# GROWTH, YIELD, AND QUALITY OF ONION (*Allium cepa* L.) AS INFLUENCED BY INTRA-ROW SPACING AND NITROGEN FERTILIZER LEVELS IN CENTRAL ZONE OF TIGRAY, NORTHERN ETHIOPIA

MSc. THEIS

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**HARAMAYA UNIVERSITY, HARAMAYA**

# Growth, Yield, and Quality of Onion (*Allium Cepa* L.) as Influenced by Intra-row Spacing and Nitrogen Fertilizer Levels in Central Zone of Tigray, Northern Ethiopia

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Guesh Tekle

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**SCHOOL OF GRADUATE STUDIES**

As thesis research advisers, we hereby certify that we have read and evaluated the thesis prepared, under our guidance by Guesh Tekle, which is entitled "**Growth, Yield and Quality of Onion (*Allium cepa* L.) as Influenced by Intra-row Spacing and Nitrogen Fertilizer Levels in Central Zone of Tigray, Northern Ethiopia".** We recommend that the thesis be accepted as it fulfills the requirements.

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As members of the Board of Examiners of the MSc. Thesis Open Defense Examination, we certify that we have read and evaluated the thesis prepared by Guesh Tekle and examined the candidate. We recommend that the thesis be accepted as it fulfills the requirements for the Degree of Master of Science in Agriculture (Horticulture).

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Final approval and acceptance of the thesis is contingent up on the submission of its final copy of the thesis to the council of graduate program (CGP) through the departmental or school of graduate committee (DGC or SGC).

# DEDICATION

I dedicate this thesis manuscript to my mother Guey Weldegerima for her advice and for nursing me with affection and care and for her partnership in the success of my life.

# STATEMENT OF THE AUTHOR

First, I declare that this thesis is a result of my work and all other sources of material and information used for writing it have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc degree at Haramaya University and is deposited at the university's library to be made available to borrowers under the rules and regulations of the library. I solemnly declare that this thesis has not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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# BIOGRAPHICAL SKETCH

The author, Guesh Tekle, was born on 17 June 1984 at Axum, Central Zone of Tigray to his father Tekle Gebregziabher and his mother Guey Weldegerima. He attended Elementary education (grades one to six) at Mytruengi Elementary School from 1993-1996, junior secondary education (grades seven to eight) at Mahbere-Dego School from 1997-1998, and secondary education at Axum Comprehensive Secondary School from 1999-2002. After completing his elementary and secondary education, he joined the College of Agriculture and Veterinary Medicine of Jimma University in 2003, and graduated with the degree of Bachelor of Science (BSc) in Horticulture in July 2006.

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# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| AxARC | Axum Agricultural Research Center |
| AVRDC | Asia Vegetable Research and Development Center |
| CEC | Cation Exchange Capacity |
| CIMMYT | Center of International Maize and Wheat Improvement |
| CSA | Central Statistical Agency |
| EARO | Ethiopian Agricultural Research Organization |
| FAO | Food and Agricultural Organization |
| HI | Harvest Index |
| DMRT | Duncan Multiple Range Test |
| MoARD | Ministry of Agriculture and Rural Development |
| MRR | Marginal Rate of Return |
| MARR | Minimum Acceptable Rate of Return |
| NUE | Nitrogen Use Efficiency |
| SAS | Statistical Analysis System |
| TSP | Triple Super Phosphate |
| TSS | Total Soluble Solids |

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# GROWTH, YIELD, AND QUALITY OF ONION (*ALLIUM CEPA* L.) AS INFLUENCED BY INTRA-ROW SPACING AND NITROGEN FERTILIZER LEVELS IN CENTRAL ZONE OF TIGRAY, NORTHERN ETHIOPIA


## ABSTRACT

*Haphazard and inappropriate plant spacing and poor soil fertility management practices are among the major factors constraining onion production in the Central Zone of Tigray. Therefore, a field experiment was conducted in Axum district from October to March 2014 to assess the influence of intra-row spacing (2.5, 5, 7.5, 10 and 12.5 cm) and nitrogen rate (0, 41, 82 and 123 kg N $ha^{-1}$) on growth, bulb yield, and quality of onion. The experiment was laid out in a randomized complete block design (RCBD) of factorial arrangement with three replications. The main effects of nitrogen rate and intra-row spacing influenced only the plant height and stand count significantly ($P < 0.01$). The tallest plants (46.70 cm) were obtained from plants treated with 82 kg N $ha^{-1}$ as well as those spaced at 7.5 cm intra-row spacing (43.78 cm). The highest stand count (90.33%) at harvest was recorded from plots that received 82 kg N $ha^{-1}$ and spaced at 12.5 cm (98.04%). Nitrogen rate and intra-row spacing interacted to significantly ($P < 0.01$) to influence all parameters. Thus, increasing the rate of nitrogen across the increasing intra-row spacing significantly prolonged days to maturity, enhanced average bulb weight, bulb diameter, bulb neck diameter, leaf number per plant, leaf diameter, shoot dry matter, and dry total biomass yield. In general, the highest values of these parameters (126.67, 123.85 g, 6.05 cm, 1.35 cm, 12.57, 1.38 cm, 3.22 g and 13.08 g, respectively) were attained in response to the application of 123 kg N $ha^{-1}$ and 12.5 cm intra-row spacing. However, their least values (100, 23.99 g, 2.33 cm, 0.68 g, 6.60, 0.47 cm, 0.73 g, and 2.72 g, respectively) were obtained at 0 kg N $ha^{-1}$ and 2.5 cm intra-row spacing. The highest value of bolting (31.95%) was observed from the application of 0 kg N $ha^{-1}$ and plant spacing of 2.5 cm. Increasing the N rate across the increasing intra-row spacing increased the yields of over-sized bulbs whereas decreasing the yields of small-sized, under-sized bulbs and unmarketable bulb yield. The highest yield of over-sized bulbs (4.03 t $ha^{-1}$) was recorded at 123 kg N $ha^{-1}$ and the intra-row spacing of 12.5 cm. Whereas, the highest yield of medium sized (28.27 t $ha^{-1}$) and large sized bulb yield (8.03 t $ha^{-1}$) was obtained both at 82 kg N $ha^{-1}$ and plant spacing of 5.0 cm and 7.5 cm, respectively. The total and marketable bulb yields increased markedly across the increasing rate of nitrogen and intra-row spacing only up to 82 kg N $ha^{-1}$ and 5.0 cm intra-row spacing which attained maximum values of (39.51 t $ha^{-1}$ and 39.69 t $ha^{-1}$), respectively and beyond which their yields decreased significantly. However, total bulb yield decreased as nil nitrogen level interacted with across the increasing of intra-row spacing. Thus, the lowest total (18.89 t $ha^{-1}$) and marketable bulb yields (17.93 t $ha^{-1}$) were obtained from plants that received no nitrogen at the intra-row spacing of 12.5 cm and 2.5 cm, respectively. The highest value of harvest index (79.98%) was produced at 82 kg N $ha^{-1}$ at the plant spacing of 5.0 cm and 7.5 cm. However, the highest total soluble solid (13.57 $^{0}$Brix) was obtained at 123 kg N $ha^{-1}$ and intra-row spacing of 2.5 cm. In conclusion, as the partial budget analysis revealed that the highest net benefit with low cost of production was obtained in response to the application of 82 kg N $ha^{-1}$ and the intra-row spacing of 10 cm and was optimum for producing the crop in the study area.*



***Key words*****:** *Onion, intra-row spacing, nitrogen, marketable yield, bulb size distributions*

# 1. INTRODUCTION

Onion (*Allium cepa* L.) is one of the most important vegetable crops commercially grown in the world. It probably originated from Central Asia between Turkmenistan and Afghanistan where some of its relatives still grow in the wild. Onion from Central Asia, the supposed onion ancestor had probably migrated to the Near East (Grubben and Denton, 2004; Bagali *et al*., 2012).

The crop onion is a popular vegetable and its bulb is used raw, sliced for seasoning salads, and cooked with other vegetables and meat. Onion bulbs are essential ingredients in many African sauces and relishes. The leaves, whole immature plants called 'salad onion' or leafy sprouts from germinating bulbs are used in the same way. In some parts of West Africa, leaves still green at bulb harvest are propounded, and then used to make sun-dried and fermented balls, which are used later for seasoning dishes. Sliced raw onions have antibiotic properties, which can reduce contamination by bacteria, protozoa or helminths in salads (Grubben and Denton, 2004).

Onions are day length sensitive, several onion types exist depending upon the latitude at which they grow. It is estimated that around the World, over 3,642,000 ha of onions are grown annually. On a worldwide scale, around 80 million metric tons of onions are produced per year. China is by far the top onion producing country in the world, accounting for approximately 28% of the world's onion production, followed by India, USA, Iran, Egypt, Turkey, Russia, Pakistan, Netherlands and Brazil. The worldwide onion exports are estimated at around 7 million Metric tons. The Netherlands is the world's largest onion exporter with a total of around 220,000 Metric tons followed at a distance by India (FAO, 2013).

Onion has economically important role in Ethiopia. The country has enormous potential to produce the crop throughout the year both for domestic use and export market. Ever since the crop is distributed to different parts of the country, it is widely cultivated as a source of income by many farmers in many parts of the country as a whole. Onion production also contributes to commercialization of the rural economy and creates many off-farm jobs

(Lemma and Shimeles, 2003; Nikus and Mulugeta, 2010). Onion production in the country is increasing from time to time. During the 2013/2014 cropping season, the total area under onion production was estimated to be 24, 375.7 ha with an average yield of about 9.02 tons per hectare and estimated a total production of greater than 2, 19, 735.27 tons (CSA, 2014).

Nutrients play a significant role in improving productivity and quality of vegetable crops. Onions are the most susceptible crop plants in extracting nutrients, especially the immobile types, because of their shallow and unbranched root system; hence they require and often respond well to addition of fertilizers (Brewster, 1994; Rizk *et al*., 2012). Therefore, optimum fertilizer application and cultivation of suitable varieties with appropriate agronomic practices in specific environment are necessary for obtaining good yield of onion.

Nitrogen (N) and phosphorus (P) are often referred to as the primary macronutrients because of the probability of plants being deficient in these nutrients and the large quantities taken up from the soil relative to other essential nutrients (Marschner, 1995). Nitrogen plays an important role for optimum yield of onion and is found to be essential to increase the bulb size and yield. Increasing nitrogen application rates significantly enhances plant height, number of green leaves per plant and weight of bulb, marketable yield and also total soluble solids (Nasreen *et al*., 2007; Al-Fraihat, 2009).

In addition to nitrogen, plant spacing is an important factor determining onion yield and quality. An essential aspect of any crop production system is the development of a crop canopy that optimizes the interception of light, photosynthesis, and the allocation of dry matter to harvestable parts. A crop canopy is commonly managed by manipulating row spacing and plant population; as plant density increases, yield per unit area increases and will approach an upper limit, the plateau. Then, the yield per unit area declines since yield per plant tends to decrease with further increase in the plant density because of competition for growth factors between adjacent plants (Silvertooth, 2001). Thus, spacing is an important factor for the production of onion since it affects both bulb yield and quality. Plating density greatly influences quality, texture, taste and yield of onion even within a particular variety (Saud *et al*., 2013). Yield responses to plant population need to be known for practical purposes, as planting density is a major management variable used in matching crop requirements to the resources by the environment (Smith and Hamel, 1999). Coleo *et al*. (1996) reported that the highest commercial bulb yield was recorded at a higher planting density, but the highest proportion of large bulbs and average bulb weight at lower planting density.

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*. Thus, research should be undertaken to determine specific application rates for individual fields since it is important to avoid over fertilization with nitrogen or phosphorus, as this will contribute to increased pest attacks and stimulation of succulent growth that may predispose the plant to damage by field or storage pathogens Ware and McCollum (1980). 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 to onion production is improper agronomic practice 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 environment, purpose of the crop and cultivar. Optimum plant spacing and nitrogen recommendations have been formulated for onion particularly in the Rift Valley region of Ethiopia, 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 $P_2O_5$ $ha^{-1}$ (Lemma and Shimeles, 2003; Nikus and Mulugeta, 2010). However, these recommendations cannot be directly adopted for the soil and growing conditions of the Central Zone of Tigray, which are different from the conditions in the Rift Valley region. This means that, it is very difficult to give general recommendations that can be applicable to the different agro-ecological zone (Upper Awash Agro-Industry Enterprise, 2001). Therefore, to optimize onion productivity in the study area, a specific package of recommendation of nitrogen fertilizer and plant spacing is required (Gupta *et al*., 1994; Lemma and Shimeles, 2003).

Onion is one of the most important vegetable crops cultivated mostly under irrigated conditions in Axum District in Central Zone of Tigray Region. There are many production constraints responsible for low yield per unit area in the Districts. According to Problem Appraisal of Axum Agricultural Research Center (Unpublished, 2012), different agronomic practices are undertaken to produce the crop in the District. For example, growers use different levels of inorganic fertilizers for production of different vegetables under irrigation particularly for onion production. The farmers often apply between 100-200 kg $ha^{-1}$ of DAP and 50-150 kg $ha^{-1}$ Urea. However, a few of the 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 DAP and 100 kg $ha^{-1}$ Urea (Nikus and Mulugeta, 2010). Farmers in the district also grow onion using double row planting method at the spacing of 40 cm between furrows and 20 cm between rows on the ridge. However, the different growers use different spacing for improving the yield of onion.

Onion is traditionally grown at the recommended spacing of 40 cm x 20 cm x 10 cm in Ethiopia (Lemma and Shimeles, 2003). However, farmers in Axum 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 and for producing bulbs with higher yields and optimum sizes per unit area and for effective use of the limited irrigable land. Moreover, oversized bulbs have little market demand in the local markets of Axum and its environs. The reasons for less market demand of large onion bulbs have not been documented, but may be attributed to the poor shelf life and other quality attributes of large bulbs. At present, onion growers in the Central Zone of Tigray produce onions with the application of blanket recommendation of nitrogen fertilizer rates and intra-row spacing or using N rates and spacing which they feel as best for obtaining higher yields. Therefore, the present study was initiated with the following objectives:

- To assess the effect of intra-row spacing and nitrogen fertilizer level on growth, yield and quality of onion; and
- To identify the appropriate intra-row spacing and nitrogen fertilizer rate that improves yield and quality of onion.

# 2. LITERATURE REVIEW

## 2.1. Description of Onion Crop

Onion (*Allium cepa* L.) belongs to the family *Alliaceae* or Amaryllidaceae which is one of the most important monocotyledonous crops. It belongs to the genus *Allium* and recent estimations accept about 750 species in the genus *Allium*, among which onion, Japanese bunching onion, leeks, and garlic are the most important edible *Allium* crops. And about 60 taxonomic groups at sub-generic, sectional and sub-sectional rank (Baloch, 1994; Rabinowitch and Currah, 2002). Onion from central Asia, the supposed onion ancestor had probably migrated to the Near East. Then it was introduced to India and South-East Asia; and into the Mediterranean area and from there to all the Roman Empire (Grubben and Denton, 2004).

Onion is a cross-pollinated cool season vegetable crop. It is the oldest known vegetable. Onion is an indispensable and important vegetable item which is used in every kitchen therefore its constant demand always remains throughout the year. Besides its high food value, it is also a good source of income for vegetable growers. It can be eaten as green leaves, bulbs that are mature and immature which can be eaten as fresh and also can be used in preparation of different dishes. The pungency of the onion bulbs is due to the presence of a volatile oil that is allylpropyl disulfide (Baloch, 1994). The onion has its own distinctive flavor and used in soups, dishes, salad and sandwiches and is cooked alone as a vegetable. It is consumed at its young green stage or after its full development and maturity when it is harvested in the form of a dry bulb. The mature bulbs contain some starch, appreciable quantities of sugar, some protein, and vitamins A, B and C (Jilani *et al.*, 2010).

Onion is a shallow rooted, biennial crop which is grown as annual. The leaves are long, hollow with widening, overlapping bases. The tubular leaf blades are flattened on the upper surface, and the stem of the plant also is flattened. Roots arise from the bottom of the growing bulb. Leaf initiation stops when the plant begins to bulb. The base of each leaf becomes one of the “scales” of the onion bulb, so the final bulb size depends in part on the number of leaves present at bulb initiation. The leaf base begins to function as a storage organ at bulb initiation, so the size of the leafy part of the plant also influences bulb size. Thus, the more leaves present and the larger the size of the plant at the onset of bulb initiation, the larger will be the bulbs and the greater will be the crop yield (Hamasaki *et al*., 1999).

The onion develops distinct bulbs depending on the varieties. These bulbs are varying in size (small, medium and large). Bulb weight may be one kg in some Southern European cultivars, and the shape covers a wide range from globose to bottle like and to flattened disk-form. The color of the membranous skins may be white, silvery, buff, yellowish, bronze, rose red, purple or violet. The color of the fleshy scales can vary from white to bluish-red. There is also much variation in flavor and keeping or storage ability of the bulbs ((Baloch, 1994; Rabinowitch and Currah, 2002).

## 2.2. Environmental Requirements of Onion

Onion can be grown in a wide range of climatic environments, but it thrives best at mild climate without excessive rainfall or extremes of heat and cold. Onion is a cool season crop that has some frost tolerance but is best adapted to a temperature range between 13 and 24 $^{0}$C. Optimum temperatures for early seedling growth are between 23 and 27 $^{0}$C; growth is slowed at temperatures above 30 $^{0}$C. Acclimatized plants are able to tolerate some freezing temperature. Best production is obtained when cool temperature prevails over an extended period of time, permitting considerable foliage and root development before bulb formation starts. After bulb formation begins, high temperature and low relative humidity extending into the harvest and curing period are desirable (Purseglove, 1985; Rubatzky and Yamaguchi, 1997; Jilani *et al.,* 2010).

Onions can be grown on a wide range of soils, varying in texture from coarse-grained sands to clays. Lighter soils are easy to manage. Soils should be 45-60 cm deep and well drained. Soils with high water holding capacity are better able to provide moisture to the shallow rooting system but must also drain well to be suitable. Growth is retarded when available soil moisture is low, but onions are also sensitive to a high water table or water logging. Uniform moisture availability about 400-800mm per crop is conducive to large bulb size and high yields.

Favorable soil pH is about 6.5–8.0 in mineral soils (Rubatzky and Yamaguchi, 1997; Savva and Frenken, 2002).

Light and temperature influence the process of bulbing. Both factors must be at optimum for the initiation of the bulbs. Cool conditions with long days are normally important for production, although there are cultivars that tolerate warm conditions and short day-lengths. Cool conditions are usually required during the first part of the season, when the plants start to form bulbs. Warm and dry weather is needed for harvesting and curing.  Each cultivar differs in its sensitivity to day-length (Savva and Frenken, 2002).

The onions are grouped into short-days and long-days depending on the day length requirements. The bulbs that acquire day length of 11.5 hours are categorized into short-day group and those take 14 hours or more for bulb formation fell into long-day group. Onion also requires varying day length and temperature for the purpose they produced. A relatively high temperature and long photoperiod are required for bulb formation, and for seed production, temperature is of immense importance than day length. Onion bulbs have specific temperature requirement for seed and bulb production (Baloch, 1994). Light intensity, light quality, and other factors interact with temperature and day length to influence the bulbing response of onion cultivars. With warm weather and bright days, onions bulb at shorter day lengths than when the days are cool and over cast (Hamasaki *et al*., 1999).

Onion dry bulb are established either by direct sowing to the field, by transplanting seedling or from dry sets depending on the growing conditions of the specific regions. Sowing seeds directly into the soil where the crop is to be grown is potentially the most economical method of raising an onion crop, particularly where the availability of labor for transplanting is limited and its cost is high or where the availability of facilities for raising transplants is limited (Brewster, 1994). Sets and transplants are used in areas where the season is not long enough for proper bulb development. Transplants have the advantage on economic use of seed, selecting superior (healthy and vigorous) seedlings. It saves weeding and watering effort during the early weeks of onion growth it enables the farmers attend to the seedlings in a compact area (Lemma and Shimeles, 2003).

## 2.3. Importance and Production Status of Onion in Ethiopia

The production of vegetables is becoming important with the expanding irrigated agriculture and with the growing awareness on the importance of the sector as source of income, improved food security, sources of raw materials for industries, employment opportunity because it demands large labor force. The expansion of water harvest schemes in small farmers sector and irrigated agricultural development projects have made significant contribution to the development of the sector. The success of production depends on the adoption of improved technologies such as cultivars that have acceptable standard and high value in the local use and export markets (Lemma *et al*., 2006).

Ethiopia has a great potential to produce onion throughout the year both for local consumption and for export. It grows best at an altitude of between 700-2200 meters above sea level. Onion is a rapidly becoming popular among producers and consumers. Its popularity among producers is because of the advantage of high yield potential, availability of desirable cultivars for various uses, ease of propagation by seed, high domestic (bulb and seed) and markets in fresh and processed forms (Lemma and Shimeles, 2003). Onion contributes substantially to the national economy, apart from overcoming local demands. With the growing irrigate agriculture in the country, there is a great potential for extensive onion seed and dry bulbs production in the different production belts of the country.

Specifically to onion production and improvement, the Ethiopian Agricultural Research Institute has made efforts to generate different improved varieties. As a result of this effort the varieties Adama Red, Bombay Red, Red Creole, Melkam, Mermiru Brown, Nasik Red and Nafis are made available to farmers (Lemma and Shimelis, 2003; MoARD, 2010). It is widely produced by small farmers and commercial growers throughout the year for local use and export market. Onion is important in the daily Ethiopian diet and all the plant parts are edible, although the bulbs are widely used as a seasoning or a vegetable in various dishes. Onion is valued for its distinct pungency and form essential ingredients for flavoring varieties of dishes, sauces, soup, sandwiches, snacks as onion rings *etc*. It is popular over the local shallot because of its high yield potential per unit area, availability of desirable cultivars for various uses and ease of propagation by seed (Lemma, 2004).

Onion is considered as one of the most important vegetable crops produced on large scale in Ethiopia. It also occupies an economically important place among vegetables in the country. The area under onion is increasing from time to time mainly due to its high profitability per unit area and ease of production, and the increases in small scale irrigation areas. The crop is produced both under rain-fed in the "*Meher"* season and under irrigation in the off season. In many areas of the country, the off season crop (under irrigation) constitutes much of the area under onion production. Despite areas increase, the productivity of onion is much lower than other African countries. The low productivity could be attributed to the limited availability of quality seeds and associated production technologies used, among the others (Nikus and Mulugeta, 2010).

## 2.4. Response of Onion to Nitrogen Application

### 2.4.1. Roles of nitrogen in onion nutrition and growth

Onion being among the high nitrogen demanding vegetables, its productivity depends on use of optimum fertilizer rates and if not adequately fertilized, considerable yield losses are apparent. Among all nutrients, nitrogen is the most important and also the most limiting to crop production. Efficient N use is important for the economic sustainability of cropping systems (Brewster, 1994; Fageria and Baligar, 2005). Excessive use of N fertilizers is a concern, since large amounts of N can remain in the soil after crop harvesting (Neeteson *et al*., 1999). In a temperate climate, usually ≤ 50% of N applied is effectively used by plants, while a considerable part is lost by leaching and contaminates ground and surface waters (Fageria and Baligar, 2005).

Mineral fertilizers are one of the principal factors that materially set up onion growth and production. Onion plants take up large amounts of the three primary nutrients, *i.e*. nitrogen, phosphorus and potassium (Kandil *et al*., 2013). Marschner (1995) also stated that nitrogen and phosphorus are often referred to as the primary macronutrients because of the large quantities taken up from the soil relative to other essential nutrients.

**2.4.2. Response of onion to nitrogen fertilization**

Onion, compared with most crops, is usually the weakest crop plant in terms of extracting nutrients, especially the immobile types, because of their shallow and unbranched root system (Brewster, 1994). Thus, the crop is a heavy feeder, requiring ample supplies of N; hence it requires and often responds well to addition of fertilizers. However, excess application of nitrogen causes excessive vegetative growth, delayed maturity, increase susceptibility to diseases, reduces dry matter contents and storability and ultimately reduces yield and quality of bulbs (Brewster, 1994; Sørensen and Grevsen, 2001).

Soleymani and Shahrajabian (2012) showed that the highest and the lowest marketable yield were obtained in to the application of 300 kg N $ha^{-1}$ and 0 kg N $ha^{-1}$, respectively. Negash *et al*. (2009) also reported that increasing the rate of N fertilization from 0 to 138 kg $ha^{-1}$ increased total bulb yield from 19.26 t $ha^{-1}$ to 32.24 t $ha^{-1}$. Similarly, increasing the rate of nitrogen application from 0 to 138 kg $ha^{-1}$ significantly increased marketable bulb yield from 18.82 t $ha^{-1}$ to 31.90 t $ha^{-1}$ which was 69.5% higher than the control. Jilani *et al*. (2004) reported that with increase in dose of nitrogen up to120 kg N $ha^{-1}$ the marketable and total bulb yield was increased, but below this level the total yield t $ha^{-1}$ began to decrease. A significant increase in total bulb yield in response to nitrogen fertilizer levels was also observed by (Balemi *et al*. 2007).

Bolting is triggered in response to exposure of the onion plant to conditions like low temperature or limited N supply which induces flowers to emerge before bulb are adequately grown to suppress flower initiation (Yamasaki and Tanaka, 2005). Al-Fraihat (2009) also, stated that highest percentage of bolting was obtained from plants fertilized with the lowest level of nitrogen (100 kg N $ha^{-1}$). Abdissa *et al*. (2011) also showed that nitrogen fertilization significantly reduced bolting in onion. The authors reported that ratio of bolting percentage per plot decreased by about 11 and 22% in response to the fertilization of 69 and 92 kg N $ha^{-1}$, respectively as compared to the control.

Yield is composed of marketable and unmarketable dry bulbs. The marketable product typically depends on onion cultivar (Lemma and Shimeles, 2003). According to the authors, marketable bulb weight can be grouped into different size of bulb categories: Oversized (above160 g), large (100-160 g), medium (50-100 g), small (20-50 g) and under-sized below (20 g). These sizes can be preferred by consumers or users according to their purpose for planting material, food, as well as for processing. EARO (2004) stated that the different bulb size category was indicated for different varieties under the Ethiopian conditions: Bombay Red (85-100 g), Adama Red (60-80 g), Red Creol (80-100 g), Melkam (70-90 g), Mermiru Brown (70-90 g) and Dereselign (85-100 g). This showed that bulb size category is also highly dependable on variety in addition to intra-row spacing.

With regard to unmarketable bulb yield of onion, it is related to the under sized bulb which is below 20 gram, diseased, decayed, physiological disorder such as thick necked, splits and bolters. Disorders are influenced by location, season, cultivar, and management practice. On the other hand, thick necked also occurs mainly when some of the proportion of bulbs fail to complete bulbing in which the leaves continue growing. Under this condition, the neck does not get soften and the bulb does not become dormant. Heavy and continuous watering and late application of nitrogen contribute to this disorder (Lemma and Shimeles, 2003). The onion bulb size increased significantly with the application of different doses of nitrogen. Application of higher nitrogen of 120 kg $ha^{-1}$ recorded the maximum bulb size while the minimum bulb size was recorded in control (Jilani *et al.*, 2009).

Nitrogen significantly affected yields of various onion bulb size categories. Onion fertilized with different N levels decreased the yield of small sized bulbs, but increased the yield of large sized bulbs. Small sized bulbs decreased by 61.8% when N application was increased from 0 to 138 kg $ha^{-1}$. On the hand, when N fertilization increased from 0 to 138 kg $ha^{-1}$ the increased large size bulbs increased from 12.58 t $ha^{-1}$to 25.67 t $ha^{-1}$, respectively, resulting in 104% increment (Negash *et al*., 2009).

Nitrogen fertilization increased the bulb yield of onion and yield components. Increasing nitrogen levels from 0 to 120 kg $ha^{-1}$ resulted in progressive increase in bulb yield. Application of 120 kg N $ha^{-1}$ increased the number of leaves per plant and plant height over the control as well as lower levels of nitrogen. There was an increase in diameter and weight of bulbs due to application of nitrogen up to 120 kg N $ha^{-1}$ and thereafter decreased (Nasreen *et al*., 2007). A report also described by Morsy *et al*. (2012) indicated that 120 kg N $ha^{-1}$ appeared higher values of plant height, number of leaves per plant, bulb diameter and days to maturity as compared to adding of 90 kg $ha^{-1}$.

Al-Fraihat (2009) stated that with increasing application of nitrogen fertilizer from 100 kg N $ha^{-1}$ to 200 kg N $ha^{-1}$ in the first and second growing seasons, the TSS value increased from 13.75% to 14.70% and 13.90% to 15.07% during the first and second growing seasons, respectively. Morsy *et al*. (2012) also showed application of 120 kg N $ha^{-1}$ led to the highest values of TSS whereas, application of 90 kg N $ha^{-1}$ resulted in the lowest values of TSS in both seasons. Moursy *et al*. (2007) also indicated that increasing the level of N fertilizer to 80 kg N $ha^{-1}$ resulted in about 8.5% increase in the TSS as compared to the level of 40 kg N $ha^{-1}$.

The different N levels affected the leaf diameter and length of onion. The application of 150 kg N $ha^{-1}$ gave the highest value with regard to leaf diameter. Generally, with increasing nitrogen level from 0 kg $ha^{-1}$ to 150 kg $ha^{-1}$ the leaf diameter of onion increased from 0.81 cm to 1.00 cm (Kokobe *et al*., 2013). Al-Fraihat (2009) reported the highest level of nitrogen significantly increased plant height and number of green leaves per plant as compared to the control treatment.

Nitrogen fertilization significantly extended the number of days required for onion crop to attain its physiological maturity. Regardless of the rate, N fertilization extended physiological maturity by about 6 days over the unfertilized treatment (Abdissa *et al*., 2011). A report by Meena *et al*. (2007) also described the delay in maturity of onion bulb due to application of enhanced level of nitrogen.

Generally, considering the status of the soil, additional nitrogen fertilizer levels application may be necessary in order to meet the crop N requirements. The amount of N needed is usually based on soil organic matter content, crop uptake and yield levels. Nitrogen uptake levels by onion crops may vary from less than 50 kg to more than 300 kg $ha^{-1}$, depending on cultivar, climate, plant density, fertilization and yield levels (Soujala *et al*., 1998).

## 2.5. Effect of Plant Spacing on Onion Yield and Yield Components

Plant population refers to number of plants per square meter (plants $m^{-2}$) or hectare (plants $ha^{-1}$) and is important in onion production since it has an influence on growth, yield and quality of onion bulbs (Brewster, 1994). Plant and row spacing are considered important to the optimum plant population which may be reflected in higher yield and quality. Onion bulb size can be controlled to a certain extent by plant population. In order to produce large bulbs (> 70 mm in diameter) a plant population of between 25 and 50 plants $m^{-2}$ is required, for medium bulbs (25-50 mm) between 50 and 100 plants $m^{-2}$ and for small bulbs (< 50 mm) more than 100 plants $m^{-2}$ are required (Brewster, 1994).

According to Dorcas *et al*. (2012) reported that with increasing plant density of onion from lower 100,000 plants $ha^{-1}$ to higher plant density of 500,000 plants $ha^{-1}$ then average bulb weight and bulb diameter decreases from 58.22 g to 40.04 g and 4.56 cm to 2.83 cm respectively. The authors also reported that highest and lowest yield was obtained in the higher plant density of 500,000 plants $ha^{-1}$ and lower plant density of 100,000 plants $ha^{-1}$. Yemane *et al*. (2013) indicated that with increasing intra-row spacing from 5 to 10 cm, statistically bulb diameter and bulb neck diameter of onion increased from 4.66 to 5.63 cm and 1.48 1.74 cm respectively. Dawar *et al.*, (2005) indicated that as plant population increased from 40 to 80 plants $m^{-2}$ onion neck diameter declined significantly. Jilani *et al*. (2009) indicate that bulbs of thick neck of onion were found in plots of lowest plant density (20 plants $m^{-2}$). Bulb neck diameter decreased as population density increased. Mean bulb weight and plant height decreased as population density increased (Kantona *et al.*, 2003).

Khan *et al*. (2002) reported that various plant spacing leads to the increase in plant height, onion bulb size, and weight of the bulbs, bulbs $ha^{-1}$ and yield of the bulbs. Khan *et al*. (2003)

reported that wider spacing (20 x 10 cm) produced higher size of plant height, leaf length and number of leaves, bulb length, diameter and weight of onion. On the contrary, highest yield was observed at the closest spacing and the lowest yield at widest spacing. Yamane *et al*. (2013) also indicated that as intra-row spacing increased from 5 to 10 cm, marketable bulb yield in t $ha^{-1}$ decreased from 34.49 to 28.10. Seck and Baldeh (2009) reported that plant density has an impact on marketable bulb size and the higher the plant density the smaller the marketable size. Kantona *et al.* (2003) also reported that as plant density increased number of marketable bulbs increased.

Sikder *et al.* (2010) evaluated three intra-row spacing (20x20, 20x15 and 20 cmx10 cm) of onion. Based on this, the maximum yield were recorded from 20 cm x 10 cm spacing and the narrow plant spacing produced comparatively lower values on fresh weight of leaves per plant, plant height, leaves number per plant, bulb diameter and fresh weight of bulb. Stoffela (1996) also found that as number of rows per bed increased, marketable onion yield linearly increased and mean bulb size decreased. Latif *et al*. (2010) showed that yield of onion bulbs produced at the spacing of 20 cm x 10 cm was recorded as the highest compared to 20 cm x 20 cm spacing. Mahadeen, (2008) also reported that narrow intra-row spacing produced higher yield.

According to Balraj *et al*. (1998) with increase in plant spacing, the bulb weight and size increased, but the yield $ha^{-1}$ decreased. Kumar *et al*. (1998) indicated that the spacing has a direct effect on the quality and production of onion. Lower planting density was the best with regard to leaf length. Latif *et al*. (2010) indicated that the numbers of leaves per plant, bulb weight, foliage dry weight, plant height was highest when the plants were grown at wider spacing of 20 x 20 cm. However, yield per unit area was higher in the narrow spacing. Nasir *et al*. (2007) also stated that the highest leaf number per plant was recorded at lower planting density. Planting of onion at 20 and 25 cm spacing produced larger bulbs compared with planting at 10 and 15 cm spacing (Mahadeen, 2008). Jilani (2004) reported that onion plants from the lowest plant population (20 plants $m^{-2}$) recorded the highest number of leaves and leaf length.

According to Jan *et al*. (2003), the highest yield (40.44 t $ha^{-1}$) was found at spacing of 17 x 4.5 cm, and the lowest yield (19.95 t $ha^{-1}$) at 27 x 14.5 cm spacing. Yemane *et al*. (2013) also indicated that the highest total bulb yields were achieved at 5 and 7.5 cm intra-row spacing, respectively as compared to the 10 cm intra-row spacing. Dereje *et al*. (2012) also indicated that total yield per hectare increased as plant density increased although yield of the individual plants and their components were significantly reduced suggesting a compensation of higher plant densities on yield in shallot.

Kantona *et al*. (2003) observed that onion yield increased from 17.4 to 39.5 t $ha^{-1}$ as plant population per square meter increased from 50 to 150. Yemane *et al*. (2013) mentioned that the highest unmarketable bulb yield of onion was produced by the narrow intra-row spacing. Dereje *et al*. (2012) also reported that high unmarketable yield of shallot was recorded in closely spaced plants. Seck and Baldeh (2009) also concluded that plant density has an impact on marketable bulb size. The smaller the marketable size is an issue for high plant densities and needs to be improved.

According to Nasir *et al*. (2007) maximum weight of small and medium sized of onion was obtained at higher population density, However, the highest weights of large bulbs were found at the lowest planting density. Dawar *et al.* (2007) also reported that maximum weight of medium and small sized bulb was achieved at higher planting density of 80 plants $4m^{-2}$. However, maximum weight of large bulbs was found at the lowest planting density of 40 plants $4m^{-2}$. Rumpel *et al*. (2000) showed that yield of medium bulbs increased with density but, the yield of large bulbs decreased as plant density increased. Stoffella (1996) also mentioned that percentage of small and medium sized bulbs increased and percentage of large bulbs decreased as intra-row spacing decreased. Yemane *et al*. (2013) stated that the highest percentage of small and medium size bulbs yield was scored at narrow intra-row spacing of 5 cm as compared to 7.5 cm and 10 cm. However, as the intra-row spacing increased from 5 to 10 cm, the percentage of large size bulbs increased from 9.3 to 20.3%.

Minimum planting density attained the highest number of leaves which decreased with increasing planting density. Minimum plant population (20 plants $m^{-2}$) had larger bulb diameter against smaller bulb diameter of higher plants density (40 plants $m^{-2}$) (Jilani *et al.*, 2009). A report by Hyder *et al.* (2007) who indicated that plant height, bulb length, bulb diameter and days to harvest were the most important yield contributing factors. There is indirect effect on bulb yield of each trait. Plant height revealed a positive indirect effect on yield and was favorable through bulb length, bulb neck thickness, TSS in Brix and dry matter content. Akoun (2005) reported that bulb diameter was greatest (8.18cm) at the lowest population density. Seid *et al*. (2014) indicated that lowest leaf width (0.73 cm) of garlic was recorded in higher plant density.

Bosch and Olivé (1999) in Spain conducted two experiments, one under natural light condition and another one under black neutral shade, with the aim of investigating an influence of plant population (20, 40, 80 and 160 plants $m^{-2}$) on bolting percentage using a long day cultivar. Based on this, under natural light condition, as plant population increased from 20 to 160 plants $m^{-2}$, number of bolters significantly increased from 8 to 75.

Onions have a high harvest index with 70 to 80% of the shoot dry weight found in the bulb at maturity. As compared to other crops, onions are poor at intercepting radiation, average at converting radiation to dry matter but good at partitioning the dry matter to harvestable material (Brewster, 1990). Dereje *et al*. (2012) reported that lower harvest index of shallot in wider intra-row spacing. Kabir and Sarkar (2008) also reported highest value of harvest index of mungbean recorded from closer spacing probably due to the reduced vegetative biomass.

The ideal spacing and plant population are those that maximize yield, vegetable quality and profits to farmers without excessively increasing costs. An essential aspect of any crop production system is the development of a crop canopy that optimizes the interception of light, photosynthesis, and the allocation of dry matter to harvestable parts. A crop canopy is commonly managed by manipulating row spacing and plant population; as plant density increases, yield per unit area will approach an upper limit, plateau, and then decline while yield per plant tend to decrease with increasing plant density because of competition for growth factors between adjacent plants (Silvertooth, 2001).

Generally, yield of onion increases with an increase in plant population because plant densities allowed the canopy to close quickly reducing the ability of weeds to compete, but only up to an optimal limit and yield will decrease beyond this optimum. Appropriate spacing enables the farmers to keep appropriate plant population in their field. Hence, a farmer can avoid over and less population in a given plot of land, which has negative effect on yield. Therefore, to avoid nutrient competition due to inappropriate use of plant spacing and N fertilizer, sufficient spacing between plants and rows and optimum amount N fertilizer application is vital to get highest yield in a given plot of land (AVRDC, 2004).

## 2.6. Response of Onion to Interaction Effect of Nitrogen and Plant Spacing

Islam *et al*. (1999) reported that interaction effect of spacing and N levels on bulb yield of onion and most of the characters. The highest spacing in association with high nitrogen level up to 180 kg $ha^{-1}$ increased number of leaves per plant and splitted bulbs. The highest bulb yield (31.6 t $ha^{-1}$) was obtained from the lowest spacing (20x10 cm) along with nitrogen level of 120 kg $ha^{-1}$ but the large sized bulbs were obtained from the combination of higher spacing (20 x 20 cm) and at 120 kg N $ha^{-1}$.

According to Naik and Hosamani (2003) the narrow spacing of 15 x 10 cm gave the maximum bulb yield of onion and decreased the bulb yield with widening spacing. The highest bulb yield was recorded with treatment interaction of closer spacing (15 x 10 cm) and higher levels of nitrogen (150 kg $ha^{-1}$). The bulb diameter was highest in the wider spaced crop (15 x 20 cm) followed by 15 x 15 cm than narrow spacing. Similarly, this parameter was also increased with increase in nitrogen levels and the bigger sized bulbs were found in the plots applied with 150 kg N $ha^{-1}$. Average bulb weight was increased with increase in nitrogen levels. The highest bulb weight was found in the plots applied with 150 kg N $ha^{-1}$ (Naik and Hosamani, 2003). The TSS was increased with increase in nitrogen levels and the maximum (10.15%) was recorded in the bulbs applied with 150 kg N $ha^{-1}$ followed by 100 kg N $ha^{-1}$ (9.15%). Shojaei *et al*. (2011) also reported that the highest mean bulb weight was produced by the plants treated with higher nitrogen and lower population density. The increase in N fertilization level and plant population also resulted in the increase in yield from 3 to 10 t $ha^{-1}$.

Maximum number of leaves per plant was produced by the treatment interaction of higher nitrogen (150 kg N $ha^{-1}$) with wider (15 cm spacing). Mean values of root diameter in response to different nitrogen levels showed superiority in 200 kg N $ha^{-1}$ over 100 kg N $ha^{-1}$ and 0 kg N $ha^{-1}$. It would be observed from the means of interactions that 200 kg $ha^{-1}$ with 10 cm spacing produced maximum root yield per hectare. Nitrogen dose of 200 kg $ha^{-1}$ when interacted with 15 cm spacing produced maximum total biomass per plant followed by 200 kg N $ha^{-1}$ with 10 cm spacing (Pervez *et al*. 2004).

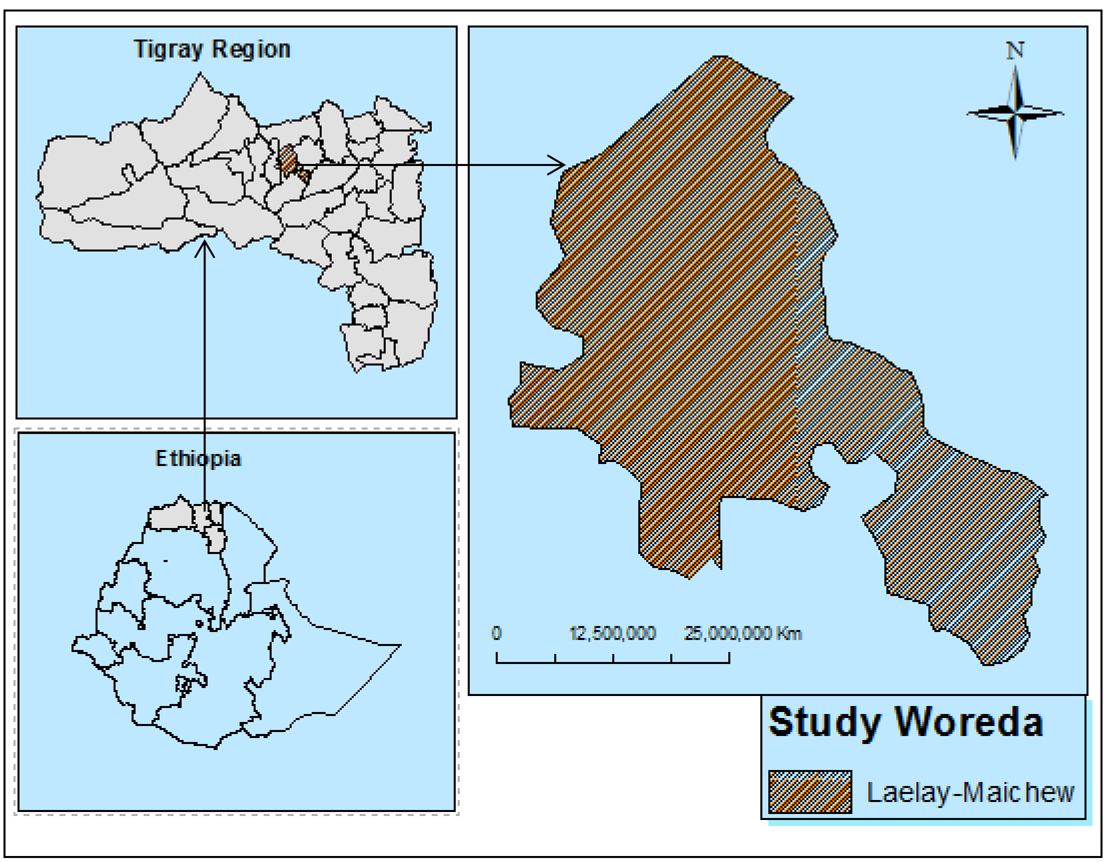
Interaction effect of different intra-row spacing (10, 15, 20 and 25 cm) and levels of nitrogen fertilizer (0, 50, 100 and 150 kg N $ha^{-1}$) showed that an increase in nitrogen dose up to 100 kg $ha^{-1}$ resulted in the increase of yield of onion bulbs 40.83 t $ha^{-1}$ by interacting with 15 cm intra-row spacing. But, further increase in N level up to 150 kg $ha^{-1}$ did not significantly increase in bulb yield. The lowest bulb yield was recorded from the control plots when interacted with wider intra-row spacing of 25 cm (Aliyu *et al*., 2008). The authors reported that treatment combinations of 0 kg N $ha^{-1}$ and 10 cm intra-row spacing gave lower values of average bulb weight, bulb diameter and leaves number per plant.

# 3. MATERIALS AND METHODS

## 3.1.Description of the Study Area

The experiment was conducted at Axum Agricultural Research Center (AxARC) which is located at 5 km away from Axum city in a westerly direction and a distance of about 245 away from Mekelle city in the north-western direction. The study site is located at Dura in La'elay Maichew Woreda, Central Zone of Tigray. It is situated at the latitude of 46$^o$35' 31'' N and longitude of 55$^o$ 96' 22" E with an altitude of 2042 meters above sea level in the semi-arid tropical belt of Ethiopia with "W*eina dega*" agro climatic zone. The rainy season is mono-modal concentrated in one season from July to September, with an average rain fall of 700 – 800 mm. The mean minimum and maximum temperature ranges from 8.7$^0$C to13.2$^0$C and 24.4$^0$C to 31.4$^0$C, respectively.

Figure 1. Map of the Study Area



## 3.2. Experimental Materials

### 3.2.1. Planting material

'Bombay red' onion variety was used for the study. Seeds for planting were obtained from Axum Agricultural Research Center (AxARC). The variety was released by Melkassa Agricultural Research Center in 1980 (EARO, 2004). The variety has light red bulb skin color, dark green leaf color, flat globe bulb shape and reddish white bulb flesh color. The variety takes 110-120 days for bulb harvest (EARO, 2004). Bombay red is one of the most commonly and widely used improved variety in Central Zone Tigray in particular and in the region in general.

### 3.2.2. Fertilizer material

The sources of the fertilizers were urea (46% N) and Triple Super Phosphate, TSP (46% $P_2O_5$) for supplying nitrogen and phosphorus, respectively

### 3.3. Treatments and Experimental Design

The treatments consisted of five intra-row spacing (2.5, 5, 7.5, 10 and 12.5 cm) and four levels of nitrogen (0, 41, 82 and 123 kg N $ha^{-1}$). The experiment was laid out as a randomized complete block design (RCBD) with three replications. Each treatment was assigned to the plots randomly. Onion seedlings were planted in double row spacing. The spacing between furrows was kept at 60 cm and the spacing between the double rows in a furrow was 20 cm.

Table 1: Treatment combinations, number of plants $m^{-2}$, number of plants per plot and plant population per hectare

| Treatment combinations | Nitrogen rates kg N $ha^{-1}$ | Intra-row spacing (cm) | Equivalent area ($m^2$) | Number of plants $m^{-2}$ | Number of plants $plot^{-1}$ | Number of plants $ha^{-1}$ |
|---|---|---|---|---|---|---|
| (T1) = $N_1$ $S_1$ | 0 | 2.5 | 0.0075 | 133.33 | 672 | 1333333 |
| (T2) = $N_2$ $S_1$ | 41 | | | | | 1333333 |
| (T3) = $N_3$ $S_1$ | 82 | | | | | 1333333 |
| (T4) = $N_4$ $S_1$ | 123 | | | | | 1333333 |
| (T5) = $N_1$ $S_2$ | 0 | 5 | 0.015 | 66.67 | 336 | 666667 |
| (T6) = $N_2$ $S_2$ | 41 | | | | | 666667 |
| (T7) = $N_3$ $S_2$ | 82 | | | | | 666667 |
| (T8) = $N_4$ $S_2$ | 123 | | | | | 666667 |
| (T9) = $N_1$ $S_3$ | 0 | 7.5 | 0.0225 | 44.44 | 224 | 444444 |
| (T10)=$N_2S_3$ | 41 | | | | | 444444 |
| (T11) = $N_3S_3$ | 82 | | | | | 444444 |
| (T12) = $N_4S_3$ | 123 | | | | | 444444 |
| (T13) = $N_1S_4$ | 0 | 10 | 0.03 | 33.33 | 168 | 333333 |
| (T14) = $N_2S_4$ | 41 | | | | | 333333 |
| (T15) = $N_3S_4$ | 82 | | | | | 333333 |
| (T16) = $N_4S_4$ | 123 | | | | | 333333 |
| (T17) = $N1S_5$ | 0 | 12.5 | 0.0375 | 26.67 | 134 | 266667 |
| (T18) = $N_2$ $S_5$ | 41 | | | | | 266667 |
| (T19) = $N_3$ $S_5$ | 82 | | | | | 266667 |
| (T20) = $N_4$ $S_5$ | 123 | | | | | 266667 |

Where N1=0 kg N $ha^{-1}$, N2= 41 kg N $ha^{-1}$, N3=82 kg N $ha^{-1}$, N4=123 kg N $ha^{-1}$ and S1=2.5 cm, S2=5 cm, S3=7.5 cm, S4=10 cm and S5=12.5 cm intra-row spacing

## 3.4. Management of Experimental Field

Seeds were sown in a nursery on well prepared seed bed in the first week of October 2014. When seedlings attained proper stage for transplanting at 3 or 4 leaves stage estimated around

12 to 15 cm height, was transplanted to the experimental field. Seedlings were planted on fine soil which was prepared following the recommended tillage practice for the crop. Each treatment combination was assigned randomly to experimental units within a block. Each experimental plot had eight single rows. During data collection the middle six single rows were considered for recording all data excluding the two border rows as well as those plants at both ends of each row to avoid edge effects.

Planting was done on ridges of the furrow adopting recommended spacing of 40 cm between furrows, 20 cm between rows on the ridge. A 2.1m x 2.4 m (5.04 $m^2$) plot size was used for each experimental unit. The blocks were separated by 1.5 m width whereas the space between each plot within a block was 1 m. Triple super phosphates (46% $P_2O_5$) was applied as a source of P in the rate of 92 kg $P_2O_5$ for all plots uniformly. The nitrogen source was Urea (46% N). All TSP fertilizer was applied at planting as a single application (92 kg $P_2O_5$ $ha^{-1}$) and incorporated to the soil on the prepared ridges in bands. Nitrogen was side dressed in two splits of equal amounts after 3 and 6 weeks of transplanting. Plots were supplemented with irrigation at field capacity depending on the moisture condition of the soil and soil type. Weeding and hoeing was done manually by hand weeding and hoeing. The crop was harvested when 80% of the leaves turned yellow and top fall, attaining full size of bulbs and then cured for a day.

## 3.5. Soil Sampling and Analysis

The soil sample taken from the experimental site was done in Mekelle soil laboratory. Soil samples were collected randomly from the entire experimental field following a zigzag fashion from 0 to 30 cm depth before planting using an augur. The soil samples were collected from the entire experimental field and it was made one kg composite sample. Determinations of some selected soil chemical properties were carried out based on the composite sample. The composite soil sample was air dried, crushed with wooden pestle and mortar to pass through a 2 mm sieve size for the analysis of physical and chemical properties. Total nitrogen, available phosphorus, potassium, organic matter, soil pH, cation exchange capacity (CEC) and soil texture was determined in the laboratory from the sample submitted.

Soil pH was measured in 1:2.5 soil-water ratios using an electrodes pH meter. Organic carbon content of the soil was determined by Walkley and Black method (Walkley and Black, 1934). Available phosphorus was estimated following the standard procedure of Olsen *et al*., (1954). Total nitrogen was estimated by the Kjeldahl method (Jackson, 1958). The results of the soil analysis were used as inputs in determining the applied amount of nitrogen fertilizer and to know the suitability of the selected site for onion production during experimental period.

## 3.6. Data Collection

Data on growth, yield and yield components of onion were recorded from the six central double rows plants which were selected randomly in each plot as specified in each plant characters below. However, data for phenology of crop was collected from the entire plot.

### 3.6.1. Phenology and growth parameters

**Stand count (% tage):** plants that successfully established in the central rows were counted at harvest and expressed as percentage.

**Days to maturity:** The number of days from seedling transplanting to a day at which more than 80% of the plants in a plot showed yellowing of leaves or attained physiological maturity.

**Plant height (cm):** This was measured from the ground to the tip of the leaves from 10 randomly selected plants at maturity.

**Leaf number per plant:** The total number of leaves per plant was counted from 10 randomly selected plants at maturity.

**Leaf diameter (cm):** The diameter of leaves at three different places of the leaves was measured from ten randomly selected plants using veneer calliper.

**Bolting percentage**: Each experimental plot was examined regularly. Plants showing flower escapes during vegetative growth was counted and calculated as the ratio of bolters per total plants in the plot and the values was expressed in percentage.

**Leaf Length (cm):** This was measured at physiological maturity from the sheath to tip of the leaf from the ten leaves of the representative plants which was used to count the number of leaves per plant using a ruler.

**Shoot dry matter (g)**: This refers to the above ground biomass of the plant, which was oven-dried at the temperature of 65 $^0$C until a constant weight was obtained. The aboveground biomass was harvested by cutting the plant at the crown part and the shoot dry matter was determined and expressed in gram at harvest.

**Dry total biomass (g):** This was determined by summation of the shoot and bulb dry weights of sample plants.

**3.6.2. Yield and yield components**

**Bulb diameter (cm):** The mean bulb diameter of ten sample bulbs was measured at the maximum wider portion of matured bulbs using calipers.

**Neck diameter (cm)**: The average neck widths of ten randomly taken mature bulbs was measured by using a veneer calliper and expressed in centimetre after harvest.

**Average bulb weight (g):** The average fresh weight of ten randomly taken mature bulbs measured by using sensitive balance and finally then expressed in grams

**Bulb dry matter (g):** Five bulbs were randomly taken from each plot and chopped into small 1-2 cm cubes, mixed thoroughly, and two sub-samples each weighing 200 gram was weighed. The exact weight of each sub-sample was determined and recorded as fresh weight. Each sub-sample was placed in a paper bag and put in an oven until constant dry matter was attained. Each sub-sample was then immediately weighed and recorded as dry matter yield.

**Marketable bulb yield (t ha$^{-1}$):** This referred to the weight of healthy and marketable bulbs that range from 20 g to 160 g in weight. Bulbs below 20 g in weight were considered too small to be marketed whereas those above 160 g were considered oversized according to Lemma and Shimeles (2003). This parameter was determined from the net plot at final harvest and expressed as t ha$^{-1}$.

**Unmarketable bulb yield (t ha$^{-1}$):** The total weight of unmarketable bulbs that are under sized (< 20 g), diseased, decayed and bulbs from plants with physiological disorder such as thick neck and split was measured from a net plot at final harvest and expressed in t ha$^{-1}$.

**Bulb size distribution of marketable bulbs:** Based on the weight of bulbs from categories of bulb size for small (20 - 50 g), medium (50 – 100 g), large (100 -160 g), and oversized (> 160 g) was recorded per net plot and converted to t ha$^{-1}$ as determined by Lemma and Shimeles (2003).

**Undersized bulb yield (t ha$^{-1}$):** Under sized bulbs (< 20 g) was recorded as unmarketable bulbs per net plot and converted to t ha$^{-1}$ as determined by Lemma and Shimeles (2003).

**Total bulb yield (t ha$^{-1}$):** The total bulb yield was measured from the total harvest of net plot as a sum weight of marketable and unmarketable yields that was measured in kg per plot and finally converted into t ha$^{-1}$.

**Harvest index (%):** This was expressed as the ratio of total bulb dry weight to the total biomass dry weight and expressed in percentage.

$$\text{Harvest index (HI)} = \frac{\text{Total bulb dry weight}}{\text{Total biomass dry weight}} \text{x100}$$

**Total soluble solid ($^0$Brix):** The TSS was determined at harvesting time from ten randomly selected bulbs using the procedures described by Waskar *et al*. (1999). Aliquot juice was extracted using a juice extractor and 50 ml of the slurry centrifuged for 15 minutes. The TSS was determined by a hand refractometer (ATAGO TC-1E) with a range of 0 to 32 $^0$Brix and resolutions of 0.20 Brix by placing 1 to 2 drops of clear juice on the prism, washed with distilled water, and dried with tissue paper before use.

## 3.7. Data Analysis

The data were subjected to analysis of variance (ANOVA) using SAS version 9.1.3 computer software (SAS Institute Inc., 2004). Duncan Multiple Range Test (DMRT) was used to separate and compare treatment means at 5% probability level. Correlation analysis was computed to generate information about the association of yield and other parameters.

# 4. RESULTS AND DISCUSSION

## 4.1. Physico-Chemical Properties of the Experimental soil

The results of the soil analysis are presented in Table 2. The mean pH value was 7.48, which is slightly alkaline according to the rating of Murphy (1968). The optimum pH for onion production ranges between 6 and 8 (Nikus and Mulugeta, 2010). Accordingly, the pH of the soil was conducive for onion production. The organic carbons as well as that of total nitrogen contents of the soil were medium according to the rating of Tekalign (1991). This shows that the soil was moderate in supplying organic carbon for soil biota and also as a source of mineralized nitrogen for uptake mineral nitrogen by crops (Hazelton and Murphy, 2007). Hence, it requires application of nitrogen for onion production. According to Olsen *et al*. (1954), the soil of the experimental site was medium in available phosphorus. This shows that application of external source of phosphorus is important for growing onions. According to the rating of Hazelton and Murphy (2007), the soil of the experimental site had medium exchangeable potassium content, which is adequate for onion production and the total cation exchange capacity of the testing site was high.

Table 2: Chemical characteristics of the experimental soil

| Soil Properties | Values | Rating | Source |
|---|---|---|---|
| pH | 7.48 | Slightly alkaline | Murphy (1968) |
| Organic carbon (%) | 1.65 | Medium | Tekalign (1991) |
| Total nitrogen (%) | 0.109 | Medium | Tekalign (1991) |
| Total Available phosphorus (mg/kg) | 8.16 | Medium | Olsen *et al*. (1954) |
| Total available potassium (cmol (+)/kg) | 0.38 | Medium | Hazelton and Murphy (2007) |
| Cation exchange capacity (cmol (+)/kg) | 35.6 | High | Hazelton and Murphy (2007) |
| Electrical conductivity (ds /m) | 0.15 | Non saline | Hazelton and Murphy (2007) |
| Particle size distribution | | | |
| Sand (%) | 19 | | |
| Silt (%) | 21 | | |
| Clay (%) | 60 | | |
| Textural class | Clay | | Hazelton and Murphy (2007) |

## 4.2. Phenology and Growth Characters

### 4.2.1. Plant height

Result from the analysis of variance revealed that the main effects of nitrogen and intra-row spacing significantly ($P < 0.01$) influenced plant height of onion. However, the two factors did not interact to influence plant height (Appendix Table 1).

Increasing the intra-row spacing from 2.5 to 5.0 cm increased plant height significantly. Increasing the plant spacing further from 5.0 to 7.5 cm also increased the height of onion plants significantly whereas; the increase in plant spacing further from 7.5 cm to 12.5 cm did not show significant difference. Thus, the heights of onion plants grown at the spacing of 7.5 cm exceeded the heights of onion plants grown at the spacing of 2.5 and 5.0 cm by about 7% and 15%, respectively. Similarly, increasing the rate of nitrogen from nil to 41 kg N $ha^{-1}$ significantly increased the height of onion. Increasing the rate of nitrogen further from 41 to 82 kg $ha^{-1}$ also increased the height of onion plants. But, the mean height of plant did not show significant difference as further increase in nitrogen rate from 82 to 123 kg $ha^{-1}$. Thus, the mean height of onion treated with nitrogen at the rate of 82 kg $ha^{-1}$ exceeded the height of onion plants treated with nil and 41 kg N $ha^{-1}$ by about 28 and 16%, respectively.

The increase in plant height at the medium intra-row spacing may be due to less interplant competition for the growth factors like water, nutrient and light, which may lead to better growth and significantly taller plant height as compared to narrow intra-row as explained by Khan *et al*. (2002). However, widening the spacing beyond the 7.5 cm threshold did not change plant height, indicating that too much widening of the spacing beyond the potential of the plant would have no added value for growth. This finding agrees with results of Khan *et al*. (2003), Kantona *et al*. (2003) and Aliyu *et al*. (2008), who reported that wider rather than narrower spacing produced taller onion plants, showing that narrower spacing leads to stiffer competition among plants for growth factors, causing reduced growth. Corroborating the results of this study, Hamma *et al*. (2013) also showed that plant heights of garlic plants increased in response to increasing intra-row spacing.

The increase in plant height with the addition of higher nitrogen fertilizer level could be attributed to more availability of the nutrient which enhances protein synthesis which lead to increased accumulation of carbohydrates and this in turn, may have resulted in increased plant growth such as leaf number and leaf length (Rizk, 2012; Marschner, 1995). This result is consistent with the findings of Morsy *et al*. (2012), Nasreen *et al*. (2007) and Al-Fraihat (2009) who reported that onion plant height significantly increased as nitrogen fertilizer rates increased.

Table 3: Main effect of intra-row spacing and nitrogen fertilizer levels on plant height of onion

| Treatment | Plant height (cm) |
|---|---|
| Intra-row spacing (cm) | |
| 2.5 | 38.08c |
| 5 | 41.04b |
| 7.5 | 43.78a |
| 10 | 44.85a |
| 12.5 | 45.27a |
| | |
| Nitrogen fertilizer (kg N $ha^{-1}$) | |
| 0 | 36.56c |
| 41 | 40.30b |
| 82 | 46.70a |
| 123 | 46.85a |
| SE(±) | 1.72 |
| CV (%) | 6.98 |

Means followed by the same letter in the same column are not significantly different at 5% probability level according to Duncan’s Multiple Range Test

### 4.2.2. Leaf number per plant

The analysis of variance revealed that main effect of intra-row spacing and nitrogen fertilizer rates and their interaction effect had significant ($P < 0.01$) effects on the number of leaves per plant of onion (Appendix Table 1).

Increasing plant spacing significantly increased onion leaf number per plant across the increasing rate of the nitrogen fertilizer. Thus, plants with the highest leaf number were produced in response to application of the highest rate of nitrogen fertilizer (123 kg $ha^{-1}$) at the widest intra-row spacing (12.5 cm). On the other hand, plants with the lowest number of leaves per plant were produced in response to the narrowest intra-row spacing (2.5 cm) and all rates of the nitrogen fertilizer as well as at nil rate of the nitrogen fertilizer and the intra-row spacing of 5.0 cm. For example, the number of leaves of onion plants grown at the intra-row spacing of 12.5 cm and nitrogen rate of 123 kg N $ha^{-1}$ exceeded the leaf number of onion plants grown at the intra-row spacing of 2.5 cm and nitrogen rate of nil kg N $ha^{-1}$ by about 110% (Table 4).

The maximum number of leaves per plant of onion obtained in treatment combination of wider (12.5 cm) intra-row spacing and higher nitrogen fertilization (123 kg N $ha^{-1}$) might be due to nitrogen mainly related to production of new shoots and vigor in vegetative growth of plants which is directly responsible for increasing leaf number as described by Rizk (2012) and Kokobe *et al*. (2013). Thus, there is less competition for nutrients, moisture and light among the plants to achieve the required food for their growth due to the wider intra-row spacing.

This result is concordant with the findings of Rao *et al*. (2013) who reported that highest leaf number per plant of onion was recorded with the highest combination of 75 kg N $ha^{-1}$ and 20 cm x 12.50 cm spacing. Consistent with the results of this study, Khan *et al*. (2002) also indicated that lower leaf number per plant of onion was recorded from the treatment interaction effect of control nitrogen level and narrow intra-row spacing. Dawar *et al*. (2007), Latif *et al.* (2010), Sikder *et al*. (2010), Kumar *et al*. (1998) and Jilani *et al*. (2009) also showed that higher leaf numbers per plant of onion were recorded in response to wider plant spacing.

### 4.2.3. Leaf length

Onion leaf length was significantly ($P < 0.01$) influenced by the main effects of both plant spacing and nitrogen application as well as by their interaction (Appendix Table 1).

With widening the intra-row spacing, leaf length of onion plants increased significantly across the increasing rate of the nitrogen fertilizer. Hence, plants treated with nitrogen at the rates of 82 and 123 kg N $ha^{-1}$ and spaced at 5.0, 7.5, 10.0, and 12.5 cm produced the longest leaves. However, plants treated with nil and 41 kg N $ha^{-1}$ and spaced 2.5 cm apart as well as those treated with nil kg N $ha^{-1}$ and spaced 5.0 cm apart produced the shortest leaf length. The shorter value of leaf length of onion found in treatment combination of nil N $ha^{-1}$ and 2.5 cm intra-row spacing decreases by about 36% as compared with the highest value of leaf length of onion achieved in treatment interaction of higher nitrogen rate (123 kg $ha^{-1}$) and wider spacing (12.5 cm) (Table 4).

The reasons for longer leaf length of onion with combination of widening intra-row spacing and increasing nitrogen fertilizer level might be due to nitrogen is a constituent of many fundamental cell components and plays a vital role in cell division and elongation in plants. It improves the vegetative growth of the onion which leads to increasing in leaf length through the increased photosynthetic area in response to nitrogen fertilization that enhanced assimilates production and partitioning to the plants (Bungard *et al*.,1999). The results of this study are in accord with those of Abdissa *et al*. (2011), Jilani *et al*. (2004) and Rao *et al*. (2013) who reported that higher nitrogen fertilization increased leaf length of onion. Likewise, Kumar *et al*. (1998), Khan *et al*. (2003), Khan *et al*. (2002) and Jilani *et al*. (2010) reported that wider intra-row spacing significantly increased leaf length of onion.

### 4.2.4. Leaf diameter

The main effects of nitrogen as well as intra-row spacing significantly ($P < 0.01$) influenced leaf diameter of onion. Similarly, the two factors also interacted to influence significantly ($P < 0.01$) leaf parameter (Appendix Table 1).

Almost similar to the effect observed on leaf length, with increase in the intra-row spacing, leaf diameter of the onion plants increased significantly across the increasing rate of the nitrogen fertilizer. Thus, plants treated with nitrogen at the rates of 123 kg N $ha^{-1}$ and spaced 12.5 cm produced leaves with the widest diameter. However, plants treated with nil kg N $ha^{-1}$ and spaced 2.5 cm apart produced leaves with the narrowest diameter. Thus, the leaf diameter of onion plants treated with 123 kg N $ha^{-1}$ and spaced at 12.5 cm intra-row spacing increased by 194% as compared to the leaf diameter of onion plants treated with no nitrogen fertilizer and spaced 2.5 cm (Table 4).

The increase in leaf diameter with the increase in the rate of nitrogen and intra-row spacing could be associated with better supply of nitrogen and less stiff competition for other growth factors among the onion plants. Thus, more widely spaced plants with higher supply of nitrogen are able to intercept more light and capture other resources for photosynthesis and better growth and development. Concurrent with the results of this study, Seid *et al*. (2014) and Yemane *et al*. (2013) also showed that the lowest leaf diameter was recorded for narrow intra-row spacing of garlic and onion respectively. Supporting the current finding, Abdissa *et al*. (2011) and Kokobe *et al*. (2013) reported that that the smallest onion leaf diameter was recorded for the nil nitrogen rate.

#### 4.2.5. Shoot dry matter yield

The analysis of variance revealed that the main effects of nitrogen application and intra-row spacing significantly ($P < 0.01$) influenced shoot dry matter yield of the onion plants. The interaction effect of nitrogen application and intra-row spacing also significantly influenced the shoot dry matter yield of the crop (Appendix Table 4).

With decreasing population density, shoot dry matter yield per plant of onion significantly increased across the different rates of nitrogen application. Thus, intra-row spacing of 12.5 cm and nitrogen fertilizer rate of 123 kg ha$^{-1}$ was the treatment combination at which the highest shoot dry matter yield was attained. On the other hand, the lowest shoot dry matter yield was recorded for onion plants spaced at 2.5 cm intra-row spacing that received the nitrogen rates of 0 kg ha$^{-1}$ and 41 kg ha$^{-1}$. For example, comparing the onion shoot dry matter yields, the treatment combination 123 kg N ha$^{-1}$ and 12.5 cm increased the shoot dry matter yield by 342% as compared to the narrow intra-row spacing of 2.5 cm and nil nitrogen fertilizer application.

The higher onion shoot dry matter yields were recorded at wider intra-row spacing and higher nitrogen rates might be linked to nitrogen increases or enhances assimilate production in onion plants (Sharma, 1992). The plant grown at the widest spacing produced the highest shoot dry matter yield might also be attributed to the less stiff competition among onion plants for growth factors, as a result more accumulation of dry matter may have occurred. The present finding is in agreement with the results of Nasreen *et al*. (2007) who indicated that higher shoot dry weight was obtained when the rate of nitrogen fertilizer was increased from 0 kg N $ha^{-1}$ to 150 kg $ha^{-1}$. Rao *et al*. (2013) also stated that the maximum weight of leaves per plant was recorded with the application of nitrogen at the higher rate of 75 kg $ha^{-1}$ and wider spacing of 20 x 12.5 cm. Consistent with this results Yemane *et al*. (2014) showed that leaf dry matter yield of onion decreased from 2.63 to 1.48 g per plant in response to increasing planting densities.

Table 4: Interaction effect of intra-row spacing and nitrogen fertilizer levels on leaf number per plant, leaf length, leaf diameter and shoot dry matter yield of onion

| N level (kg $ha^{-1}$) | Intra-row spacing (cm) | Parameters | | | |
|---|---|---|---|---|---|
| | | Leaf number per plant | Leaf length (cm) | Leaf diameter (cm) | Shoot dry matter (g $plant^{-1}$) |
| 0 | 2.5 | 6.60h | 23.00g | 0.470l | 0.73l |
| | 5 | 6.90gh | 25.47fg | 0.590k | 0.86jk |
| | 7.5 | 7.53fg | 27.13ef | 0.682ij | 0.92jk |
| | 10 | 7.63fg | 27.27ef | 0.707i | 1.26i |
| | 12.5 | 7.70fg | 28.40def | 0.783h | 1.56h |
| 41 | 2.5 | 6.43h | 25.00fg | 0.570k | 0.81kl |
| | 5 | 7.57fg | 28.23def | 0.693ij | 1.25i |
| | 7.5 | 8.53ef | 28.67def | 0.838g | 1.56h |
| | 10 | 8.93e | 28.83def | 0.980e | 1.70g |
| | 12.5 | 9.33de | 30.00cde | 1.057d | 2.20d |
| 82 | 2.5 | 6.83gh | 29.03def | 0.643j | 0.97j |
| | 5 | 9.96cd | 33.23abc | 0.920f | 1.71g |
| | 7.5 | 10.00cd | 34.23ab | 1.00cd | 2.07e |
| | 10 | 10.40cd | 34.33ab | 1.117c | 2.70c |
| | 12.5 | 10.53bc | 34.53ab | 1.210b | 2.96b |
| 123 | 2.5 | 7.03gh | 31.40b-e | 0.783h | 0.97j |
| | 5 | 10.06cd | 31.67a-d | 0.957ef | 1.87f |
| | 7.5 | 10.33cd | 33.30abc | 1.097cd | 2.28d |
| | 10 | 11.47b | 35.53ab | 1.190b | 2.96b |
| | 12.5 | 12.57a | 35.87a | 1.380a | 3.22a |
| CV (%) | | 6.62 | 4.38 | 3.31 | 4.27 |
| SE (±) | | 0.34 | 0.77 | 0.02 | 0.04 |

Means followed by the same letter with in a column are not significantly different at 5% probability level according to Duncan’s Multiple Range Tests

### 4.2.6. Dry total biomass yield

The main effect of intra-row spacing and that of nitrogen as well as the interaction effect of the two factors significantly ($P < 0.01$) influenced dry total biomass yield (Appendix Table 4).

With the increase in intra-row spacing, dry total biomass yield of the onion plants increased significantly across the increasing rate of the nitrogen fertilizer. Thus, plants treated with nitrogen at the rates 123 kg N $ha^{-1}$ and spaced at 12.5 cm intra-row spacing produced the highest dry total biomass yield. However, plants treated with nil kg N $ha^{-1}$ and spaced 2.5 cm apart produced the lowest dry total biomass yield. Thus, the total dry biomass yield obtained from plants treated with the combination of 123 kg N $ha^{-1}$ and intra-row spacing of 12.5 cm was about 6.5 fold higher than the total dry biomass yield produced by onion plants treated with no nitrogen fertilizer and spaced 2.5 cm apart (Table 5).

The increase in total dry biomass yield in response to the increasing rate of nitrogen fertilizer and wider intra-row spacing may be probably associated with the nitrogen supply, which enhances the vegetative growth of plants like leaf number, leaf diameter, leaf length and plant height which contribute for improved rate of photosynthesis and assimilate production in the vegetative part and partitioning to the bulbs (Sharma, 1992). In addition, plants grown at the widest spacing produced the highest dry total biomass yield possibly due to less competition among them for growth resources.

Supporting the current study, Sikder *et al*. (2010) reported that higher values of shoot and bulb dry weight leads to higher in dry total biomass of onion in wider spacing. Similarly, Nasreen *et al*. (2007) and El-Tantawy and El-Beik (2009) indicated that application of higher N doses $ha^{-1}$ increased dry total biomass yields of onion. In harmony with the results of this study, Pervez *et al*. (2004) indicated that maximum total biomass per plant of radish was obtained in response to the application of higher nitrogen doses interacting with wider intra-row spacing of radish.

**4.2.7. Days to maturity**

The result of the analysis of variance indicated that days to maturity was significantly ($P < 0.01$) affected by the interaction effect of intra-row spacing and nitrogen fertilizer rate. Moreover, the main effect of intra-row spacing also revealed significant ($P < 0.01$) effect on days to maturity (Appendix Table 4).

Increasing the rate of nitrogen markedly prolonged the days to maturity of the onion crop across the increasing intra-row spacing. Thus, plants grown at the higher rates of nitrogen application and the wider intra-row spacing required progressively more number of days to mature than plants that were supplied with the lower rates of nitrogen and narrower intra-row spacing. For instance, onion plants grown at 82 and 123 kg N $ha^{-1}$ at the spacing of 12.5 cm as well as those grown at the rate of 123 kg N $ha^{-1}$ at the spacing of 10 cm required the highest number of days to reach maturity. In contrast, the lowest number of days to reach maturity was required by onion plants grown at nil and 41 kg N $ha^{-1}$ spaced 2.5 cm between plants as well as those grown at nil rate of nitrogen fertilizer spaced with 5.0 cm between plants. For example, the days to maturity required by plants grown at the rate of 123 kg N $ha^{-1}$ and intra-row spacing of 12.5 cm exceeded the days to maturity required by plants grown in the control treatment by about 27% (Table 5).

The delay in maturity in response to the increased rate of nitrogen application and wider intra-row spacing may be attributed to nitrogen enhancing plant biochemical processes, which in turn extends vegetative growth as a result of which it leads to delayed maturity (Brewester, 1994; Marschner, 1995). This result is consistent with the findings of Abdissa *et al*. (2011), Meena *et al*. (2007) and Morsy *et al*. (2012) who reported that maturity of onion plants was delayed in response to increasing nitrogen application. In agreement with the result of this study, Brewster (1994) and Sørensen and Grevsen (2001) reported that ample nitrogen supply could result in excessive vegetative growth and delayed maturity of onion.

### 4.2.8. Bolting percentage

The main effect of nitrogen and intra-row spacing significantly ($P < 0.01$) affected the bolting percentage of onion. Moreover, the two factors interacted to influence this parameter significantly ($P < 0.01$) (Appendix Table 1).

Bolting percentage of the onion plants significantly decreased with increasing rate of nitrogen application across the increasing intra-row spacing between plants. Thus, the highest bolting percentages were recorded for plants grown at nil rates of nitrogen and intra-row spacing of 2.5 and 5.0 cm. However, the lowest bolting percentages were recorded for onion plants grown at the rates of 82 and 123 kg N $ha^{-1}$ and intra-row spacing of 10 and 12.5 cm (Table 5).

The increase in bolting percentage in response to the lower rates of N application as well as the narrower intra-row spacing might be due to less available nitrogen for the plant growth which lead to reduced vegetative growth and early flowering as described by Al-Fraihat (2009). However, the decrease in bolting percentage in response to the application of 82 and 123 kg N $ha^{-1}$) and wider spacing (10 and 12.5 cm) intra-row spacing may be associated with enhanced availability of nitrogen and less stiff competition among plants for resources which may have led to enhanced vegetative growth and delayed maturity thereby enhancing vegetative growth that would slow bolting.

Similar observations were made by Al-Fraihat (2009) and Abdissa *et al*. (2011) where increased nitrogen fertilizer applications reduced percentage of bolters in onions. Consistent with the results of this study, Bosch and Olivé (1999) also reported that the increased population density of onion significantly increased number of bolters. Mohamed (1991) also indicated that closer spacing of 5 x 20 cm increased percentage of bolters by 14.5%, while nitrogen application decreased the incidence of bolting.

Table 5: Interaction effect of intra-row spacing and nitrogen fertilizer levels on dry total biomass, days to maturity and bolting percentage of onion

| N level (kg ha$^{-1}$) | Intra-row spacing (cm) | Parameters | | |
|---|---|---|---|---|
| | | Dry total biomass (g plant$^{-1}$) | Days to maturity | Bolting percentage (%) |
| 0 | 2.5 | 2.72n | 100.00i | 31.95a |
| | 5 | 3.32lm | 102.00hi | 29.45a |
| | 7.5 | 3.62l | 104.67gh | 26.40b |
| | 10 | 4.82j | 110.3cde | 21.33cd |
| | 12.5 | 5.98i | 105.00gh | 11.36ij |
| 41 | 2.5 | 3.23m | 101.76hi | 23.72c |
| | 5 | 4.84j | 106.00g | 21.74cd |
| | 7.5 | 6.24i | 105.33gh | 20.60d |
| | 10 | 7.09h | 110.33ef | 19.59de |
| | 12.5 | 8.75fg | 115.0cd | 8.68jk |
| 82 | 2.5 | 4.02k | 107.33fg | 17.21ef |
| | 5 | 8.53g | 113.00de | 14.24gh |
| | 7.5 | 9.77e | 115.67cd | 11.88hi |
| | 10 | 11.54c | 119.67b | 6.37kl |
| | 12.5 | 12.59b | 124.33a | 4.17l |
| 123 | 2.5 | 4.01k | 113.33de | 15.16fg |
| | 5 | 8.90f | 115.67cd | 12.41hi |
| | 7.5 | 10.38d | 117.67bc | 10.74ij |
| | 10 | 12.25b | 123.33 a | 4.98l |
| | 12.5 | 13.08a | 126.67a | 3.93l |
| CV (%) | | 2.85 | 1.86 | 9.93 |
| SE (±) | | 0.12 | 1.20 | 0.91 |

Means followed by the same letter with in a column are not significantly different at 5% probability level according to Duncan's Multiple Range Tests

### 4.2.9. Stand count percentage

The different intra-row spacing and nitrogen rates exerted a statistically significant ($P < 0.01$) difference on stand count percentage of onion. Nevertheless, the interaction of effect intra-row spacing and nitrogen fertilizer levels did not show significant variation on this parameter (Appendix Table 1).

In response to widening the intra-row spacing, stand count percentage increased significantly. Hence, the highest stand count was obtained for 12.5 cm intra-row spacing. Generally, up on increasing the intra-row spacing from 2.5 cm to 12.5 cm, the stand count percentage increased from 78.56 to 98.04%. Thus, when the intra-row spacing increased to 12.5 cm, the stand count percentage increased by 25% as compared to the narrowest intra-row spacing (Table 6).

The higher stand count percentage at higher intra-row spacing could be attributed to less interplant competition for growth factors. Thus, the unavailability of the major plant food nutrient as a result of which the plants became weaker and lower in number (Khan *et al*, 2002). The current result is in conformity with that of Ashenafi *et al*. (2014) who indicated that higher population density led to lower stand count percentage of onion due to its higher mortality rate. Khan *et al*. (2002) also found reduced plant competition and plant mortality in onion at the lower plant population densities thereby resulted in increased stand count percentage.

With the increase in the rate of nitrogen fertilizer application from nil to 82 kg N $ha^{-1}$, stand count percentage increased significantly. Thus, the highest stand count percentage was obtained from nitrogen rate of 82 kg $ha^{-1}$. In contrast, the nil nitrogen fertilizer rates produced the lowest stand count percentages. In response to the increasing rate of nitrogen from 0 to 41 kg $ha^{-1}$, stand count percentage increased by 1.4%. When increasing the rate of nitrogen from 41 to 82 kg $ha^{-1}$, the stand count percentage further increased by about 0.3%. However, increasing the rate of nitrogen beyond 82 kg N $ha^{-1}$ did not change stand count percentage. Increasing application of nitrogen from 0 to 82 kg N $ha^{-1}$ increased stand count percentage by about 2% (Table 6).

The increase in stand count percentage of onion at 82 kg N $ha^{-1}$ might be associated with less interplant competition among plants for growth factors. This report is consistent with the finding of Ghaffoor *et al*. (2003) who showed that survival percentage of onion bulbs increased when 150 kg N $ha^{-1}$ was applied. Jilani *et al*. (2004) also reported that minimum numbers of bulbs were recorded for the control level of nitrogen.

Table 6: Main effect of intra-row spacing and nitrogen fertilizer levels on stand count percentage of onion

| Treatments | Stand count (%) |
|---|---|
| Intra-row spacing (cm) | |
| 2.5 | 78.56e |
| 5 | 86.42d |
| 7.5 | 89.63c |
| 10 | 97.30b |
| 12.5 | 98.04a |
| Nitrogen levels ( kg $ha^{-1}$) | |
| 0 | 88.83 c |
| 41 | 90.06b |
| 82 | 90.33ab |
| 123 | 90.75a |
| SE(±) | 0.48 |
| CV (%) | 0.93 |

Means followed by the same letter in a column are not significantly different at 5% probability level according to Duncan's Multiple Range Tests

## 4.3. Yield and Yield Related Traits

### 4.3.1. Average bulb weight

The main effect of nitrogen and that of intra-row spacing significantly (P <0.01) influenced the average bulb weight of the onion plants. In addition, the two factors interacted to influence this parameter significantly (P < 0.01) (Appendix Table 2).

Increasing the rate of nitrogen application progressively increased the average bulb weight of the onion plants across the increasing intra-row spacing. Thus, the highest average bulb weight was found in response to the application of 123 kg N $ha^{-1}$ and intra-row spacing of 12.5 cm due to the wider spacing accommodated less number of plants which received adequate nutrient, moisture and light which helped to increase the average weight of bulb per plant (Khan *et al*., 2002). However, the lowest average bulb weight was obtained at the lowest nitrogen rate (0 kg $ha^{-1}$) and smallest intra-row spacing (2.5 cm) (Table 7) due to absence of external supply of nitrogen, which is an important element needed for proper growth and development of every plant including onion (Brady, 1985).

In harmony with this result, Muhammad *et al*. (2011), Mahadeen, (2008), Dorcas *et al*. (2012) and Jilani *et al*. (2010) found that the lowest average bulb weight was obtained for narrowly spaced onion plants. Corroborating the results of this study, Soleymani and Shahrajabian (2012), Aliyu *et al*. (2008) and Morsy *et al*. (2012) mentioned that average bulb weight of onion increased with nitrogen rate.

**4.3.2. Bulb diameter**

The main effect of nitrogen and that of intra-row plant spacing significantly ($P < 0.01$) influenced the onion bulb diameter. The two factors interaction also influenced this parameter significantly ($P < 0.01$) (Appendix Table 2).

Similar to the average bulb weight, increasing the rate of nitrogen application consistently increased the bulb diameter of onion across the increasing intra-row spacing. Thus, the widest bulb diameter was recorded in response to the application of 123 kg N $ha^{-1}$ and intra-row spacing of 12.5 cm. The narrowest average bulb diameter was obtained at the lower nitrogen rates and smaller intra-row spacing of 2.5 and 5.0 cm (Table 7).

The development of wider bulb diameter with increasing intra-row spacing and rate of N fertilizer could be associated with the availability of more growth resources due to less competition and with application of N, which could be associated with promoting nature of nitrogen in cell elongation, above ground vegetative growth and synthesis of chlorophyll to impart dark green color of leaves. This may be linked to metabolic processes which increase dry matter production and translocation to the bulbs (Brady, 1985).

The current results are supported by the findings of Jilani *et al*. (2009), Akoun (2005) and Muhammad *et al*. (2011) who stated that higher bulb diameter was achieved for the wider plant spacing as compared to the closer spacing of onion. Similarly, Soleymani and Shahrajabian (2012) showed that nitrogen fertilization increased bulb diameter of onion compared to the control plots. Ghaffoor *et al*. (2003) also reported that the nitrogen dose of 120 kg N $ha^{-1}$ proved the best for the maximum bulb diameter of onion.

#### 4.3.3. Bulb neck diameter

The main effect of nitrogen and that of intra-row spacing significantly ($P < 0.01$) affected the bulb neck diameter. The interaction effect of the two factors also influenced bulb neck diameter of onion ($P < 0.01$) (Appendix Table 2).

Just like the average bulb weight and bulb diameter, increasing the rate of nitrogen application consistently increased bulb neck diameter across the increasing intra-row spacing. Thus, the widest bulb neck diameter was recorded in response to the application of 82 and 123 kg N $ha^{-1}$ and intra-row spacing of 12.5 cm. The narrowest bulb neck diameter, on the other hand, was obtained in combination to the application of nil rate of nitrogen fertilizer and intra-row spacing of 2.5, 5.0, and 7.5 cm (Table 7).

The highest bulb neck diameter at the wider intra-row spacing and higher nitrogen dose may be attributed to vigorous growth of the plants as a result of less stiff competition for growth resources. On the other hand, the narrow intra-row spacing with its high plant populations may have exerted pressure on scarce growth resources such as light, space, moisture and nutrients, leading to reduced growth and narrow bulb neck diameter (Khan *et al*., 2002). Analogous findings were mentioned by Dawar *et al*. (2005), Jilani *et al*. (2009) and Kantona *et al*. (2003) who showed that bulb neck diameter of onion decreased in response to increasing onion population density. Consistent with the results of this study, Jilani *et al*. (2004) reported that application of N at the rate of 200 kg $ha^{-1}$ increased the number of thick-necked bulbs.

#### 4.3.4. Bulb dry matter yield

The analysis of variance revealed that bulb dry matter yield per plant of onion was significantly ($P < 0.01$) affected by the main effect of the intra-row spacing and nitrogen fertilizer rate. Moreover, the interaction effect of these two factors also revealed significantly ($P < 0.01$) influence on bulb dry matter yield (Appendix Table 4).

Increasing the rate of nitrogen application steadily increased the bulb dry matter yield of the onion plants across the increasing intra-row spacing. Accordingly, the highest bulb dry matter was found in response to the application of 123 kg N ha$^{-1}$ and 82 kg N ha$^{-1}$ and spaced at the intra-row spacing of 12.5 cm. On the other hand, lower bulb dry matter yield was achieved at the nil nitrogen rates and narrowest intra-row spacing. Thus, when plants were grown at the lower treatment combinations of 0 kg N ha$^{-1}$ and 2.5 cm of intra-row spacing, the bulb dry matter yield of onion decreased by about 80% as compared to the higher rate of nitrogen (123 kg ha$^{-1}$) and the widest intra-row spacing (12.5 cm) (Table 7).

The lower bulb dry matter yield of onion observed at closer intra-row spacing and application of the nil rate of nitrogen might be due stiffer to competition among plants for the limited growth resources, which may have resulted in reduced vegetative growth like leaf number, leaf diameter, leaf length and plant height (Khan *et al*., 2002). Thus, finally the weight of bulb and diameter becomes small, leading to lower value of bulb dry matter of onion. These results are in conformity with the findings of Dereje *et al.* (2012) and Sikder *et al*. (2010) who explained that higher bulb dry weight was achieved in wider spacing in shallot and onion respectively. This result is consistent with the findings of Yadav *et al*. (2003) and El-Tantawy and El-Beik (2009) who found that higher N doses resulted in the production of higher bulb dry matter yields than lower doses of nitrogen.

Table 7: Interaction effect of intra-row spacing and nitrogen fertilizer levels on average bulb weight, bulb diameter, neck diameter and bulb dry matter yield per plant of onion

| N level (kg $ha^{-1}$) | Intra-row spacing (cm) | Parameters | | | |
|---|---|---|---|---|---|
| | | Average bulb weight (g) | Bulb diameter (cm) | Neck diameter (cm) | Bulb dry matter (g $plant^{-1}$) |
| 0 | 2.5 | 23.99l | 2.33l | 0.68k | 2.00m |
| | 5 | 27.09kl | 2.62k | 0.69jk | 2.45l |
| | 7.5 | 31.20jk | 3.50i | 0.74jk | 2.70l |
| | 10 | 34.21ij | 3.63hi | 0.84gh | 3.56j |
| | 12.5 | 41.88gh | 3.90g | 0.84gh | 4.42i |
| 41 | 2.5 | 38.48hi | 3.07j | 0.75ij | 2.42l |
| | 5 | 46.77g | 3.52i | 0.81hi | 3.59j |
| | 7.5 | 55.41f | 3.70hi | 0.89fg | 4.68i |
| | 10 | 66.83e | 4.80e | 0.96de | 5.39h |
| | 12.5 | 70.18e | 5.23d | 1.00d | 6.55g |
| 82 | 2.5 | 53.62f | 3.50i | 0.87fgh | 3.05k |
| | 5 | 71.11e | 4.46f | 0.97de | 6.82fg |
| | 7.5 | 77.23d | 4.70e | 1.07c | 7.70e |
| | 10 | 90.79c | 5.27d | 1.11c | 8.83c |
| | 12.5 | 101.64b | 5.48c | 1.38a | 9.63a |
| 123 | 2.5 | 59.89f | 3.80gh | 0.92ef | 3.04k |
| | 5 | 78.03d | 4.88e | 1.12c | 7.03f |
| | 7.5 | 85.15c | 5.57c | 1.21b | 8.10d |
| | 10 | 99.02b | 5.77b | 1.25b | 9.30b |
| | 12.5 | 123.85a | 6.05a | 1.35a | 9.86a |
| CV | | 5.66 | 2.60 | 3.97 | 3.00 |
| SE(±) | | 2.08 | 0.06 | 0.02 | 0.01 |

Means followed by the same letter with in a column are not significantly different at 5% probability level according to Duncan's Multiple Range Tests

**4.3.5. Total bulb yield**

The main effect of nitrogen as well as that of intra-row spacing significantly ($P < 0.01$) influenced the total bulb yield of onion. Additionally, the interaction effect of nitrogen application and intra-row spacing significantly ($P < 0.01$) influenced the total bulb yield of the onion (Appendix Table 2).

Total bulb yield increased significantly in response to increasing the rate of nitrogen application across the increasing rate of the intra-row spacing except in treatment combination of nil nitrogen application of which it deceased with increasing intra-row spacing. However, the increase occurred only up to the application of 82 kg N $ha^{-1}$ and 5.0 cm intra-row spacing, beyond which the total bulb yield decreased. The highest total bulb yield was obtained from onion plants grown at the rate of 82 kg N $ha^{-1}$ and the intra-row spacing of 5.0 cm. On the other hand, the lowest total bulb yield was obtained in response to no application of nitrogen at the rate of nil kg N $ha^{-1}$ and intra-row spacing of 10.0 cm and 12.5 cm. Thus, the total bulb yield obtained in response to the application of 82 kg N $ha^{-1}$ at the intra-row spacing of 5.0 cm exceeded the total bulb yield obtained from plants grown with no application of the N fertilizer at the intra-row spacing of 2.5 cm by 90% (Table 8).

The enhancement of total bulb yield in response to the treatment combination of 5 cm intra-row spacing and 82 kg N $ha^{-1}$ might be due to the higher number of harvestable bulbs per unit area as described by Latif *et al*. (2010). Hence, onion plants planted at the optimum intra row spacing helps for attaining their optimum bulb size (Rumpel *et al*., 2000). However, bulb yield per plant was observed to have increased with increase in intra row spacing at all nitrogen rates via increasing their bulb weight. This result agrees with the finding of Khan *et al*. (2003), Muhammad *et al*. (2011), Latif *et al*. (2010), Yemane *et al*. (2013) and Jan *et al*. (2003) who reported that the highest onion bulb yields were observed at the closest spacing. Dereje *et al*. (2012) also indicated that total bulb yield decreased with increase in the intra-row spacing of shallot.

Similarly, Jilani *et al*. (2004) showed that with increase in dose of nitrogen up to120 kg $ha^{-1}$, the total bulb yield was increased, but below this rate, the total bulb yield began to decrease. Soleymani and Shahrajabian, (2012) and Al-Frahat (2009) also indicated that the control plots achieved lower total yields as compared to the higher nitrogen doses. Balemi *et al*. (2007) also observed a significant increase in total bulb yield in response to increased application of nitrogen.

### 4.3.6. Unmarketable bulb yield

Unmarketable bulb yield was significantly influenced by the combined effect of intra-row spacing and nitrogen fertilizer levels. Moreover, significant ($P < 0.01$) variations were observed in this parameter in response to the main effects of both intra-row spacing and nitrogen fertilizer rate (Appendix Table 2).

With the increase in the intra-row spacing and nitrogen fertilizer rate, unmarketable bulb yield of onion decreased significantly. Thus, the highest value of unmarketable bulb yield was recorded in zero nitrogen fertilizer application at the intra-row spacing of 2.5 cm. This was followed by the narrow intra-row spacing at the rate of 41 kg N $ha^{-1}$. On the other hand, the minimum unmarketable bulb yield was obtained both when onion plants were fertilized with 123 kg N $ha^{-1}$ and planted at spacing of 5.0 cm, 7.5 cm, 10 cm and 12.5 cm of intra-row spacing and when the 82 kg N $ha^{-1}$ was combined with the intra-row spacing of 7.5 cm, 10 cm and 12.5 cm. Similarly, when 12.5 cm of intra-row spacing was combined with 41 kg N $ha^{-1}$, minimum unmarketable bulb yield was produced.

The higher unmarketable bulb yield of closely spaced onion plants and combined with nil nitrogen levels (2.5 cm and 0 kg N $ha^{-1}$) might be due to more interplant competition for nutrient, water, light and air (Sikder *et al*, 2010). These results are in accord with those of Seck and Baldeh (2009), Yemane *et al*. (2013) and Dereje *et al*. (2012) who mentioned that narrow intra-row spacing increased unmarketable bulb yield of onion, onion, and shallot respectively. Similarly, Brewster (1994) reported that under sub-optimal supply of nitrogen, the marketable yields of onion and shallot can be severely reduced. Likewise, Negash *et al*. (2009) and Jilani *et al*. (2004) indicated that nil nitrogen fertilizer rates resulted in more unmarketable bulb yield.

### 4.3.7. Marketable bulb yield

The main effect of nitrogen as well as that of intra-row spacing significantly ($P < 0.01$) influenced the marketable bulb yield of the onion crop. Similarly, the interaction effect of nitrogen application and intra-row spacing significantly ($P < 0.01$) influenced the marketable bulb yield of the crop (Appendix Table 2).

Similar to the total bulb yield, increasing the rate of nitrogen application significantly increased the production of marketable bulb yield across the increasing rate of the intra-row spacing. However, the increase occurred only up to the application of 82 kg N $ha^{-1}$ and 5.0 cm intra-row spacing, beyond which the marketable bulb yield decreased. Thus, the highest marketable bulb yield was recorded from onion plants grow at the rate of 82 kg N $ha^{-1}$ and the intra-row spacing of 5.0 cm. On the other hand, the lowest marketable bulb yield was obtained in response to no application of nitrogen combined with the intra-row spacing of 2.5 cm. Thus, the marketable bulb yield obtained in response to the application of 82 kg N $ha^{-1}$ at the intra-row spacing of 5.0 cm exceeded the marketable bulb yield of plants grown with no application of the N fertilizer at the intra-row spacing of 2.5 cm by 120% (Table 8).

The maximum marketable bulb yield of onion obtained at treatment combination of 5 cm intra-row spacing and 82 kg N $ha^{-1}$ might be attributed to optimum number of plant population per unit area which leads to maximum number of bulbs due to closer spacing and optimal supply of nitrogen in the soil. Although plant height, number of leaves per plant and leaf length increased with increasing spacing, it could not be compensated for the yield of closely spaced plants due to higher plant population. Thus, the marketable bulb yield of onion per unit area does not completely depend up on the performance of individual plants but also related with the total number of plants per unit area and yield contributing parameters (Latif *et al*., 2010 and Aliyu *et al*., 2008).

Similar observations were reported by Latif *et al*. (2010), Jan *et al*. (2003), Sikder *et al.* (2010), Dorcas *et al*. (2012) and Mahadeen (2008) who reported that maximum marketable bulb yields of onion were obtained at lower intra-row spacing. Islam *et al*. (1999) and Naik and Hosamani (2003) also stated that maximum bulb yield of onion was recorded in treatment combination of narrow intra-row spacing and optimum nitrogen fertilizer level. Similarly, Soleymani and Shahrajabian (2012) and Balemi *et al*. (2007) also showed that the higher value of marketable yield was achieved under higher rate of nitrogen fertilization (120 kg $ha^{-1}$).

Table 8: Interaction effect of intra-row spacing and nitrogen fertilizer levels on marketable, unmarketable and total bulb yield of onion

| N level (kg ha$^{-1}$) | Intra-row spacing (cm) | Parameters | | |
|---|---|---|---|---|
| | | Marketable bulb yield (t ha$^{-1}$) | Unmarketable bulb yield (t ha$^{-1}$) | Total bulb yield (t ha$^{-1}$) |
| 0 | 2.5 | 17.93j | 2.96 a | 20.89i |
| | 5 | 19.41i | 1.32c | 20.73ij |
| | 7.5 | 19.39i | 0.97e | 20.36ij |
| | 10 | 18.75ij | 0.88ef | 19.63jk |
| | 12.5 | 18.13j | 0.76g | 18.89k |
| 41 | 2.5 | 21.36h | 1.87b | 23.23h |
| | 5 | 27.63e | 0.85fg | 28.48e |
| | 7.5 | 26.98e | 0.41h | 27.39ef |
| | 10 | 22.97g | 0.19i | 23.17h |
| | 12.5 | 23.21g | 0.15ijk | 23.36h |
| 82 | 2.5 | 24.13fg | 1.14d | 25.27g |
| | 5 | 39.51a | 0.19ij | 39.69a |
| | 7.5 | 36.17b | 0.14ijk | 36.31b |
| | 10 | 31.00d | 0.13ijk | 31.13d |
| | 12.5 | 24.76f | 0.08jk | 24.84g |
| 123 | 2.5 | 23.23g | 0.47h | 23.70h |
| | 5 | 37.02b | 0.14ijk | 37.16b |
| | 7.5 | 33.65c | 0.07jk | 33.73c |
| | 10 | 26.47e | 0.04k | 26.51f |
| | 12.5 | 23.18g | 0.03k | 23.21h |
| CV (%) | | 2.61 | 10.00 | 2.55 |
| SE (±) | | 0.39 | 0.04 | 0.39 |

Means followed by the same letter are with in a column not significantly different at 5% probability level according to Duncan's Multiple Range Tests

4.3.7.1. Bulb size distribution of marketable bulb yield

4.3.7.1.1. Small-sized bulb yield (20-50g)

The analysis of variance showed that both the main effect of intra-row spacing and nitrogen fertilizer level and their interaction effect significantly ($P < 0.01$) influenced the small bulb size distribution of onion (Appendix Table 3).

Increasing the intra-row spacing significantly decreased the production of small sized bulb yield across the increasing rate of nitrogen application rate. Thus, the highest small sized bulb yield was obtained from onion plants grown at the rate of 0 kg N $ha^{-1}$ and 41 kg N $ha^{-1}$ and spaced at the intra-row spacing of 2.5 cm. In contrast, the lowest small sized bulb yield of onion was recorded in response to the application of higher nitrogen rate at 123 kg $ha^{-1}$ and 82 kg $ha^{-1}$ and planted at the intra-row spacing of 10 cm and 12.5 cm. For instance, the small sized bulb yield obtained in response to the application of 0 kg N $ha^{-1}$ planted at the intra-row spacing of 2.5 cm exceeded small sized bulb yield of plants grown with 123 kg $ha^{-1}$ application of the N rates planted at the intra-row spacing of 12.5 cm by 2131% (Table 9).

The increment in small size bulb yield of onion in response to the application of nil nitrogen rate and narrow intra-row spacing may have resulted in reduction in above growth biomasses like leaf number, leaf area, leaf length and diameter due to less availability and more competition for growth resources. With narrower plant spacing, bulb expansion suffers (Rumpel *et al*., 2000; Negash *et al*., 2009). In accordance with the current finding, increasing the rate of nitrogen application from 0 kg $ha^{-1}$ to 138 kg $ha^{-1}$ significantly decreased the yield of small sized bulbs of onion by 61.8% as reported by Negash *et al*. (2009). Similarly, Nasreen *et al*. (2007) indicated that small size bulb yield reduction in response to increased N fertilization. Moreover, supporting the current result, Dorca *et al*. (2012), Balraj *et al*. (1998) and Yemane *et al*. (2013) indicated that higher population density increased the yield of small-sized bulbs.

4.3.7.1.2. Medium bulb size yield (50-100g)

Intra-row spacing and nitrogen fertilizer levels exhibited highly significant ($P < 0.01$) variation on medium bulb size yield of onion. Likewise, interaction effect also exerted a significant ($P < 0.01$) influence on this parameter (Appendix Table 3).

The production of medium sized bulb yield of onion was significantly increased by increasing the nitrogen rate application across the increasing of intra-row spacing. However, the increase was not consistent and occurred only up to the nitrogen rate of 82 kg N $ha^{-1}$ at the intra-row spacing of 5.0 cm, beyond which the medium sized bulb yield decreased. However, medium sized bulb yield increased with application of nil nitrogen rates spaced at all intra-row spacing. Hence, the highest medium sized bulb yield was achieved from onion plants grown with the application of 82 kg N $ha^{-1}$ at the intra-row spacing of 5.0 cm. On the other hand, in response to nil application of nitrogen and planted at the intra-row spacing of 2.5 cm produced the lowest medium sized bulb yield. Thus, the medium sized bulb yield obtained in response to the application of 82 kg N $ha^{-1}$ at the intra-row spacing of 5.0 cm exceeded the medium sized bulb yield of plants grown with the application of 0 kg N $ha^{-1}$ at the intra-row spacing of 2.5 cm by 632% (Table 9).

The increase in medium sized bulb yield of onion in response to the application of 82 kg $ha^{-1}$ nitrogen at the intra-row spacing of 5.0 cm may be due to the fact that this rate of nitrogen and intra-row spacing were optimum for growth and enhanced productivity of the crop. The results of the present study are in agreement with the finding of Negash *et al*. (2009) and Nasreen *et al*. (2007) who reported that highest weights of medium sized bulb yield were recorded at application of higher nitrogen. Similarly, Nasir *et al*. (2007), Rumpel *et al*. (2000) and Stoffela (1996) reported that maximum weights of medium sized bulbs were obtained at higher planting densities.

4.3.7.1.3. Large-sized bulb yield (100-160g)

The analysis of variance showed that the main effect of nitrogen rate was significant ($P < 0.01$) on large sized bulb yield of onion. The main effect of intra-row spacing also significantly ($P < 0.01$) affected large sized bulb yield. Moreover, nitrogen and intra-row spacing interacted to influence this parameter (Appendix Table 3).

Similar to medium sized bulb yield, large sized bulb yield increased significantly in response to the increased application of nitrogen rate across the increasing of intra-row spacing except for the application of nitrogen rate of nil and 41 kg $ha^{-1}$ combined with all the intra-row spacing. However, the increase occurred only up to the nitrogen application and intra-row spacing combination of 82 kg N $ha^{-1}$ and 7.5 cm of intra-row spacing above which decrease in the yield of large sized bulb occurred. When the onion plants were spaced at 2.5 cm large sized bulb yield increased across the different nitrogen rates. The maximum large sized bulb yield was obtained in response to the application of 82 kg N $ha^{-1}$ and intra-row spacing of 7.5 cm. On the other hand, the minimum value was achieved from the treatment combination of narrowest intra-row spacing and nil nitrogen rate (Table 9).

The achievements of higher yields of large sized bulbs by increasing intra-row spacing up to the optimum intra-row spacing and N level might be due to resource availability and assimilation and less stiff competition among the onion plants (Khan *et al*., 2002). This may lead to increased weights of individual bulbs shifting from small to medium and then to large bulb categories. Corroborating this result, Negash *et al*. (2009) and Kokobe *et al*. (2013) reported that onion bulb size increased with increasing nitrogen dose. Islam *et al*. (1999) also explained that large sized bulbs were recorded for wider intra-row spacing and higher nitrogen rates. Similarly, Dawar *et al*. (2007), Jilani *et al*. (2009), Yemane *et al*. (2013) and Mallor *et al*. (2011) indicated that maximum value of large bulbs were obtained in lower population densities.

4.3.7.1.4. Over-sized bulb yield (>160 g)

The main effect of intra-row spacing and nitrogen fertilizer rates significantly ($P < 0.01$) affected oversized bulb yield of onion. Interaction effect of intra-row spacing and nitrogen rate also exerted a significant ($P < 0.01$) influence on oversized bulb yield of onion (Appendix Table 3).

Increasing the rate of nitrogen markedly increased over sized bulb yield of onion across the increasing intra-row spacing. Thus, the lowest oversized bulb yield was recorded when the onion plants were grown with nil nitrogen fertilizer application and planted at the intra-row spacing of 2.5 cm, 5.0 cm, 7.5 cm and 10 cm as well as when the onion plants were treated with 41 kg N $ha^{-1}$ and 2.5 cm intra-row spacing. Nevertheless, intra-row spacing and nitrogen rate combinations of 123 kg $ha^{-1}$ and 12.5 cm intra-row spacing resulted in the highest over-sized bulb yield of onion.

The lower oversized bulb yield recorded at narrow intra-row spacing and nil rate of nitrogen application might be due to stiffer competition among onion plants for growth resource, which may have resulted in smaller bulb expansion in size (Rumpel *et al*., 2000). On the other hand, ample availability of growth resources including wider space may lead to high bulb expansion and growth, leading to the production of markedly higher yields of over-sized bulbs. Comparable results were reported by Khan *et al.* (2002), Coleo *et al*. (1996) and Nasir *et al*. (2007) that the highest proportions of large bulbs were found at lower planting densities.

Table 9: Interaction effect of intra-row spacing and nitrogen fertilizer levels on marketable bulb size distribution of onion

| N level (kg $ha^{-1}$) | Intra-row spacing (cm) | Parameters | | | |
|---|---|---|---|---|---|
| | | Small sized bulb yield (t $ha^{-1}$) | Medium sized bulb yield (t $ha^{-1}$) | Large sized bulb yield (t $ha^{-1}$) | Oversized bulb yield (t $ha^{-1}$) |
| 0 | 2.5 | 13.83a | 3.86m | 0.25j | 0.00j |
| | 5 | 10.07b | 8.49k | 0.85hi | 0.00j |
| | 7.5 | 7.95c | 10.52j | 0.91hi | 0.05j |
| | 10 | 6.37d | 11.19ij | 1.19gh | 0.11ij |
| | 12.5 | 4.79e | 11.71i | 1.63g | 0.22ghi |
| 41 | 2.5 | 13.17a | 7.50l | 0.69ij | 0.09ij |
| | 5 | 9.30b | 16.67ef | 1.66g | 0.22hi |
| | 7.5 | 7.88c | 16.95de | 2.15f | 0.31gh |
| | 10 | 4.54ef | 15.82fg | 2.61e | 0.36g |
| | 12.5 | 3.50g | 13.35h | 6.36d | 0.73e |
| 82 | 2.5 | 9.56b | 13.51h | 1.05hi | 0.22ghi |
| | 5 | 3.72fg | 28.27a | 7.59bc | 0.72e |
| | 7.5 | 3.26g | 24.89b | 8.03a | 1.02d |
| | 10 | 1.51h | 22.08c | 7.41bc | 1.44c |
| | 12.5 | 0.67h | 16.84e | 7.25bc | 2.39b |
| 123 | 2.5 | 7.55c | 14.03h | 1.64g | 0.56f |
| | 5 | 3.81fg | 25.64b | 7.58b | 0.97d |
| | 7.5 | 3.70fg | 22.62c | 7.34bc | 1.31c |
| | 10 | 1.33h | 17.85d | 7.29bc | 2.47b |
| | 12.5 | 0.62h | 15.49g | 7.04c | 4.03a |
| CV (%) | | 8.63 | 3.59 | 6.69 | 9.61 |
| SE(±) | | 0.29 | 0.33 | 0.16 | 0.05 |

Means followed by the same letter with in a column are not significantly different at 5% probability level according to Duncan's Multiple Range Tests

**4.3.8. Under size bulb yield (< 20 g)**

Results from the analysis of variance revealed that combined effect of intra-row spacing and nitrogen fertilizer rate was found to be significant ($P < 0.01$) on under sized bulb yield. Effect of the different intra-row spacing and nitrogen level also significantly ($P < 0.01$) affected the under sized bulb yield of onion (Appendix Table 3).

Across with widening intra-row spacing, increasing the rate of nitrogen application markedly decreased the yield of under sized bulbs. Therefore, the maximum under sized bulb yield was recorded when onion plants were fertilized with 0 kg N $ha^{-1}$ at the spacing of 2.5 cm intra-row spacing. Next to this treatment combination, a high value of under sized bulb yield was recorded at treatment combination of 2.5 cm intra-row spacing and 41 kg N $ha^{-1}$. Conversely, the minimum under-sized bulb yield was recorded at the treatment interaction of 123 kg N $ha^{-1}$ and 7.5 cm, 10 cm and 12.5 cm intra-row spacing. In line with this, onion plants treated with 82 kg N $ha^{-1}$ and 12.5 cm intra-row spacing produced a minimum under-sized bulb yield of onion (Table 10).

The higher under sized bulb yield at closer intra-row spacing combined with nil nitrogen level could be due to more competitive effect among the different planting density for growth resources at the closer plant spacing. The increase in the yield of the under-sized bulbs might also be related with the lower nitrogen doses, which may have reduced vegetative growth like leaf number, leaf area and leaf length by decreasing synthesis and partitioning of photosynthetic to the bulbs (Rumpel *et al*., 2000). In harmony with this result, higher under-sized bulb yield of onion at the highest planting density was reported by Nasir *et al. (*2007). Similarly, Jilani *et al*. (2009) showed that minimum bulb sized yield obtained in the control plots or nil nitrogen dose. Negash *et al*. (2009) reported that nil nitrogen fertilizer application increased small sized bulbs yield of onion.

### 4.4. Harvest Index

The analysis of variance showed that means of harvest index was significantly ($P < 0.01$) affected by the interaction effect of nitrogen and intra-row spacing. Moreover, harvest index was significantly ($P < 0.01$ influenced by the main effects of nitrogen application and intra-row spacing) (Appendix Table 4).

In response to increasing the rate of nitrogen application across the increasing rate of the intra-row spacing, harvest index increased markedly. Thus, the highest harvest index was recorded from the application of nitrogen at the rate of 82 kg $ha^{-1}$ and intra-row spacing of 5.0 cm and 7.5 cm. Application of 123 kg N $ha^{-1}$ at the intra-row spacing of 5.0 cm also produced the maximum harvest index. On the other hand, onion plants that received 0 kg N $ha^{-1}$ and at the intra-row spacing of 2.5 cm, 5.0 cm, 7.5 cm, 10 cm and 12.5 cm had the minimum harvest indices. Similarly, application of 41 kg N $ha^{-1}$ combined with all the intra-row spacing, except 10 cm, led to the lowest in harvest index. For instance, the harvest index of onion plants treated with nil nitrogen at the intra-row spacing of 2.5 cm decreased by about 8% compared to the harvest index obtained in response to the application of 82 kg N $ha^{-1}$ at the intra-row spacing of 5 cm.

The highest harvest index at the optimum intra-row spacing and optimum nitrogen fertilizer levels (5 cm with 82 kg N $ha^{-1}$) could be associated with comparatively high marketable bulb yield. It might also be related with the presence of relatively shorter leaf length and leaf diameter and plant height in treatment combination of 5 cm with 82 kg N $ha^{-1}$, which may have reduced the above ground biomass and resulted in higher harvest index (Kabir and Sarkar 2008; Yemane *et al*., 2013). On the other hand, the lowest harvest index in the treatment combination of 0 kg N $ha^{-1}$ and 2.5 cm intra-row spacing may be due to relatively lower marketable bulb yield. Similar results were obtained by Abdissa *et al*. (2011) who reported that the lowest harvest index of onion occurred in response to the application of nil rate of nitrogen fertilizer. Similarly, Yemane *et al*. (2013) for onion and Dereje *et al*. (2012) for shallot reported that wider intra-row spacing resulted in lower harvest indices. Highest values of harvest index of mungbean was recorded from closer spacing probably due to the reduced vegetative biomass (Kabir and Sarkar, 2008).

## 4.5. Total Soluble Solid

The main effect of nitrogen as well as that of intra-row spacing significantly ($P < 0.01$) influenced the total soluble solids of the onion plants. Moreover, nitrogen application and intra-row spacing interacted to significantly ($P < 0.01$) influence the total soluble solids of the crop (Appendix Table 4).

Increasing rate of nitrogen application significantly increased total soluble solids, but the parameter consistently decreased across the increasing intra-row spacing. Thus the highest total soluble solids were recorded for plants grown at the rates of 82 and 123 kg N $ha^{-1}$ and at the intra-row spacing of 2.5 cm. On the other hand, the smallest total soluble solids were recorded for onion plants grown at the nil rate of nitrogen application and planted at the intra-row spacing of 10 cm and 12.5 cm. Thus, the total soluble solids recorded at the rates of 82 and 123 kg N $ha^{-1}$ and the intra-row spacing of 2.5 cm exceeded the total soluble solids obtained at nil rate of N fertilizer and the intra-row spacing of 10 and 12.5 cm by about 32 and 35%, respectively.

The possible reason for increasing the total soluble solids with higher application of nitrogen fertilizer along with narrow intra-row spacing might be higher nitrogen content increases the chlorophyll content and dry weight per plant (Brady, 1985). The wider intra-row spacing also resulted in larger onion bulbs which gets its soluble solids diluted due to higher volume and more water content (Mallor *et al*., 2011). The results are in conformity with the findings of Moursy *et al*. (2007) and Morsy *et al*. (2012) who stated that the application of nitrogen fertilizer levels increased TSS values. Consistent with the results of this study, Naik and Hosamani (2003) also showed that maximum TSS was recorded for higher nitrogen rates and narrow intra-row spacing. Mallor *et al*. (2011) also reported a significant negative correlation between bulb weight and soluble solids content.

Table 10: Interaction effect of intra-row spacing and nitrogen fertilizer levels on under sized bulb yield, harvest index and total soluble solid yield of onion

| N level (kg $ha^{-1}$) | Intra-row spacing (cm) | Parameters | | |
|---|---|---|---|---|
| | | Under sized bulb yield (t $ha^{-1}$) | Harvest index (%) | Total soluble solids ($^{0}$Brix) |
| 0 | 2.5 | 2.61a | 73.25i | 12.17ef |
| | 5.0 | 0.94c | 74.00ghi | 11.70hi |
| | 7.5 | 0.65e | 74.61e-i | 10.47l |
| | 10 | 0.46f | 73.84hi | 10.17m |
| | 12.5 | 0.45f | 73.90hi | 10.07m |
| 41 | 2.5 | 1.70b | 74.99d-i | 12.57d |
| | 5 | 0.40fg | 74.35f-i | 12.10ef |
| | 7.5 | 0.36g | 74.89d-i | 11.73gh |
| | 10 | 0.17h | 75.99def | 10.63kl |
| | 12.5 | 0.13hi | 74.84d-i | 10.57l |
| 82 | 2.5 | 0.79d | 75.87def | 13.33ab |
| | 5 | 0.17h | 79.96a | 12.90c |
| | 7.5 | 0.12hij | 78.84ab | 12.00fg |
| | 10 | 0.12hij | 76.56cd | 10.97j |
| | 12.5 | 0.05ijk | 76.46cde | 10.90jk |
| 123 | 2.5 | 0.35g | 75.83d-g | 13.57a |
| | 5 | 0.12hij | 78.94ab | 13.20b |
| | 7.5 | 0.06ijk | 78.02bc | 12.33de |
| | 10 | 0.04jk | 75.87def | 11.43i |
| | 12.5 | 0.02k | 75.39d-h | 11.00j |
| CV (%) | | 10.35 | 1.27 | 1.43 |
| SE (±) | | 0.03 | 0.55 | 0.10 |

Means followed by the same letter with in a column are not significantly different at 5% probability level according to Duncan's Multiple Range Tests

### 4.6. Correlation Analysis

Correlation coefficient was calculated for the different response variables which help to show how the yield components and growth characters affecting the marketable bulb yield of onion. Thus, it was observed that marketable bulb yield was highly significantly and positively correlated with medium bulb size (r=0.95**), large bulb size (r=0.74**), total yield (r=0.99**), leaf number (r=0.53**), plant height (r=0.56**), leaf length (r=0.47**), leaf diameter (r=0.45**), bulb diameter (r=0.47**), neck diameter (r=0.46**), average bulb weight (r=0.50**), days to maturity (r=0.43**), bulb dry matter (r=0.55**), shoot dry matter (r=0.39**), harvest index (r=0.84**), dry total biomass (r=0.52**) and TSS (r=0.46** ) (Appendix 5). This shows that the use of different combination of intra-row spacing and nitrogen fertilizer levels for increasing of vegetative growth, results to the indirect selection of intra-row spacing and nitrogen level combinations for increasing onion yield. However, marketable yield was highly statistically and negatively correlated to unmarketable bub yield (r=-0.56**), under sized bulb (r=-0.50**) and bolting percentage (r=-0.43**). Hyder *et al*. (2007) also showed that plant height has positive indirect effect on marketable bulb yield and bulb sizes.

Similarly, average bulb weight was positively correlated and highly significant with plant height (r=0.86**), leaf number (r=0.91**), leaf length (r=0.79**), leaf diameter (r=0.95**), bulb diameter (r=0.94**), neck diameter (r=0.95**), bulb dry matter (r=0.94**), days to maturity (r=0.92**), harvest index (r=0.50**), dry total biomass (r=0.94*), medium size bulb (r=0. 63**), large bulb size (r=0.86**), marketable bulb yield (r=0.50**), total yield (r=0.44*), oversized bulb (r=0.91**) and shoot dry matter (r=0.93**) indicating that N fertilization and intra-row spacing increased bulb weight by improving these parameters. Abdissa *et al*. (2011) indicated that bulb weight had positively strongly association with plant height, leaf number, leaf length and days to maturity as affected by nitrogen and phosphorus fertilization.

Negatively and significantly association was observed as bulb weight was correlated with unmarketable yield (r=-0.76**) and small bulb size (r=-0.85**), under size bulb (r=-0.68**) and bolting percentage (r=-0.88**); but negatively and not significantly correlated with TSS ($r=-0.02^{ns}$) signifying that N level and intra-row spacing increasing bulb weight by decreasing TSS contents. Mallor *et al*. (2011) also reported significant negative correlation found between bulb weight and soluble solids content. Rajcumar (1997) also reported that high bulb weight have lower total soluble solids content and a negative correlation (r=-0.85) between bulb size and TSS.

It was also observed that leaf number was positively correlated with total yield (r=0.47**), plant height (r=0.84**), leaf length (r=0.75**), leaf diameter (r=0.94**), bulb diameter (r=0.91**), and neck diameter (r=0.89**); plant height, leaf length, leaf diameter and shoot dry matter was significantly and positively correlated with total yield (r=0.50**), (r=0.40**), (r=0.37**) and (r=0.32**), respectively. This association indicates that an increased photosynthetic area in response to N fertilization and intra-row spacing had noticeably contributed to enhance onion yield and quality which could be through the production of more assimilates and finally translocate to the bulbs (Marschner, 1995). Bulb diameter has also strong and positive correlation (r=0.40**) with the total yield. Similar findings were also reported by Nasreen *et al*. (2007).

## 4.7. Partial Budget Analysis

Partial budget is a method of organizing experimental data and information about the costs and benefits of various alternative treatments. It is the process of examining only those costs, returns and resource needs that change with a proposed adjustment. A partial budget is a way of calculating the total costs that vary and the net benefits of each treatment (CIMMYT, 1988).

From the result of this study, the average yield of 20 treatments was obtained. According to CIMMYT (1988), the average yield was adjusted down wards by 10 %. This is for the reason that, researchers have assumed that using the same treatments the yields from the experimental plots and farmers' fields are different, thus average yields should be adjusted downward. Based on this, the recommended level of 10% was adjusted from all 20 treatments to get the net yield. In addition to this, to obtain the gross field benefits, it is essential to know the field price value of one kg of onion bulb during harvesting time. Then finally, adjusted yield was multiplied by field price to obtain gross field benefit of onion.

For the different treatment combinations the total costs and net benefits were calculated. The different costs of this experiment which includes cost for nitrogen (Urea), seed and labour cost for nitrogen fertilizer application and for transplanting are varied among the different treatments. The purchasing price of Urea and seeds were 12.00 Birr $kg^{-1}$ and 160.00 Birr $kg^{-1}$

respectively. The cost for daily labor during the season was 60 Birr per day. The field price of onion during the harvesting season was 5 birr $kg^{-1}$. All the variable costs were subtracted from gross benefit to obtain net benefit.

The partial budget analysis revealed, the highest net benefit of Birr 168550 with higher cost was recorded from the combination of 82 kg N $ha^{-1}$ and 5 cm intra-row spacing with marginal rate of 696% which was followed by net benefit of Birr 155408 from the nitrogen rate of 82 kg $ha^{-1}$ and spacing of 7.5 cm intra-row spacing with the marginal rate of 2365%. However, the highest net benefit of Birr 133087 with least cost production of about Birr 6413 were obtained from application of nitrogen rate 82 kg $ha^{-1}$ and 10 cm of intra row spacing with MRR of (14372%).This means that for every Birr 1.00 invested in 82 kg N $ha^{-1}$ and 10 cm intra-row spacing, growers can expect to recover the Birr 1.00 and obtain an additional 143.72 Birr.

The minimum acceptable marginal rate of return (MARR %) should be between 50% and 100% CIMMYT (1988). Thus, the current study indicated that marginal rate of return is higher than 100% (Table 11). This showed that all the treatment combinations are economically important as per the MRR is greater than 100%. Hence, the most economically attractive combinations for small scale farmers with low cost of production and higher benefits were in response to the application of 82 kg N $ha^{-1}$ and 10 cm intra row spacing. However, for resource full producers (investors), application of 82 kg N $ha^{-1}$ spaced at 5.0 cm intra row-spacing was also profitable with higher cost and highest net benefit is recommended as a second option.

Table 11. Partial budget and MRR analysis for fertilizer rate and intra row spacing trial on marketable yield of onion

| N (kg $ha^{-1}$) with intra-row (cm ) combination | Unadjusted marketable yield (t $ha^{-1}$) | Adjusted marketable yield (t $ha^{-1}$) | Gross Benefit (Birr $ha^{-1}$) | Variable cost (Birr) | Net Benefit (Birr $ha^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|
| 0*12.5 | 18.13 | 16.32 | 81600 | 2260 | 79340 | 0 |
| 0*10 | 18.75 | 16.88 | 84375 | 2834 | 81541 | 386 |
| 0*7 .5 | 19.39 | 17.44 | 87210 | 3778 | 83432 | 200 |
| 41*12.5 | 23.21 | 20.89 | 104445 | 4770 | 99675 | 1637 |
| 82*12.5 | 24.76 | 22.28 | 111400 | 5839 | 105581 | 552 |
| 41*7.5 | 26.98 | 24.28 | 121400 | 6288 | 115122 | 2124 |
| 82*10 | 31.00 | 27.90 | 139,500 | 6413 | 133087 | 14372 |
| 82*7.5 | 36.17 | 32.55 | 162,765 | 7357 | 155408 | 2365 |
| 82*5 | 39.51 | 35.56 | 177,795 | 9245 | 168550 | 696 |

# 5. SUMMARY AND CONCLUSION

Onion (*Allium cepa* L.) is one of the most important vegetable crops commercially grown in the world. It is a high value and high income generating vegetable crops for most farmers in Ethiopia which is widely produced in small scales and by commercial growers. Onion is considerably important in the daily Ethiopian diet which the bulbs and the lower stem sections are the most popular as seasonings or as vegetables in stews.

The enhancement of onion production and productivity can be related with different growth factors. Thus, the use of appropriate agronomic management has an undoubted contribution to increased crop yields. Although several constraints are associated with onion production; improper agronomic practice used by farmers are among the major problems to onion production and productivity improvement in the study area. Hence, intra-row spacing and nitrogen fertilizer levels are among the key agronomic practices which affect yield and quality of onion bulbs.

A field experiment was carried out at Axum Agricultural Research Center during the 2014/15 cropping season with the objectives of to assess the effect of intra-row spacing and nitrogen fertilizer level on growth, yield and quality of onion and to identify the appropriate intra-row spacing and nitrogen fertilizer rate that improves yield and quality of onion. A factorial randomized complete block design with 4 x 5 combinations in which four levels of nitrogen fertilizer (0, 41, 82 and 123 kg $ha^{-1}$) which results in 0, 89, 178, 267 kg Urea $ha^{-1}$, respectively and with five levels of intra-row spacing (2.5, 5, 7.5 10 and 12.5 cm), which resulted in 1333333, 666667, 444444, 333333, 266667 plants $ha^{-1}$, respectively) was used with three replications.

The analysis of variance showed that leaf number per plant, leaf length, leaf diameter, shoot dry matter per plant, dry total biomass yield, days to maturity, bolting percentage, average bulb weight, bulb diameter, bulb neck diameter, bulb dry matter per plant, marketable bulb yield, unmarketable bulb yield, total bulb yield, small-sized bulb, medium-sized bulb, large-sized bulb, over-sized bulb, under-sized bulb yield, harvest index and total soluble solid were significantly influenced by the interaction effect of intra-row spacing and nitrogen fertilizer rates. However, plant height and stand count percentage had significantly affected due to the main effects of intra-row spacing and different rates of nitrogen fertilizer.

From this study, significantly taller plant height was obtained at the intra-row spacing of 7.5 cm and 82 kg $ha^{-1}$ nitrogen fertilizer rate. Likewise, higher leaf number per plant, leaf diameter, shoot dry matter per plant, and dry total biomass were recorded in the treatment combination of 12.5 cm intra-row spacing and 123 kg $ha^{-1}$ nitrogen rate. Significantly, maximum value of leaf length was produced in onion plants treated with nitrogen at the rates of 82 and 123 kg $ha^{-1}$ and spaced at 5.0, 7.5, 10.0, and 12.5 cm of intra-row spacing. However, significantly, higher bolting percentage was recorded for plants grown at nil rates of nitrogen fertilizer and intra-row spacing of 2.5 and 5.0 cm. Plants grown at the higher rates of nitrogen application (123 kg and 82 kg $ha^{-1}$) and the wider intra-row spacing (12.5 cm) were required higher number of days to mature the onion plants. Moreover, the stand count percentage was significantly increased with increasing intra-row spacing from 2.5 cm to 12.5 cm and nitrogen fertilizer rates from 0 kg $ha^{-1}$ up to 82 kg $ha^{-1}$.

The highest average bulb weight and bulb diameter were produced at treatment combinations of the widest intra-row spacing and the highest rate of nitrogen. Bulb neck diameter and bulb dry matter per plant was higher at plants treated with both nitrogen rate of 82 kg $ha^{-1}$ and 123 kg $ha^{-1}$ and planted at the intra-row spacing of 12.5 cm. Increasing nitrogen rate of application across the increasing intra-row spacing marketable bulb yield and total bulb yield were markedly increased up to the nitrogen rate of 82 kg $ha^{-1}$ and 5.0 cm intra-row spacing beyond which it declines. Thus, the highest marketable bulb yield and total bulb yield were produced at treatment combinations of 5.0 cm intra-row spacing along with nitrogen fertilizer application of 82 kg $ha^{-1}$. Likewise, the highest medium-sized bulb, and large-sized bulb yield were obtained at 82 kg N $ha^{-1}$ application when onion plants were spaced at 5.0 cm and 7.5 cm intra-row spacing, respectively. However, significantly the highest value of unmarketable bulb yield was produced in response to the application of nil nitrogen rate and 2.5 cm of intra-row spacing.

Response to increasing nitrogen rate across increasing intra-row spacing significantly decreased the yield of small-sized bulb yield, and under-sized bulb yield. The highest yields of these parameters were achieved in treatment combination of the narrowest intra-row spacing and nil nitrogen application. However, increasing in nitrogen rate across increasing intra-row spacing significantly increased in oversized bulb yield. Hence, the highest oversized bulb yield was recorded in 123 kg N $ha^{-1}$ application and 12.5 cm intra-row spacing. Onion plants that received 123 kg N $ha^{-1}$ at the intra-row spacing of 5.0 cm and nitrogen rate of 82 kg $ha^{-1}$ intra-row spacing of 5.0 cm and 7.5 cm had the maximum harvest indices. Total soluble solids were achieved significantly higher in response to higher nitrogen dose of both 82 kg $ha^{-1}$ and 123 kg $ha^{-1}$ and at the narrowest narrow intra-row spacing of 2.5 cm.

The partial budget analysis revealed, the highest net benefit of Birr 168550 with higher cost (9245 Birr) was recorded from the combination of response to nitrogen rate of 82 kg $ha^{-1}$ and 5 cm intra-row spacing with marginal rate of 696%. However, the highest net benefit of Birr 133087 with least cost of production about Birr 6413 were obtained from the treatment interaction of 82 kg N $ha^{-1}$ and 10 cm of intra row spacing with MRR of (14372%).

Therefore, the most economically attractive combinations for small scale farmers with low cost of production and higher benefits were application of 82 kg N $ha^{-1}$ and 10 cm of intra row spacing in the study area. However, for growers who have full resources (investors), application of 82 kg N $ha^{-1}$ spaced at 5.0 cm intra row-spacing was also profitable with higher cost of production and highest net benefit is recommended as a second option. However, as the experiment was done for only one season and single location, it has to be repeated over seasons and locations to make a conclusive recommendation.

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# 7. APPENDICES

Appendix Table 1. Mean squares of analysis of variance for leaf length (LL), leaf diameter (LD), plant height (PH), leaf number per plant (LN), bolting percentage (BP) and stand count percentage (SCP)

| Source of variation | Degree of Freedom | Mean square values | | | | | |
|---|---|---|---|---|---|---|---|
| | | LL | LD | LN | PH | SCP | BP |
| Replication | 2 | 2.81 | 0.0002 | 0.069 | 2.28 | 1.93 | 11.46 |
| N level | 3 | 158.07** | 0.551** | 29.54** | 383.18** | 10.26** | 719.42** |
| Spacing | 4 | 79.97** | 0.434** | 21.75** | 109.41** | 785.64** | 416.62** |
| Spacing*N | 12 | 16.46** | 0.010** | 1.30** | 3.60ns | 1.33ns | 15.12** |
| Error | 38 | 1.79 | 0.001 | 0.338 | 8.84 | 0.700 | 2.46 |
| CV (%) | | 4.38 | 3.31 | 6.62 | 6.98 | 0.93 | 9.93 |

ns=non-significant, * and ** indicates significant difference at probability levels of 5% and 1%, respectively

Appendix Table 2. Mean squares of analysis of variance for yield and yield related traits of onion

| Source of Variation | Degree of Freedom | Mean square values | | | | | |
|---|---|---|---|---|---|---|---|
| | | ABW | ND | BD | UBY | MBY | TBY |
| Replication | 2 | 15.73 | 0.001 | 0.009 | 0.006 | 0.289 | 0.226 |
| N level | 3 | 9918.18** | 0.53** | 11.28** | 4.39** | 443.31** | 364.32** |
| Spacing | 4 | 2844.77** | 0.20** | 7.58** | 3.76** | 200.12** | 184.69** |
| Spacing*N | 12 | 177.19** | 0.01** | 0.189** | 0.31** | 27.31** | 28.45** |
| Error | 38 | 13.03 | 0.001 | 0.013 | 0.004 | 0.451 | 0.453 |
| CV (%) | | 5.66 | 3.97 | 2.60 | 10.00 | 2.61 | 2.55 |

* and ** indicates significant difference at probability levels of 5% and 1%, respectively , ABW = Average bulb weight; BD = Bulb diameter; TBY = Total bulb yield; ND = Neck diameter; MBY = Marketable bulb yield;  UBY = Unmarketable bulb yield

Appendix Table 3. Mean squares of analysis of variance for marketable and unmarketable size distribution of onion

| Source of Variation | Degree of Freedom | Mean square values | | | | |
|---|---|---|---|---|---|---|
| | | SSB | MSB | LSB | OSB | USB |
| Replication | 2 | 0.013 | 0.237 | 0.012 | 0.005 | 0.004 |
| N level | 3 | 106.63** | 432.63** | 103.63** | 9.96** | 2.41** |
| Spacing | 4 | 135.91** | 192.79** | 38.82** | 4.84** | 2.98** |
| Spacing*N | 12 | 1.55** | 20.90** | 7.01** | 1.09** | 0.37** |
| Error | 38 | 0.256 | 0.324 | 0.072 | 0.007 | 0.002 |
| CV (%) | | 8.63 | 3.59 | 6.69 | 9.61 | 10.35 |

* and ** shows significant difference at probability levels of 5% and 1%, respectively, SSB = Small sized bulb, MSB = Medium sized bulb, LSB = Large sized bulb, OSB = Oversized bulb and USB = Under sized bulb

Appendix Table 4. Mean squares of analysis of variance for Shoot dry matter per plant (SDMY), Harvest index (HI), Dry total biomass (DTB), Total soluble solids (TSS), Days to maturity (DTM) and Bulb dry matter yield per plant (BDMY)

| Source of variation | Degree of Freedom | Mean square values | | | | | |
|---|---|---|---|---|---|---|---|
| | | SDMY | BDMY | DTB | TSS | DTM | HI |
| Replication | 2 | 0.002 | 0.009 | 0.007 | 0.01 | 2.40 | 0.88 |
| N level | 3 | 4.48** | 69.18** | 108.72** | 5.61** | 731.12** | 40.98** |
| Spacing | 4 | 4.76** | 44.02** | 77.37** | 12.04** | 296.56** | 8.36** |
| Spacing*N | 12 | 0.24** | 2.64** | 4.32** | 0.13** | 14.89** | 3.38** |
| Error | 38 | 0.006 | 0.028 | 0.043 | 0.028 | 4.33 | 0.93 |
| CV (%) | | 4.27 | 3.00 | 2.85 | 1.43 | 1.86 | 1.27 |

* and ** indicates significant difference at probability levels of 5% and 1%, respectively

Appendix 5. Simple correlation between yield, yield components and growth characters

| Variables | SBS | MBS | LBS | MY | UMY | TY | OBS | USB | BP | SCP | LN | PH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SBS | 1.00 | | | | | | | | | | | |
| MBS | -0.67** | 1.00 | | | | | | | | | | |
| LBS | -0.85** | 0.80** | 1.00 | | | | | | | | | |
| MY | -0.45** | 0.95** | 0.74** | 1.00 | | | | | | | | |
| UMY | 0.89** | -0.76** | -0.75** | -0.56** | 1.00 | | | | | | | |
| TY | -0.37** | 0.91** | 0.70** | 0.99** | -0.46** | 1.00 | | | | | | |
| OBS | -0.74** | 0.36** | 0.71** | 0.24ns | -0.57** | 0.19ns | 1.00 | | | | | |
| USB | 0.85** | -0.72** | -0.66** | -0.50** | 0.98** | -0.41** | -0.50** | 1.00 | | | | |
| BP | 0.88** | -0.59** | -0.81** | -0.43** | 0.79** | -0.36** | -0.78** | 0.74** | 1.00 | | | |
| SCP | -0.82* | 0.29* | 0.54** | 0.06ns | -0.67** | -0.03ns | 0.56** | -0.66** | -0.65** | 1.00 | | |
| LN | -0.88** | 0.66** | 0.88** | 0.53** | -0.78** | 0.47** | 0.84** | -0.72** | -0.81** | 0.69** | 1.00 | |
| PH | -0.81** | 0.69** | 0.79** | 0.56** | -0.79** | 0.50** | 0.72** | -0.73** | -0.80** | 0.52** | 0.84** | 1.00 |
| LL | -0.82** | 0.62** | 0.76** | 0.47** | -0.82** | 0.40** | 0.63** | -0.75** | -0.81** | 0.55** | 0.75** | 0.81** |
| LD | -0.93** | 0.61** | 0.87** | 0.45** | -0.84** | 0.37** | 0.87** | -0.77** | -0.88** | 0.75** | 0.94** | 0.84** |
| BD | -0.93** | 0.64** | 0.87** | 0.47** | -0.85** | 0.40** | 0.82** | -0.78** | -0.91** | 0.74** | 0.91** | 0.84** |
| ND | -0.86** | 0.59** | 0.85** | 0.46** | -0.75** | 0.40** | 0.88** | -0.68** | -0.88** | 0.60** | 0.89** | 0.86** |
| ABW | -0.85** | 0.63** | 0.86** | 0.50** | -0.76** | 0.44** | 0.91** | -0.68** | -0.88** | 0.58** | 0.91** | 0.86* |
| BDW | -0.92** | 0.68** | 0.93** | 0.55** | -0.77** | 0.49** | 0.86** | -0.70** | -0.88** | 0.71** | 0.94** | 0.84** |
| DTM | -0.88** | 0.58** | 0.84** | 0.43** | -0.77** | 0.36** | 0.88** | -0.70** | -0.88** | 0.63** | 0.85** | 0.83** |
| SDW | -0.90** | 0.54** | 0.86** | 0.39** | -0.74** | 0.32* | 0.89** | -0.67** | -0.88** | 0.78** | 0.92** | 0.80** |
| HI | -0.48** | 0.83** | 0.69** | 0.84** | -0.55** | 0.83** | 0.27* | -0.47** | -0.43** | 0.04ns | 0.51** | 0.56** |
| DTB | -0.92** | 0.65** | 0.92** | 0.52** | -0.77** | 0.46** | 0.88** | -0.69** | -0.89** | 0.73** | 0.94** | 0.83** |
| TSS | 0.34** | 0.26* | 0.02ns | 0.46** | 0.1ns | 0.51** | -0.14ns | 0.20ns | 0.14ns | -0.77** | -0.19ns | 0.002ns |

*, ** and ns indicates that significant, highly significant and non-significant difference at probability levels of 5% and 1%, respectively and SBS, MBS, LBS, MY, UMY, TY, OBS, USB, BP, SCP, LN and PH= Small sized bulb, Medium Sized bulb, Large sized bulb, Marketable yield, Unmarketable yield, Total yield, Oversized yield, Under sized yield, Bolting percentage, Stand count percentage, leaf number per plant and Plant height respectively.

Appendix 5. Simple correlations (*CONTINUED*)

| Variables | LL | LD | BD | ND | ABW | BDW | DTM | SDW | HI | DTB | TSS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LL | 1.00 | | | | | | | | | | |
| LD | 0.83** | 1.00 | | | | | | | | | |
| BD | 0.83** | 0.97** | 1.00 | | | | | | | | |
| ND | 0.79** | 0.93** | 0.92* | 1.00 | | | | | | | |
| ABW | 0.79* | 0.95** | 0.94** | 0.95** | 1.00 | | | | | | |
| BDW | 0.77** | 0.96** | 0.94** | 0.94** | 0.94** | 1.00 | | | | | |
| DTM | 0.79** | 0.92** | 0.91** | 0.92** | 0.92** | 0.91** | 1.00 | | | | |
| SDW | 0.73** | 0.96** | 0.94** | 0.93** | 0.93** | 0.98** | 0.90** | 1.00 | | | |
| HI | 0.53** | 0.45** | 0.48** | 0.50** | 0.50** | 0.53** | 0.44** | 0.34** | 1.00 | | |
| DTB | 0.76** | 0.97** | 0.95** | 0.94** | 0.94** | 0.99** | 0.91** | 0.99** | 0.49** | 1.00 | |
| TSS | -0.07ns | -0.25ns | -0.21ns | -0.08ns | -0.02ns | -0.18ns | -0.11ns | -0.31* | 0.40** | -0.21* | 1.00 |

LL, LD, BD, ND, ABW, BDW, DTM, SDW, HI, DTB ant TSS= Leaf length, Leaf diameter, Bulb diameter, Neck diameter, Average bulb weight, Bulb dry weight, Days to maturity, Shoot dry weight, Harvest index, Dry total biomass and Total soluble solids respectively