science 29(2):184-185. *https://doi.org/10.5958/0976-0547.2015.00056.7*

Ketter CAT, Randle WM (1998). Pungency assessment in onions. Proceedings of the 19-workshop conference of the Association for Biology Laboratory Education (ABLE) 19:177-196.

Khan MA, Hasan MK, Miah MAJ, Alam MM, Masum AS (2003). Effect of plant spacing on the growth and yield of different varieties of onion. Pakistan Journal of Biological Sciences 6(18):1582-1585. *https://doi.org/10.3923/pjbs.2003.1582.1585*

Loredana L, Giuseppina A, Filomena N, Florinda F, Marisa DM, Donatella A (2019). Biochemical, antioxidant properties and antimicrobial activity of different onion varieties in the Mediterranean area. Journal of Food Measurement and Characterization 13:1232-1241. *https://doi.org/10.1007/s11694-019-00038-2*

Meena A, Paliwal R, Meena KJ (2015). Effect of organic manures and bio-fertilisers on growth and quality attributes of kharif onion (*Allium cepa* L.) in semi-arid region. Indian Research Journal of Genetics and Biotechnology 7(01):73-76.

Mohamed A, Elkhoby W, Abdo I, Al-Harbi N, Al-Qahtani S, Abdelaal Kh (2023). Effect of two sowing methods and some compound fertilizers on rice growth, yield and yield components. Fresenius Environmental Bulletin 32(1):345-350.

Mohamed A, Mazrou Y, Al-Shammari W, El-Shamy M, EL-Kholy K, Abdelaal Kh (2022). Impact of intercropping faba bean with onion, garlic and fenugreek on crop productivity and control of *Orobanche crenata*. Fresenius Environmental Bulletin 31(8):7596-7603.

Mosalem M, Mazrou Y, Badawy Sh, Abd Ullah MA, Mubarak MGh, Hafez YM, Abdelaal Kh (2021). Evaluation of sowing methods and nitrogen levels for grain yield and components of durum wheat under arid regions of Egypt. Romanian Biotechnology Letters 26(6):3031-3039. *https://doi.org/10.25083/rbl/26.6/3031-3039*

Mutetwa M, Mtaita T (2014). Effects of mulching and fertilizer sources on growth and yield of onion. Journal of Global Innovations in Agricultural Sciences 2(3):102-106. *https://doi.org/10.17957/JGIASS/2.3.561*

Novozamsky I, Van Eck R (1977). Total sulphur determination in plant material. Fresenius' Zeitschrift fur analytische Chemie 286: 367-368. *https://doi.org/10.1007/BF00431199*

Omar A, AboYoussef M, Shoughy A, Abd El-Aty MS, Abdelaal Kh, Hafez Y, Kamara M (2022). Response of Egyptian Yasmin rice cultivar to different seeding number per hill and different nitrogen levees. Fresenius Environmental Bulletin 31(1A):1258-1265.

Omar AE, Al-Khalaifah HS, Mohamed WA, Gharib HS, Osman A, Al-Gabri NA, Amer S (2020). Effects of phenolic-rich onion (*Allium cepa* L.) extract on the growth performance, behavior, intestinal histology, amino acid digestibility, antioxidant activity, and the immune status of broiler chickens. Frontiers in Veterinary Science 7:582612. *https://doi.org/10.3389/fvets.2020.582612*

Priyadarshini A, Rajauria G, O'Donnell CP, Tiwari BK (2019). Emerging food processing technologies and factors impacting their industrial adoption. Critical Reviews in Food Science and Nutrition 59(19):3082-3101. *https://doi.org/10.1080/10408398.2018.1483890*

Ragab AY, Geries LSM, Abdelaal KAA, Hanna SA (2019). Growth and productivity of onion plant (*Allium cepa* L.) as affected by transplanting method and NPK fertilization. Fresenius Environmental Bulletin 28(11): 7777-7786.

Resende GM, Costa ND (2005). Yield characteristics and postharvest conservation of onion under different planting spacing. Horticultura Brasileira 23:707-711. *https://doi.org/10.1590/S0102-05362005000300003*

Singh A, Ram R (2014). Evaluation of the performance of onion cv. NHRDF red 2 in response to inorganic, organic and bio-fertilizers. India Journal of Applied Research 4(11):263-265.

Snedecor GW, Cochran WG (1980). Statistical Methods. 7th ed., Iowa State University Press, Iowa, USA. pp 593.

Woldetsadik K (2003). Shallot (*Allium cepa* var. *ascolonicum*) responses to plant nutrients and soil moisture in a sub-humit tropical climate. Acta Universitatis Agriculturae Sueciae. Agraria 2003:367.

Yahaya Y, Uauri UA, Bagudo BU (2010). Study of nutrient content variation in bulb and stalk of onions (*Allium cepa*) cultivated in Aliero, Aliero, Kebbi State, Nigeria. Nigerian Journal of Basic and Applied Sciences 18(1):83-89.

Zalat S, EL-Sayed A, Elkhoby R, Hafez Y, Ali E, Abdelaal Kh (2021). Effect of method and time of micronutrients application on sugar beet productivity under two nitrogen fertilizer sources. Fresenius Environmental Bulletin 30(7A):9135-9141.

Zhao X-X, Lin F-J, Li H, Li H-B, Wu D-T, Geng F, Ma W, Wang Y, Miao B-H, Gan R-Y (2021). Recent advances in bioactive compounds, health functions, and safety concerns of onion (*Allium cepa* L.). Frontiers in Nutrition 8:669805. *https://doi.org/10.3389/fnut.2021.669805*