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Yield and Yield Components of Onion as Influenced by Intra-Row Spacing and Nitrogen Fertilizer Levels in Rift Valley, Ethiopia

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Background and Objectives: Farmers currently employ nationally approved fertilizer rates and plant spacing when growing onions, but knowledge of plant population density and fertilizer rates that may produce the best bulb production for different cultivars and locations is limited. As a result, gardeners frequently use nonspecific plant population densities for various cultivars, resulting in sub-optimal bulb yields.
Materials and Methods: A field experiment was conducted in 2019 from August to December to study the effects of intra-row plant spacing and levels of nitrogen on yield and quality of onion (*Allium cepa* L.) variety Nafis under irrigation.
Results: The main effect of intra-row spacing on stand count and both nitrogen levels and intra-row spacing on plant height and the number of leaves per plant was observed. The interaction of nitrogen level and intra-row distance affected days to maturity, leaf length, leaf diameter, bulb

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diameter, mean bulb weight, marketable and unmarketable bulb yield, and all bulb size categories. Increased intra-row spacing to 10.5 cm and N rate of 82 kg ha^{-1} increased marketable and total bulb yield by approximately 3.14 and 3.21 t ha^{-1}, respectively, spacing and decreased unmarketable bulb yield by 1.38 t ha^{-1}.

Conclusion: The use of 82 kg $^{ha-1}$ N at the intra-row spacing of 10.5 cm was optimum for bulb production of onions. 82 kg ha^{-1} N at 10.5 cm intra-row spacing resulted in the highest net benefit.

Keywords: Allium cepa L.; plant population; marketable bulb; bulb size distributions.

1. INTRODUCTION

"One of the first vegetables to be domesticated, the onion dates back more than 4,000 years. Between Turkmenistan and Afghanistan, where some of its cousins still grow naturally, is where it most likely originated" [1]. The alleged onion ancestor most likely moved from central Asia to the Near East. After that, it was spread throughout the Roman Empire, first to India and Southeast Asia, then to the Mediterranean region [2]. Onion (*Allium cepa L.*) is a day-length plant. Several onion varieties exist depending on the latitude at which they grow. Ever since the crop was distributed to different parts of Ethiopia, it has been widely cultivated as a source of income.

"Onions are extracting nutrients, especially immobile types, because of their shallow and un-branched root systems, which means they require and often respond well to the addition of fertilizers" [3,4]. "Optimum fertilizer application and cultivation of suitable varieties with appropriate agronomic practices in a specific environment are necessary for obtaining a good yield of onion. Nitrogen plays an important role in the optimum yield of onions and is essential to increasing bulb size and yield" [5]. "Increasing nitrogen application rates enhances plant height, the number of green leaves per plant, the weight of the bulb, marketable yield, and total soluble solids" [6,7]. "Plant spacing is an important factor in determining onion yield and quality"8. "An essential aspect of any crop production system is the development of a crop canopy that optimizes interception of light, photosynthesis, and allocation of dry matter to harvestable parts. Planting density influences the quality, texture, taste, and yield of onions" [8]. "A crop canopy is commonly managed by manipulating row spacing and plant population; as plant density increases, yield per unit area can increase" [9]. "Yield responses to plant population need to be known, as planting density is a major management variable used in matching crop requirements to resources" [10]. "High commercial bulb yield occurred at a higher planting density, but the highest proportion of large bulbs and average bulb weight were from a lower planting density" [11].

"The enhancement of onion production and productivity can be related to different growth factors. Onion dry bulb production depends on nutrient requirements, location of production, variety, soil type, agronomic practices, etc. Over-fertilization with nitrogen or phosphorus will contribute to increased pest attacks and stimulate succulent growth, which may predispose the plant to damage by field or storage pathogens" [12]. Thus, research should be undertaken to determine specific application rates for individual fields. On the other hand, under fertilization should also be avoided lest low yield and quality of the crop are obtained.

"The use of appropriate agronomic management has an undoubted contribution to increased crop yields. One of the major problems with onion production is improper agronomic practices used by farmers. The optimum level of any agronomic practice, such as plant population, planting date, harvesting date, and fertilizer of the crop, varies with the environment, the purpose of the crop, and the cultivar. In Ethiopia, optimum plant spacing and nitrogen recommendations have been formulated for onions, particularly, which is double row spacing of 10 cm between plants and 20 cm between rows and application of 46 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1}" [13,14]

"However, these recommendations cannot be directly implemented for all types of soil types and altitudes. This means that it is very difficult to give general recommendations that can apply to the different agroecological zones. Therefore, to optimize onion productivity in the study area, a specific package of recommendations for nitrogen fertilizer and plant spacing is required" [13, 15].

"In Awash Melkassa District, Oromiya Region's Central Rift Valley, onion is one of the most important vegetable crops grown primarily under irrigated conditions. There are many production constraints resulting in low yield per unit area in the districts. In the study district, growers use different levels of inorganic fertilizers for the production of different vegetables under irrigation, particularly onion production (personal observation). The farmers often apply 200-300 kg ha^{-1} of Ammonium phosphate (DAP) (18%N, 20%P) and 100-200 kg ha^{-1} of Urea (46% N)" [15].

"However, a few farmers use higher doses of these fertilizers, and a significant number of farmers use small doses of N fertilizer in the form of Urea. This shows no specific nitrogen levels are applied by smallholder farmers in the district. However, the blanket recommended rates of fertilizers are 200 kg ha^{-1} of Diammonium phosphate (DAP) and 100 kg ha^{-1} of Urea [14]. Farmers in the district also grow onions using the double row planting method by using different spacing methods than the nationally recommended spacing of 20 cm x 10 cm [13] to improve the yield of onions".

"Onion is traditionally grown at the recommended spacing of 40 cm x 20 cm x 10 cm in Ethiopia" [13]. "However, farmers in the study District use narrower intra-row spacing. Farmers' reasons for using narrow plant spacing are to minimize the number of oversized bulbs produced in wider plant spacing, to produce bulbs with higher yields and optimum sizes per unit area, and to make effective use of the limited irrigable land". [13] At present, onion growers in the area produce onions with the application of different N rates and intra-row spacing or by using N rates and spacing that they feel are best for obtaining higher yields. Therefore, the present study was initiated to determine the most suitable intra-row spacing and nitrogen fertilizer rate for optimum onion yield and quality.

2. MATERIALS AND METHODS

2.1 Description of the Experiment Site

The experiment was conducted in 2019 at Awash Melkassa, located at 8^o 24' N latitude and 39^o 12' E longitude with an altitude of 1550 meters above sea level. The site is situated in the Central Rift Valley of the Awash River Basin having a semi-arid climate. Long-term 1977-2006 mean annual rainfall was 791.7 mm with most occurring in July and August. The rainfall follows a bimodal pattern with a short rainy season extending from March to April and a long rainy season from July to September. The short rainy season is highly variable and undependable for economic farming. Mean monthly maximum and minimum temperatures range from 30.9 ^oC (May) to 26.2^{o}C (August) and from 16.2 ^{o}C (June) to 10.8 ^{o}C (December), respectively. Soils of Melkassa Agricultural Research Center are classified as Haplic Andosol [16] with a characteristic feature of deep pumice or volcanic soil type having high water retention capacity.

2.2 Experimental Design and Treatment

The onion variety used was 'Nafis' obtained from Melkassa Agricultural Research Centre (MARC) and has a very firm bulb, deep red color, and globe in shape. The leaves are light green. The cultivar takes 90-100 days for bulb harvest. A factorial combination of 0, 59, 82, or 105 kg ha^{-1} N and intra-row spacing of 2.5, 5, 7.5, 10.5, or 12.5 cm were used. The experiment was then arranged in 4 × 5 factorial arrangements within a randomized complete block design with four replications.

2.3 Experimental Management

Following the usual tillage practice in the study area, the field was poled and harrowed to a fine plow before planting. Seeds were sown in a nursery on a well-prepared seedbed in July. When seedlings were at the 3 or 4-leaf stage or 12 to 15 cm height, seedlings were transplanted manually in the experimental field in August. Each experimental plot had 4 double rows and the middle 6 single rows were used for data collection. Planting was on ridges of about 25 cm height with a spacing of 40 cm between water furrows, 20 cm between rows on the ridge, and 18, 21, 30, 44, and 88 plants were planted per row for 12.5, 10.5, 7.5, 5 and 2.5 cm intra-row spacing, respectively. A 2.4 × 2.2 m (5.28m^2) plot was used for each experimental unit. The blocks were separated by 1 m width and the space between each plot within a block was 0.75 m. Triple superphosphates (46% P_2O_5) were applied as a source of P for the control plot and Diammonium phosphate (DAP) (18%N, 46%P_2O_5) was applied for the treatment plots based on the amount of N found in it and N was applied as Urea (46% N). The Triple Super Phosphate (TSP) and Diammonium phosphate (DAP) were applied as a single application at transplanting and nitrogen was applied in two split doses of equal amounts, at 3 and 6 weeks after transplanting. Planting was at the end of

August 2019 and harvesting was at the end of December 2019. When 80% of the leaves turned yellow and top fall, attaining the full size of bulbs and then cured for five days [17].

2.4 Soil Sampling and Analysis

Soil samples were randomly collected from the entire experimental site before planting to make one composite sample. Determinations of some selected soil physical and chemical properties were carried out on the composite sample. The soil sample was air-dried and crushed to pass through a 2 mm size sieve for analysis of pH, available P, and texture; for determination of total nitrogen and organic carbon, it was made to pass through a 1 mm pore size sieve.

Soil pH was measured in 1:2.5 soil-water ratios using a pH meter. The organic carbon content of the soil was determined by the [18] methods. Available P was estimated following a procedure of [19]. Total nitrogen was estimated by the Kjeldahl method [20]. The results of the soil analysis were used as inputs in determining the amount of nitrogen fertilizer applied.

2.5 Data Collection

Data on crop phenology, growth parameters, yield component, and yield were recorded starting at transplanting to physiological maturity, full plant development, and harvesting time, respectively. The collected data were expressed as an average based on randomly taken plants in each experimental plot.

2.6 Data Analysis

The data were subjected to analysis of variance (ANOVA) using SAS version 9.2 computer software (SAS Institute Inc., 2008). The least significant difference (LSD) at a 5% level of probability was used to evaluate significant differences between treatment means.

2.7 Economic Analysis

"Partial budget analysis was employed for economic analysis of fertilizer application and plant spacing which was carried out for combined bulb yield. The potential response of crops towards added fertilizer and plant spacing was estimated where the price of fertilizers and other costs during planting ultimately determined the economic feasibility of fertilizer application and plant spacing. The economic analysis was computed using the procedure described by CIMMYT" [21]. Gross average bulb yield (kg ha^{-1}) (Avg, average yield of each treatment). Adjusted yield (kg ha^{-1}) (AjY, the average yield was adjusted downward by 10% to reflect the difference between the experimental yield and yield of farmers).

3. RESULTS AND DISCUSSION

3.1 Selected Soil Physicochemical Properties of Experimental Site Before Planting

The laboratory analysis results conducted on major soil Physico-chemical characteristics of the experimental site before planting is given in (Table. 1). Results of the soil analysis before planting showed that the soil of the site is sandy clay loam in texture. According to CIMMYT [21] the soil was medium in total nitrogen (0.19%). The experimental site had high available phosphorus (18.02 ppm) and low organic matter (2.15%) content according to Walkley and Black [21]. The pH of the soil was analysed to be 7.75 showings a nearly neutral nature of the soil. FAO [22] reported that the preferable pH ranges for most crops and productive soils are 4 to 8. Thus, the pH of the experimental soil was within the range for productive soils.

Table 1. Physico-chemical characteristics of the experimental soil before planting

Soil Properties	Values	Remark
Particle size distribution (%)		
Clay (%)	22.08	
Silt (%)	24.78	
Sand (%)	52.13	
Soil textural class		Sandy clay loam
pH	7.75	nearly neutral
Organic matter (%)	2.15	low
Available phosphorus (mg kg^{-1})	18.02	high
Total nitrogen (%)	0.19	medium

3.2 Phenology and Growth Parameters

3.2.1 Days to physiological maturity

This study showed that day to physiological maturity of onion was significantly affected by the interaction of N application and intra-row spacing ($P<0.05$), the individual treatment effects were also significantly different ($p<0.01$) (Table. 2).

Increasing intra-row spacing and levels of applied N fertilizer delayed days of physiological maturity of the crop. Statistically, the highest days to maturity (116.33) was recorded from a treatment combination of 12.5cm intra-row spacing with 105 kg ha-1N fertilizer rate but was not significantly different from the combination of 5-12.5 spacing and 59-105 Nitrogen combination. Whereas, the shortest days to maturity (102.66) were recorded from 2.5cm intra-row spacing and 0 kg ha-1 nitrogen fertilizer rate. The delay in maturity due to N fertilizer application and wider intra-row spacing could be possible because plants with wider intra-row spacing and higher nitrogen rates did not compete for resources (nutrients, sunlight, water, and space) so they prolonged their vegetative stage. This result was in agreement with the findings of Sorensen and Khokhar [23], who reported that too much N can result in excessive vegetative growth and delayed maturity of onions. The results on physiological maturity obtained from this study agreed with the fact that an abundant supply of nitrogen delayed physiological maturity by promoting vigorous vegetative growth of the plant [24].

3.2.2 Plant height (cm)

This study showed that the plant height of onion was significantly affected by intra-row spacing and nitrogen levels ($P<0.01$) but their interaction effect was not significant (Table 3). The plant height of the onion increased with an increase in the N rate. Plants treated with 82 kg ha^{-1} N had the tallest plants 54.33 cm from those plants treated with 105 kg N ha^{-1}.

The control plot treated with zero N (46.03cm) and 59 N produced significantly the lowest height. Increased nitrogen levels may have caused plants to grow taller since nitrogen is a crucial component of protein, the basic building block of cells, a component of all enzymes, and is also involved in metabolic processes throughout the entire plant. Because of the additional N fertilizer, the plants grow very well during the vegetative phase. In support of this, Blandino [25] and Bryla & Machado [26] indicated that plant vigor generally increases with the supply of nitrogen fertilizer.

In this study, intra-row spacing significantly increased the plant height. The plant height of the onion increased with an increase in intra-row spacing. The highest height of 53.05 cm was recorded in the plants spaced at 10.5 cm, followed by 7.5cm apart with (51.43). Whereas the lowest plant height (47.40 cm) was obtained in the closest spacing of 2.5 cm (Table 4). The reduction in plant height at higher plant density might be attributed to the possible competition for soil moisture, light, and nutrients. This result was in line with that of Bodnar et al. [27], Karaye and Yakubu [28], and Jilani et al. [29], who reported that the maximum height (55.48 cm) of onion was recorded in the plants spaced at 25 cm, followed by 20 and 15 cm spacing which produced 52.45 and 51.24 cm long plants, respectively, whereas the least plant height (49.14 cm) was reported in the closet plant spacing of 10 cm. Similarly, Lencha & Buke [30] also reported that due to high competition among the closest plant spacing, onions produced the least responsible for plant height. This result was also in agreement with the previous findings of Shiberu [31], who also reported that wider plant spacing (20 cmx10 cm) produced a higher plant size in onions.

3.2.3 Leaf length (cm)

The different intra-row spacings and nitrogen fertilizer rates gave a significant variation ($P<0.01$) in the leaf length (cm) and their interaction was significantly different ($P<0.05$) (Table 2).

Nitrogen Fertilizer rate (82 kg ha^{-1}) gave the highest leaf length (55.24 cm) at 10.5cm spacing and was not significantly different with the highest rates both at 10.5 and 12.5 plant spacing. While plots with 2.5 cm spacing and no N fertilizer produced the shortest leaves (38.38 cm). The increase in N concentration might due to the availability of the nutrient for enzymes and proteins synthesis and less competition for nutrients and moisture at wider intra-row spacing due to lower plant density. Similar results were reported by Shiberu [31], were wider spacing produced higher leaf lengths in various onion cultivars. Jilani et al. [29], also reported that maximum leaf length (43.68 cm) was recorded in plants spaced 20 cm apart, and 25 cm, (43.14 cm) though statistically not significantly different. Whereas plants grown on plots with smaller spacing (2.5 cm) and no N had leaves with the shortest length (38.38 cm). Similarly, Abdissa et al [32], described that N is the major constituent of proteins and the presence of abundant protein tends to increase the size of the leaves, and accordingly, bring about an increase in carbohydrate synthesis. A similar result was also reported by Jilani et al. [29], who found that N at the rate of 200 kg ha^{-1} enhanced the length of onion leaves.

Table 2. Interaction effects of nitrogen rates and intra-row spacing on days to 75% physiological maturity, leaf length (cm), and leaf diameter (cm) of Nafis onion variety grown at Awash Melkassa

N(kg ha^{-1})	Intra-rows spacing(cm)	D75%PM	LL(cm)	LD(cm)
0	2.5	102.66e	38.38k	0.467j
	5	102.667e	43.33ij	0.597gh
	7.5	104.667de	41.63j	0.606gh
	10.5	106.33cde	44.75i	0.641fg
	12.5	107.667cde	45.10hi	0.683ef
59	2.5	104.667ed	42.89ij	0..517i
	5	109.667abcd	47.70fg	0.571h
	7.5	111.000abcd	51.78bc	0.66ef
	10.5	112.333abc	47.79fg	0.704e
	12.5	112.667abc	50.84bcd	0.693e
82	2.5	108.667bcde	48.38efg	0.803cd
	5	112.667abc	48.83defg	0.799cd
	7.5	113.000abc	50.18cde	0.785d
	10.5	113.000ab	55.24a	0.985a
	12.5	113.667ab	54.72a	0.834c
105	2.5	108.000bcde	47.15gh	0.793cd
	5	113.00abc	48.42efg	0.793cd
	7.5	113.667ab	49.65cdef	0.788d
	10.5	114.00ab	52.97ab	0.921b
	12.5	116.333a	54.81a	0.932b
LSD(0.05)		12.14	2.37	0.012
CV (%)		1.05	3.01	3.77

Where means within a column followed by the same letter(s) are not significantly different; CV: Coefficient of variation; LSD: Least Significant Difference; DPM=Days to 75% physiological maturity; LL= Leaf length; LD= Leaf Diameter

Table 3. The main effect of nitrogen rates and intra-row spacing on plant height (cm) and leaf number per plant of Nafis onion variety grown at awash melkassa

Nitrogen level (kg ha-1)	PH (cm)	LNPP
0	46.03b	9.18c
59	47.00b	9.71b
82	54.33a	10.26a
105	52.79a	10.09a
LSD (0.05)	4.79	0.35
Intra-row spacing(cm)		
2.5	47.40b	8.93d
5	49.13b	9.48c
7.5	51.43a	9.93b
10.5	53.05a	10.28ab
12.5	49.19b	10.43a
LSD (0.05)	1.98	0.39
CV (%)	47.46b	4.78

Where means within a column followed by the same letter(s) are not significantly different; CV: Coefficient of variation; LSD: Least Significant Difference; PH=plant height; LNPP=leaf number per plant

3.2.4 Leaf diameter (cm)

The effect of intra-row spacing, N fertilizer rate, and their interaction on leaf diameter (cm) showed a significant (P<0.01) effect (Table 2). Significantly the highest leaf diameter (0.98 cm) was produced by the treatment combination of 10.5 cm intra-row spacing with kg$^{.}$ ha^{-1} N fertilizer rate. Whereas the lowest leaf diameter (0.46 cm) was recorded from 2.5 cm intra-row spacing without nitrogen fertilizer.

The effect of N rates and intra-row spacing on leaf diameter increased up to 82 kg ha^{-1} and 10.5cm, respectively. This could be partly because wider-spaced plants with good N fertilizer application have luxurious utilization of nitrogen that resulted in wider leaves than plants spaced at closer spacing. The increase in the vegetative growth of the onion plants could be due to the effect of N in the synthesis of the different components of protein through the increased production of carbohydrates in the plant system. This result was in agreement with that of Kahsay et al [33], who reported that the leaf diameter of different Allium species grown at

20 cm spacing was larger than plants grown at 15 cm which in turn was larger than plants grown at 10 cm spacing. This result was in line with that of Diriba-Shiferaw et al [34], also who concluded that increasing the application rate of N increased the growth parameters of the onion plant.

3.2.5 Leaf number per plant

The number of leaves per plant was found to be significantly ($P < 0.01$) affected due to different rates of applied N fertilizers and intra-row spacing but their interaction was not significant (Table 3).

The highest number of leaves per plant (10.43) was recorded at 12.5cm intra-row spacing followed by 10.5cm with (10.28) and the lowest (8.92) number of leaves per plant was recorded at 2.5cm. However, the difference in the number of leaves per plant between the intra-row spacing of 10.5 and 12.5 cm was not statistically significant. It is apparent that when intra-row spacing increases, the number of plants per unit area becomes less; more mineral nutrients, light, moisture, and space become available for the plant. On the other hand, it is possible that an increase in planting density resulted in a reduction in the number of leaves because of a shortage of mineral nutrients, light, moisture, and space. Many investigations also revealed that increased plant spacing increased the number of leaves per plant on different crops. For instance, Lencha & Buke [35], and Teshale, & Tekeste [36], reported that an increase in the planting density of onions resulted in a reduction in the number of leaves. Jilani et al. [29], also reported that the maximum number of leaves per bulb (9.94) was obtained from the spacing of 25 cm followed by 20 cm and 15 cm spacing, which produced 9.58 and 9.22 leaves per plant, respectively. Whereas the closest (10 cm) spaced plants gave the minimum number of leaves per plant (8.45). It might be due to the competition among the plants to achieve the required resources for their growth due to the closer spacing. Similar results were reported by Imran et al [37], on potato spacing trials which showed that plant population significantly affected leaf number where the lowest plant population produced significantly the highest leaf number.

Concerning the effect of the applied rate of N fertilizer, the highest number of leaves per plant (10.26) was obtained at the rate of 82 kg ha^{-1} followed by 105 kg ha^{-1} with (10.08) and the lowest (9.18) number of leaves per plant was recorded at 0 kg ha^{-1}N rate. However, the difference in the number of leaves per plant between N rates of 105 and 82 kg ha^{-1} was not significant. Even though, further increasing the N fertilizer level beyond 82 kg ha^{-1} did not respond to the number of the leaf of onion per plant generally, increasing application rates of N fertilizer increase the number of leaves per plant. This could be attributed to the increase in the vegetative growth of the onion plants through the effect of N in the synthesis of the different components of protein through increased production of carbohydrates in the plant system. Messele [5] found that the number of leaves per plant was the highest with the application of 150 kg ha^{-1} N. A similar result was also reported by Geries & Elsadany [6], who found that application of 120 kg ha^{-1}N significantly increased the number of leaves of onion per plant and a further increase in the level of N (160 kg ha^{-1}) tended to decrease it. In contrast, Yeshi [38], found non-significant variation in the leaf number of shallots due to N application.

3.3 Yield and Yield-Related Traits of Onion

3.3.1 Average bulb weight (g)

Mean bulb weight was significantly ($P<0.01$) affected by intra-row spacing and nitrogen fertilizer levels and significantly ($P<0.05$) affected by the interaction effect. (Table 4). Statistically, the highest bulb weight (136.54 g and 131.17g) was recorded from a nitrogen fertilizer rate of 105 kg ha^{-1} at the spacing of 12.5 cm and a nitrogen fertilizer rate of 105 kg ha^{-1} at the spacing of 10.5 cm, respectively. While the lowest bulb weight of 37.93 g was obtained from a rate of 0 kg ha^{-1} nitrogen at the closest intra-row spacing of 2.5 cm.

“The increment in bulb weight due to the increase in intra-row spacing by nitrogen levels might be due to the growth of taller plants with a higher number of leaves causing higher synthesis and transportation of photosynthetic product from source to sinks and plants widely spaced experienced little or no competition for limited growth resources compared to closely spaced plants” [30,39]. The increase in bulb weight could be attributed to the increase in plant height, the number of leaves produced, and leaf length in response to the N treatments with less plant nutrient competition that might have increased dry matter production. Tekeste et al.[40], found that application of 120 kg ha^{-1}N gave the best onion bulb yield. Kahsay et al [33], also reported that plants 9 cm spaced gave the lowest average weight (37.17gm) of onion bulbs while in 15cm spacing plans the average weight of the bulb remained maximum (62.27gm) and also increased in N dose resulted in the increased weight of bulb but above 100kg ha^{-1} it started to decline. Belay et al [41], and Shiberu [31], also reported that wider plant spacing in onion resulted in heavier bulb weight. Jilani [29] also reported that significantly the highest bulb weight (59.82 g) was recorded in plants spaced at 25 cm apart, followed by 20 cm spacing (57.45 g) weighed bulbs.

3.3.2 Bulb diameter (cm)

The effect of intra-row spacing, N fertilizer rate, and their interaction showed a significant (P<0.01) effect on bulb diameter (Table 4).

The highest N fertilizer rate (105 kg ha^{-1}) gave a higher bulb diameter (5.71cm) at 12.5 cm intra-row spacing. Whereas the lowest bulb diameter (2.37cm) was obtained from a treatment combination of 2.5cm intra-row spacing with no nitrogen. The increase in bulb diameter at wider intra-row spacing and the highest rate of N fertilizer could be attributed to the availability of more nutrients and moisture due to fewer competition effects and the activities of N in different physiological and metabolic processes through the increase in dry matter production. The present result was in line with that of Lencha & Buke [30] who reported that wider intra-row spacing (12cm) gave a larger bulb diameter (5.13cm) of onion. Whereas the closest (9cm) spaced plants gave the lowest bulb diameter (3.80cm) [42]. Moreover, Jilani et al. [29], reported a significantly higher bulb diameter of 5.69 cm in the widest (25 cm) plant spacing, followed by 20 cm spaced plants, producing a 5.00 cm bulb diameter, and the closest spacing of 10 cm gave 3.99 cm bulb diameter. Geries & Elsadany [6] also reported a significant increase in the diameter of bulbs due to the application of N up to 120 kg ha^{-1}. Similar results were also reported by Yadav et al. [43], who found that N at 150 kg ha^{-1} enhanced the formation of the bulb with the highest diameter.

Table 4. Interaction effects of nitrogen rates and intra-row spacing on mean bulb weight (g) and bulb diameter (cm) of Nafis onion variety grown at awash melkassa

N(kg ha^{-1})	Intra-rows spacing(cm)	MBW (g)	BD (cm)
0	2.5	37.93j	2.38m
	5	52.03hij	2.85l
	7.5	44.70ij	3.77i
	10.5	67.63ghij	3.77i
	12.5	57.27ghij	4.03h
59	2.5	56.63ghij	3.23k
	5	67.17fghi	3.22k
	7.5	77.97defg	4.22g
	10.5	107.23cb	4.51f
	12.5	95.13cd	4.77e
82	2.5	76.60defg	3.62j
	5	91.43cde	4.22g
	7.5	90.37cdef	4.84e
	10.5	106.67cb	5.14d
	12.5	121.27ab	5.15d
105	2.5	68.30efgh	3.53j
	5	65.00ghi	4.17g
	7.5	96.17cd	5.31c
	10.5	131.17a	5.52b
	12.5	136.54a	5.71a
LSD(0.05)		23.5	0.12
CV (%)		17.29	1.76

Where means within a column followed by the same letter(s) are not significantly different; CV: Coefficient of variation; LSD: Least Significant Difference; MBW=mean bulb weight; BD=bulb diameter

3.3.3 Marketable bulb yield (t ha^{-1})

The effect of intra-row spacing, nitrogen fertilizer levels, and their interaction showed a significant ($P<0.01$) effect on marketable bulb yield (Table 5).

The highest marketable bulb yield (30.13 tha^{-1}) was obtained from treatment that received a nitrogen fertilizer rate of 82 kg ha^{-1}N and intra-row spacing of 10.5cm. Whereas the lowest marketable yield (17.73 t ha^{-1}) was obtained from the combination of a nitrogen fertilizer level of 0 kg ha^{-1} and at an intra-row spacing of 2.5 cm. Further, an increase in nitrogen rate beyond 82 kg ha^{-1} and intra-row spacing beyond 10.5cm did not bring a significant difference in marketable bulb yield suggesting that nitrogen rate of 82 kg ha^{-1} and intra-row spacing of 10.5 cm are optimum to obtain the highest marketable bulb yield of onion at Melkassa. This may be due to closer spacing giving the lowest bulb diameter which results in higher unmarketable yield and decreased marketable yield whereas, wider intra-row spacing gives a higher number of marketable (>20g) and lower numbers of unmarketable (<20) sized bulbs on these treats. It is possible to affect bulb size by adjusting plant population and N fertilizer rate that resulted in a decrease in undersize (unmarketable bulb yield) that leads to a lack of demand on the market for the desirable bulb and increasing small, medium, large, and oversize (marketable bulb yield) that lead to satisfying consumer demand. Thus, based on market and consumer demand, it is possible to produce onion bulbs of different sizes through the selection of appropriate intra-row-spacing and N fertilizer rates. The result of Tsegaye et al. [44], also showed that the marketable yield of onion increased with an increase in nitrogen levels while the yield of unmarketable bulbs was significantly decreased as the rate of N increased up to 358 kg· ha^{-1} N and hence high rates of fertilizer N were required to maximize marketable yield. Additionally, the findings are in line with those of Ghaffoor et al. [3], who found that the maximum nitrogen application (150 kg ha^{-1}) results in the maximum onion bulb yield (13.20 t/ha).

3.3.4 Unmarketable bulb yield (t ha^{-1})

The effects of both intra-row spacing and nitrogen fertilizer levels and their interaction effect were significant ($P<0.01$) on unmarketable bulb yield (Table 5).

The highest unmarketable bulb yield (2.29 t ha^{-1}) was recorded at the narrowest intra-row spacing of 2.5 cm and nitrogen rate of 0 kg ha^{-1} respectively. Whereas, the lowest unmarketable bulb yield (0.91 t ha^{-1}) was recorded at the intra-row spacing of 10.5 cm with 82 kg ha^{-1} nitrogen fertilizer levels. This is for the reason that close spacing and the lowest nitrogen rate resulted in the high undersize bulbs as the consequence of higher competition between plants.

Increasing the nitrogen level up to 82 kg.ha^{-1}N and intra-row spacing 10.5 significantly decreased the unmarketable bulb yield, but the further increment of nitrogen level beyond 82 kg.ha^{-1}N and intra-row spacing 10.5 cm did not statistically decrease the unmarketable bulb yield (Table 5).In agreement with this result, Tsegaye et al [44], also showed the yield of unmarketable bulbs decreased as the rate of nitrogen increased up to 358 kg.ha^{-1}N Likewise, Brewster [3] reported that under a sub-optimal supply of N, the marketable yields of onion and shallot can be severely reduced. The result indicates that at the nitrogen level of 82 kg ha^{-1} and intra-row spacing of 10.5 cm increasing the nitrogen levels increases the yield of marketable bulbs at the expense of the unmarketable bulb yield. This finding was in agreement with a similar study by Demisie & Tolessa [45], who concluded that plant density, has an impact on marketable bulb size.

3.3.5 Total bulb yield (t ha^{-1})

The effects of both intra-row spacing and nitrogen fertilizer levels and their interaction effect were significant ($P<0.01$) on total bulb yield (Table 5). Significantly the highest total bulb yield (31.04 t ha^{-1}) was recorded at intra-row spacing and nitrogen level combination of 10.5 cm with 82 kg ha^{-1}. Whereas, the lowest total bulb yield (19.06 t ha^{-1}) was recorded at the intra-row spacing of 2.5 cm with 0 kg ha^{-1}N fertilizer levels.

This might be due to higher plant competition on growth resources at closer spacing, small-sized bulbs but large in number at much-closed plant spacing gives low total bulb yield, and also at wider spacing beyond 10.5cm intra row spacing the number of plants per hectare reduced, thus causing a reduction in yield. From this association, since a further increase in N rate beyond 82 kg ha^{-1} and intra-row spacing beyond 10.5cm did not bring a significant effect, a marginal increase of N and intra-row spacing up to 82 kg ha^{-1} and 10.5cm, were found to be optimum for maximizing the total bulb yields of onion at Melkassa. The difference in total yield as a result of decreased population densities was observed to be compensated in part by an increase in yield of medium and large-sized bulbs and a decrease in small-sized ones. A similar result was also reported by Khokhar [46], who found that application of 60 kg ha^{-1}N gave the highest bulb yield of onion

Tegen et al [47] and Arundale et al [48] reported similar results by stating the total yield of ripe bulbs increased with the increasing number of plants per square meter until an optimum was reached and thereafter the yield declined. On the contrary, Ali et al [49] reported that decreasing the plant spacing will ultimately increase the total yield of onions. This positive response might be due to the role of N in promoting the growth of the onion plant.

3.3.6 Bulb Size distribution of marketable dry bulbs

The marketable dry bulb yield was grouped into s mall (20 -50g), medium (50-100g), large (85 - 16 0g), and oversized (>160g) to see how far the tre atments influenced the performance of the dry bulb.

3.3.6.1 Small-size bulb yield (20-50g)

The effect of intra-row spacing, nitrogen levels, and their interaction on small-size bulb yield (t ha^{-1}) showed a significant (P<0.01) difference (Table 6).

The highest yield of small bulb size (10.29 t ha^{-1}) was observed for the treatment combination of 5 cm intra-row spacing with 59 kg N ha^{-1} nitrogen treatment. While the lowest yield (3.49 t ha^{-1}) was recorded for the treatment combinations of 12.5 cm intra-row spacing and 105 kg. ha^{-1}N. The reason for this might be that close intra-row spacing and suboptimum nitrogen fertilizer rate restricted bulb development due to limited growth factors that resulted in an excessive proportion of small bulbs. Lencha & Buke [35] and Nourai [50] also reported that, as plant density increased, there was a progressive shift of the modal-size grade to smaller grades of garlic.

Table 5. Interaction effects of nitrogen rates and intra-row spacing on marketable, unmarketable, and total bulb yield (t ha^{-1})) of Nafis onion variety grown at awash melkassa

N(kg ha-1)	Intra-rows spacing(cm)	MB(t ha-1)	UB(t ha-1)	TBY (t ha-1)
0	2.5	17.73n	2.29a	19.00l
	5	20.09l	1.68c	21.77k
	7.5	23.04h	1.90b	24.94f
	10.5	20.91k	1.51d	22.42ij
	12.5	19.18m	1.28e	21.47k
59	2.5	20.83k	2.00b	22.83hi
	5	22.28i	1.16e	23.44g
	7.5	21.93i	2.00e	23.13gh
	10.5	22.18i	1.19e	23.38g
	12.5	21.32j	0.97f	22.28j
82	2.5	25.05g	1.27e	26.32e
	5	27.15cd	0.94f	28.10c
	7.5	27.40c	1.48d	28.88b
	10.5	30.13a	0.91f	31.04a
	12.5	26..41e	0.92f	27.34d
105	2.5	27.08cd	1.01f	28.09c
	5	26.24e	1.19e	27.43d
	7.5	26.94d	1.30e	28.24c
	10.5	29.42b	1.23e	30.66a
	12.5	25.71f	1.00f	26.71
LSD(0.05)		0.69	0.15	0.67
CV (%)		1.54	6.61	1.06

Where means within a column followed by the same letter(s) are not significantly different; CV: Coefficient of variation; LSD: Least Significant Difference; MB=marketable bulb; UB=unmarketable bulb; TBY=total bulb yield

Table 6. Interaction effects of nitrogen rates and intra-row spacing on the bulb size distribution of marketable dry bulbs (t ha^{-1}) of Naïfs onion variety grown at awash melkassa

N(kg ha^{-1})	Intra-rows spacing(cm)	US (t ha^{-1})	SS (t ha^{-1})	MS (t ha^{-1})	LS (t ha^{-1})	OS (t ha^{-1})
0	2.5	2.02a	7.53cd	6.16j	3.04k	0.457m
	5	1.91b	6.25g	8.31i	6.131i	1.63k
	7.5	1.62c	6.84e	9.29h	7.37efg	1.80k
	10.5	1.26e	7.28d	9.41gh	7.06gh	2.10j
	12.5	1.13f	7.83c	6.59j	7.64e	2.20ij
59	2.5	1.38d	6.17g	7.78i	4.88j	0.63m
	5	0.94g	10.29a	9.15h	6.72h	2.01j
	7.5	0.90hij	8.25b	11.75de	6.23i	2.75h
	10.5	0.87hijk	5.42i	10.89f	7.05gh	3.27f
	12.5	0.85ijkl	4.19k	10.64f	7.12fgh	3.59e
82	2.5	1.00g	7.361d	11.63de	6.09i	0.97l
	5	0.83jklm	6.50efg	11.20ef	8.75d	2.38i
	7.5	0.81klm	6.68ef	11.751de	9.08cd	3.36f
	10.5	0.81klmn	6.37fg	15.15a	10.81a	3.85d
	12.5	0.77lmn	4.531k	12.46bc	9.57b	4.13c
105	2.5	0.92ghi	5.791h	12.56b	7.04gh	1.06l
	5	0.82jklm	4.91j	12.83b	7.55ef	3.06g
	7.5	0.76mn	4.33k	11.97cd	9.26cb	4.37b
	10.5	0.731n	3.79l	14.80a	9.56b	4.87a
	12.5	0.58o	3.49l	11.48de	9.69b	4.97a
LSD(0.05)		0.08	0.36	0.57	0.49	0.21
CV (%)		4.55	3.29	3.11	3.98	4.65

Where means within a column followed by the same letter(s) are not significantly different; CV: Coefficient of variation; LSD: Least Significant Difference; US=under size=small size; MS=medium size; LS=large size; OS=oversize

3.3.6.2 Medium bulb size yield (50-100g)

The effect of intra-row spacing, nitrogen levels, and their interaction on medium bulb size yield (50-100g) showed a significant (P<0.01) difference (Table 6).

The highest yield of medium bulb size (15.15 t ha^{-1}) was recorded for intra- row spacing of 10.5 cm and 82 kg ha^{-1}N treatment combination. While the lowest yield of medium bulb size (6.16 t ha^{-1}) was observed for a treatment combination of 2.5 cm intra-row spacing and with no nitrogen application. This is probably because with the increase in applied nitrogen and intra-row spacing the yield of medium bulb size increases due to an increase in the weight of individual bulbs thus transferring the bulbs from the small to the mediums. The result agreed with that of Lemma & Shimeles [13], who reported that investigation on a different level (0, 46, 92, and 138 kg. ha^{-1}) of N and P_2O_5 the difference was observed only on different levels of N and at 92 kg. ha^{-1}N there was better vegetative growth and the average bulb weight increased to 49 and 60 g/bulb. This is also the most proffered size in the local and export markets.

3.3.6.3 Large size bulb yield (100-160g)

The responses of large bulb-size yield due to the different levels of nitrogen fertilizer, intra-row spacing, and their interaction effects were significant (P<0.01) (Table 6).

Large bulb size yield increased at wider planting density with optimum nitrogen level according to these study conditions. Thus, the highest large bulb size yield (10.80 t ha^{-1}) was recorded at 10.5 cm intra- row spacing and 82 kg. ha^{-1}N combination. Whereas, the lowest yield of large bulb size (3.03 t ha^{-1}) was observed at a high planting density of 2.5 cm intra-row spacing with no nitrogen application. However, further increase of nitrogen fertilizer rate beyond 82 kg ha^{-1}N and intra-row spacing beyond 10.5 cm had a decreasing effect on large bulb size yield. The reason that yields of large bulbs increased significantly by increasing intra-row spacing and N rate with a corresponding decrease in the yield of small bulbs was due to resource availability and less competition increased the weight of individual bulbs thus transferring the bulbs from the medium to the large grades. This result was in agreement with the results of Kahsay et al.

[33], who reported that the yield of large tubers increased significantly by the wider spacing with a corresponding decrease in the yield of small tubers due to reduced inter-plant competition at low plant density. Messele [5] reported that intra-row spacing had a significant effect on the bulb weight of onion with 20 and 25cm spacing recording similar bulb weight but significantly higher than 10 and 15 cm spacing.

3.3.6.4 Oversized bulb yield (>160g)

Both the main and interaction effects of nitrogen level and intra-row spacing had significant (P<0.01) effects on oversized bulb yield (Table 6).

The results showed that increasing intra-row spacing and nitrogen rate increased the yield of oversized bulbs. Among the 20 treatment combinations, two of them, N rate of 105 kg ha^{-1}N with 12.5 cm and 10.5 cm intra-row spacing, gave the highest yield of oversized bulbs of 4.97 t ha^{-1} and 4.87 t ha^{-1} respectively. On the other hand, the lowest (0.457 t ha^{-1}) yield of oversized bulbs was recorded from a treatment combination of 2.5 cm intra-row spacing with 0 kg ha^{-1}N.

In this study, it was evident that the effect of nitrogen and intra-row spacing was to increase the number of bulbs that grew sufficiently to be incorporated in the larger grades. The reasons that the yield of an over-sized bulb increased with wider spacing and a higher rate of nitrogen might be due to decreased intra-plant competition at low density or relatively more available nitrogen or other soil nutrients and luxurious utilization of essential resources to the plant at wider spacing and high rate of nitrogen. Similar results were reported by Belay et al. [41], Lencha & Buke [30], and Shiberu [31], where wider plant spacing in onions, resulted in heavier bulb weight. This result was also in agreement with that of Israel et al [51]. who reported a significant effect of nitrogen on the number and weight of large-sized potato tubers, and also that of Yeshi et al [38]. on shallot crops that increased leaf length resulted in a significant increase in bulb size.

3.3.7 Bulb Size distribution of unmarketable dry bulbs

The unmarketable dry bulb size was also taken as bulbs weighted less than 20 g to see how far the treatments influenced the performance of the dry bulb.

3.3.7.1. Undersize bulb yield (<20g)

The effect of intra-row spacing, nitrogen levels, and their interaction on under-size bulb yield (t ha^{-1}) showed a significant (P<0.01) difference (Table 6). The yield of a very small bulb size (<20g) increased at higher planting density and low levels of nitrogen. Thus, the highest yield of very small bulb size (2.02 t ha^{-1}) was observed at the highest planting density of 2.5 cm intra-row spacing with 0 kg ha^{-1}N treatment combination and the lowest yield (0. the^{-1}) was recorded at the widest intra-row spacing of 12.5 cm with 105 kg ha^{-1}N. High under-sized bulb yield in closed intra-row spacing and non-nitrogen fertilizer conditions could be due to interplant competition for growth resources. This result was in agreement with other similar studies by Dawar et al [52]. found in onion that the maximum (738.11g) weight of a very small bulb at the highest planting density of 80 plants $4m^{-2}$ was noted, while the minimum (181.78g) weight of very small bulbs was achieved at planting density of 40 plants 4 m^{-2}. In support of the present result Netsanet [53], reported that increased N fertilizer from 0 to 120 kg ha^{-1}N increased the number and weight of very large-sized cloves by 46.94% and 51.37%, respectively compared to the control.

3.4 Stand Count

The effect of nitrogen fertilizer and the interaction effect of nitrogen fertilizer and intra-row spacing did not show a significant effect on stand count difference while there was a highly significant (P<0.01) difference among the intra-row spacing levels (Table 7).

Table 7. The main effect of nitrogen rates and intra-row spacing on stand count (%)of the Nafis onion variety grown at awash melkassa

Nitrogen level (kg ha^{-1})	Stand count (%)
0	87.78a
59	87.72a
82	87.72a
105	87.84a
LSD(0.05)	NS
Intra-row spacing(cm)	
2.5	74.43e
5	78.51d
7.5	89.48c
10.5	98.60a
12.5	97.81b
LSD(0.05)	0.45
CV (%)	0.62

Table. 8. Economic analyses for N rates and intra-row spacing experiment of onion

N(kg ha^{-1}) with intra-row(cm) combination	Unadjusted marketable yield (kg ha^{-1})	Adjusted marketable yield (kg ha^{-1})	Gross Benefit (Birr ha^{-1})	Variable cost (Birr)	Net Benefit (Birr ha^{-1})	MRR%
0*12.5	19180	17262	51786	1690.35	49926.61	0
0*10.5	20910	18819	56457	1786.98	54491.31	4294.37
0*7.5	23040	20736	62208	2815.66	59110.77	408.24
82*12.5	26410	23769	71307	4200.21	66686.77	497.43
82*10.5	30130	27117	81351	4296.84	76624.47	9349.1

The highest plant stand (98.60%) was recorded at 10.5cm intra-row spacing, while the lowest plant stand (74.43%) was recorded at the intra-row spacing of 2.5cm. This might be due to intense plant competition for light, nutrients, and soil moisture at closer plant spacing, as a result of which the plant becomes weaker, die, and higher number of losses of the onion plant.

3.5 Cost-Benefit Analysis

In the result of the present study, the costs for the different Nitrogen fertilizer, seed, and labor costs for transplanting and fertilizer application varied according to their purchasing and incurred cost requirements being other costs were constant for each treatment. To recommend the present result for producers, it is necessary to estimate the minimum rate of return acceptable to producers in the recommendation domain. Based on partial budget analysis, with a 10% increase in input price and a 10% decrease in output price, the highest net benefit 76624.47.16 birr was obtained from a treatment combination of 82 kg ha^{-1}N with 10.5 cm intra-row spacing with a marginal rate of return of 9349.16 % but the highest net benefit (54491.31 birrs) with the least cost (1786.98-birr ha^{-1}) were obtained from the combination of 0 kg ha^{-1}N with 10.5 cm intra row spacing with (4294.37%) MRR.

Only in one growing season (Table 8). This means that for every 1.00 birr invested for 82 kg N ha^{-1} application with 10.5cm intra-row spacing in the field, producers can expect to recover the 1.00 birr and obtain an additional 102.94 birr.

According to CIMMYT [21] the minimum acceptable marginal rate of return (MRR %) should be between 50 and 100%. The present study indicated that MRR is much greater than 100%. Therefore, the most attractive rates for small-scale farmers with low cost of production and higher benefits, in this case, were 0 kg ha^{-1}N and 10.5cm intra-row spacing combination. However, for resource-full farmers (investors), 82 kg ha^{-1}N with 10.5 cm intra-row spacing combination was also profitable with the highest net benefit and recommended as 2nd option.

The marketable bulb yield was adjusted by a 10% adjustment coefficient and the marginal rate of return (MRR) and net benefits are calculated by adding a 10% birr/kg increase from the current fertilizer price and the field price of onion was 3.00-birr kg^{-1} and the market price of Urea and seed were 13.30 kg^{-1} and 2.40 kg^{-1} respectively. And also labor incurred price for fertilizer application and planting was 77.96 qt^{-1} and 0.0004 Birr/ seedling respectively.

4. CONCLUSION

Understanding how intra-row spacing and nitrogen fertilizer amounts affect onion output and yield components is an important concern to enhance its productivity.Applied N fertilizer levels revealed highly significant differences in all of the growth, bulb characters, and yield except the stand count of onion and intra-row spacing also revealed highly significant differences in all of the growth, bulb characters, and yield. It is concluded that different spacing, N rate, and their interaction affect the yield of onion, finally for areas like Adaamaa district, Awash Melkassa Kebele (East Shewa zone of the Oromiya Region) intra row spacing of 10.5 cm with 82 kg ha^{-1} N rate is highly recommended to earn maximum marketable yield and to reduce unmarketable bulb yield, Whereas the combination of 2.5cm intra row spacing with 0 level N rate and 12.5cm with105kgN ha^{-1} found to be inferior for marketable bulb yield as measured by unmarketable bulb yield, undersized (<20g) and oversized (>160) bulb category. However, multi-location and multi-season research could be suggested to reach full recommendation because a single experiment at one location and one season may not be applicable in climatic and location variability. The agronomic and economic feasibility study is needed to know the applicability of the different spacing and N rates with other agronomic management practices.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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