INFLUENCE OF BULB TOPPING AND INTRA ROW SPACING ON YIELD AND YIELD COMPONENTS OF SOME SHALLOT *(Allium cepa* var. Aggregatum*)* VARIETIES AT ANEDED WOREDA, WESTERN AMHARA

M.Sc. Thesis

DEREJE ADEME

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Jimma University

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A Thesis Submitted to the College of Agriculture and Veterinary Medicine, Department of Horticulture and Plant Science, School of Graduate Studies
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In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN HORTICULTURE (VEGETABLE SCIENCE)

By

Dereje Ademe

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SCHOOL OF GRADUATE STUDIES

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As thesis research advisor, I here by certify that I have read and evaluated this thesis prepared, under my guidance, by Dereje Ademe, entitled “Influence of Bulb Topping and Intra Row Spacing on Yield and Yield Components of Shallot (*Allium cepa* var. Aggregatum) Varieties at Aneded Woreda, Western Amhara.” I recommend that it be submitted as fulfilling thesis requirement.

Derbew Belew (Ph.D) ---------------------

Major Advisor Signature

Getachew Tabor (Ph.D) ---------------------

Co-advisor Signature

As member of the Board of Examiners of the M.Sc. Thesis Open Defense Examination, We certify that we have read and evaluated the Thesis prepared by Dereje Ademe and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Horticulture.

Taye Kufa (PhD) ---------------------

Chairperson Signature

Ali Mohammed (PhD) ---------------------

Internal Examiner Signature

Kebede Woldetsadik (PhD) ---------------------

External Examiner Signature

DEDICATION

I dedicate this thesis manuscript to my best friend Nigatie Alemayehu

STATEMENT OF AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of material used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfilment of the requirements of MSc. degree at Jimma University and is deposited at the University Library to be made available to users under rules of the Library. I declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Name: Dereje Ademe Birhan Signature: ……………………

Place: Jimma University

Date of Submission: ---------------.

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BIOGRAPHICAL SKETCH

The author, Dereje Ademe was born in Sekela Woreda, West Gojam zone of the Amhara National Regional State on August 22, 1979. He attended his elementary and junior school education in the same district and later attended his High-school education at Shekudad Senior secondary school. After completion of his high school education, he joined Debub University, Awassa College of Agriculture and graduated with a Bachelor of Science degree in plant science in 2003.

After completion of the undergraduate degree, he served at the Agricultural Technical and Vocational Education Training College for more than one year and the Amhara National Regional Bureau of Agriculture for four years and joined Jimma University College of Agriculture and Veterinary Medicine to attend his post graduate study in 2008/09.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AVRDC	Asian Vegetable Research and Development Center
BoA	Bureau of Agriculture
CSA	Central Statistical Authority
DZARC	Debre Zeit Agricultural Research Centre
EIAR	Ethiopian Institute of Agricultural Research
LAI	leaf area index
LSD	Least significant difference
RCBD	Randomized Complete Block Design
RH	Relative Humidity
SAS	Statistical analysis software

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BY

DEREJE ADEME (BSC IN PLANT SCIENCE)

ADVISORS: DERBEW BELEW (PHD), JIMMA UNIVERSITY

GETACHEW TABOR (PHD), DZARC

ABSTRACT

Lack of improved varieties and production practices have been the major bottlenecks of shallot production and productivity in western Amhara. Practices such as bulb topping have been traditionally practiced among shallot growers in the region though the merits and demerits of the practice remained controversial among producers and agricultural experts worldwide. Moreover, there was no recommended plant spacing for the crop in the study area and farmers used to practice non uniform plant spacing. Thus, a field experiment was conducted to investigate the influence of intra-row spacing, variety, bulb topping and their interactions on yield, yield components, and bulb quality of shallot and thereby to recommend the optimum practices to farmers in the study area. The study was undertaken between December 2009 and May 2010 at Gudalima nursery site, Aneded Woreda. Three different intra-row spacings (10, 15 and 20 cm) and two bulb treatments (whole and topped at one-third of bulb height) were evaluated using four varieties of shallot ('local', 'Negelle', 'Huruta' and 'Minjar') using RCBD replicated three times. Data on growth, yield, quality and disease reaction parameters were recorded and subjected to ANOVA using SAS 9.2 software. The results of the study showed significant interaction effects between intra-row spacing and variety on leaf number and diameter, bulb diameter and shape index. As a result, Local and 'Negelle' planted at 20 cm intra-row spacing produced the highest leaf number and leaf diameter, respectively. 'Huruta' planted at 20 cm intra-row spacing produced the highest bulb diameter and the lowest bulb shape index. Significant interactions were also obtained between variety and bulb topping for plant height, leaf number and length, and bulb dry weight. The combined effect of intra-row spacing and bulb topping were also significant for leaf length and bulb length. In addition, the combined effect of variety, intra-row spacing and bulb topping were significant for shoot number, number of total, marketable and unmarketable bulbs, bulb fresh weight, biological yield and harvest index, total, marketable, and unmarketable yield per ha, total soluble solid and disease incidence. Topped bulbs of 'Huruta' planted at 20 cm and 'Minjar' planted at 10 cm intra-row spacings produced the highest and the lowest bulb weight per plant respectively. Topped bulbs of Huruta and Negelle planted at 20 cm intra-row spacing produced the highest marketable yield per ha. Using the topped bulbs of 'Huruta' and 'Negelle' at wider intra-row spacing positively influenced the majority of yield and quality parameters evaluated. Thus, it is advisable to use the wider intra-row spacing (20 cm) and topped bulbs for better production of marketable yield with desirable bulb shape index while Local variety advisable for high dry matter content, total soluble solid and better bulb skin color. However, production of 'Minjar' is not advisable in areas having similar conditions with the study area because of its high bolting and the consequent reduction in yield. However, further investigations should be made to come up with complete recommendations.

1. INTRODUCTION

Shallot *(Allium cepa* L. Aggregatum group; Robinowitch and Kamenetesky, 2002) is a perennial plant produced as annual and produces several bulbs from a single parent bulb (Tindall, 1983; Splittstoesser, 1990; Smartt and Simmonds, 1995). It is thought to be originated in western Asia where it has been cultivated since very early period. It is being cultivated in Tropical Asia, West Africa, Central and East Africa, Tropical South America and the Caribbean.

On a global base, shallot is a minor alliaceous crop. However, in areas where onion seed is hard to produce, or onion production is difficult and the growing season is too short for the production of bulb onion, the vegetatively propagated shallot is cultivated as an important substitute for bulb onion in Southeast Asia, as well as in some African countries including Ethiopia (Robinowitch and Kamenetesky, 2002; Thomas, 2008). Shallot is widely produced in high- and mid- altitudes of Ethiopia and mainly used as condiment (Getachew and Asfaw, 2000; Getachew *et al.*, 2009). According to CSA (2008), 18003 ha of land was covered with shallot and a total yield of 175,106 tones was produced in 2007/08 cropping season. According to BoARD (2002), shallot is among the major cash crops produced in Amhara region including the study area, East Gojjam Zone. However, production and productivity has been limited due to its propagation using vegetative bulbs, absence of improved varieties, lack of improved production and protection technologies, high post-harvest losses, and absence of vibrant market system that encourages producers ((Robinowitch and Kamenetesky, 2002; Getachew *et al.*, 2009).

Shallot bulbs are more flavoured than the single hearted bulb onion (Robinowitch and Kamenetesky, 2002). Due to their high pungency; a raw shallot bulb has a more pronounced taste than an onion. When a shallot is fry in small amount of fat, the sugars caramelized and give a sweeter taste than onion. Shallots contain water, protein, fat, carbohydrate, minerals, and vitamins. Regular consumption of shallots reduces cholesterol and fat content of the blood and improves the blood circulation. The very high concentration of flavonoids present in shallots reduces the risk of cardio-vascular diseases, and they used to cure earache and fevers and are helpful in; allaying intestinal gas pains, reducing hypertension and high blood sugar, and relieving pain and inflammation (Tindall, 1983; Maynard and Hochmuth, 2007; Schellman, 2007; Thomas, 2008).

Shallot is planted as topped and whole bulb in different parts of the world. Rashid and Singh (2000) and Robinowitch and Kamenetesky (2002) reported that the growing portion of the bulb is topped one-fourth to one-third of the height for easy and quickly sprouting of more growing buds. Yoo and Pike (1995) cited in Gubb and MacTavish (2002) pointed out that cutting off the tops of bulbs to encourage sprouting for onion seed production is a well-known practice and in a trial conducted in Texas, onion bulbs with the top halves removed sprouted immediately after harvest. Peter (2006) also reported that during shallot planting bulbs are topped to break bud dormancy and enhance uniform sprouting. Godfrey-Sam-Agrey *et al.* (1987) reported that topped bulbs emerge four to five days earlier than whole bulbs. However, Sharma *et al.* (2008) reported that planting of whole onion bulbs produced significantly higher bulb yield (1.57 t per ha more) than one-third topped bulbs. Getachew and Asfaw (2000) also reported that topped medium sized bulbs established significantly lower crop stand and less fresh bulb yield than whole bulbs of the same and large-sized bulbs and attributed to reduced initial food reserve and predisposal of the bulbs to fungal diseases and other decaying organisms. The authors, however, suggested that bulb topping could be practiced under conditions where bulb diseases are not problems. Despite the aforementioned research results, farmers in the study area have been practicing topping as one of the indispensable production practices. Thus, there is a need to investigate the contradictory research results and the practice of the farming community in order to recommend the practice for use in major shallot producing areas of the region.

Moreover, the optimum intra-row spacing is not yet established for Western Amhara. Williams *et al.* (1991) and Tindall (1983) reported that shallots are commonly planted at intra-row spacings between 12 to 15 cm. Devi and Anal (2008) recommended 10 cm as optimum intra-row spacing for shallot for higher marketable yield. Bodnar *(*2010) also reported shallots planted at 15-20 cm between the bulbs gave highest marketable yield. Thus, internationally, optimum intra-row spacing for shallot is contentious and is dependent on the experience of the production areas. There is no recommended plant spacing for shallot in the study area and farmers traditionally practice non-uniform plant spacing to establish shallots. Extension Agents also counsel farmers to use the spacing recommended for onion (40 x 20 x 10 cm) (BoARD, 2002) despite the fact that shallots produce multiple bulbs per plant unlike a single hearted bulb onion and thus need totally different intra-row spacing. Moreover, spacing is also determined by variety, agro-ecology, soil type, crop management practices, severity or occurrence of diseases and insect pests.

In addition to the lack of clear information on bulb treatment (topped vs whole bulbs) and intra-row spacing, absence of improved shallot varieties in the region has been a bottleneck to its production and productivity. Hence, the objective of the present study was to investigate the effects of bulb topping, intra-row spacing and their interaction on yield and yield components of some shallot varieties in Aneded Woreda, Western Amhara.

2. LITERATURE REVIEW

2.1. The Shallot Crop

Shallots and other members of onion family (Alliaceae) are native to central Asia and drive their characteristic flavor from the enzyme alliinase that acts on sulfur compounds (Delahaut and Newenhouse, 2003). All plants in the family are herbaceous, cool season, biennial vegetables that are grown as annuals commonly for fresh market gardens. They have fibrous shallow root system with all roots arising from a basal plate, including a few lateral roots. Their fleshy basal leaves are tubular or slightly flattened on upper surface, 7-20 mm width and up to 40 cm long. Shallot has individual flowers born in spherical umbels comprised of more than one thousand flowers which produce globular fruit capsules that contain many seeds which are black, wrinkled at maturity. Its bulbs are variable in size, shape and color, covered with thin red scale leaves and formed from enlarged leaf bases called scales. Shallots are uniquely flavoured, more delicate, often used in preparing gourmet dishes and are expensive to buy even though they are very easy to grow (Tindall, 1983; Delahaut and Newenhouse, 2003).

Shallot characterized with producing a cluster of small pointed and distinct bulbs from a single planted bulb, differs from common onions and propagates almost exclusively by bulbs (Brewster, 2008). Hanelt (1990) subdivide the large *Allium cepa* species into two groups namely, common onion (synonyms: *A. cepa* L. var. *cepa; A. cepa* L. spp. *cepa* and spp. *australe* Trofim.) and Aggregatum group (synonyms: *A. ascalonicum* auct. Non strand; *A. cepa* spp. orientale kazak.; *A. cepa* var. *ascalonicum* Baker). Messiaen *et al.* (1993) named the shallot *A. cepa* var. *aggregatum* (Robinowitch and Kamenetesky, 2002). However, Robinowitch and Kamenetesky (2002) explained that the fertile shallot intercrosses freely with bulb onion to produce fertile offspring and the two plants exhibit a strong cytological and morphological resemblance. Hence it is proposed that both plants belong to one botanical species, *A. cepa* and therefore, they prefer to name the shallot *A. cepa* L. Aggregatum group. The shallot distinguished from green onions, scallions and leeks by its distinctive bulbs which are made up of cloves and the individual bulbs are not encircled together by a common membrane unlike garlic (Bodnar, 2010).

Morphologically, a shallot bulb is very similar to the bulb of the common onion. A mature bulb consists of a compressed stem axis or basal plate, storage leaf base of the outer leaves, which have lost their blades and bladeless ‘true scales’. In the center of each bulb, there are a few leaf buds which under favorable conditions sprout when dormancy ends. Shallot flowers are radially symmetrical and are perfect (Robinowitch and Kamenetesky, 2002; Delahaut and Newenhouse, 2003). In Ethiopia, the local shallot is the most widely grown allium species and is much favored for its pungency in cooking (Williams *et al.*, 1991; Getachew and Asfaw, 2000).

2.2. Factors Affecting Shallot Growth, Yield and Quality

Growth, yield and quality are complex characters which depend on genetic makeup and are influenced by environmental factors. Variety and growing conditions are the major factors that determine the performance of a crop. Appropriate management practices can alter natural conditions to make them more favourable for crop productivity which are changing considerably in recent years (AVRDC, 1990). This is partly due to changes in varietal characteristics as a result of plant breeding and many improved practices, which are still being developed. A good understanding of principles and the theoretical bases of current growing practices should help growers in deciding the most appropriate management practices for their conditions (AVRDC, 1990). Generally, environmental conditions, variety, population density and other cultural practices like bulb topping influence the growth, yield and quality of shallot (Getachew and Asfaw, 2000; BoARD, 2002; Fasika *et al*., 2008; Sharma *et al*., 2008).

2.2.1. Environmental and soil factors

Environmental conditions such as temperature, soil pH and moisture extremes affect pungency along with characteristics of the specific cultivar. Environmental conditions can also affect foliage size and color, bulb formation and size, bulb splitting, scale color and thickness, seed stalk formation, and storage quality (Delahaut and Newenhouse, 2003).

2.2.1.1. Temperature and light

Shallots are very tolerant to high temperature up to 30^0C and relatively high temperature encourages bulb development in most cultivars. Bulbs are not formed at temperatures lower than 20^0C. Shallots rarely produce flowers at high temperatures and in short conditions. Yields are liable to reduce during heavy rainfall due to the incidence of disease. A dry period is required for ripening of mature bulbs and drying of laves. Most cultivars grow well in altitudes varying from sea level to 2500 meters above sea level. Large bulbs are formed in day lengths of 12 hours than of 10 hours. Although the shallot can be regarded as requiring long days for maximum bulb development, most tropical cultivars will form bulbs of an adequate size in relatively short day lengths (Tindall, 1983). A combination of day length and temperature triggers bulb formation. High temperature favor bulbing once a critical day length has been reached. Since yield is determined by the number of leaves present at bulb initiation, early planting ensures the maximum number of leaves and the largest bulbs. When temperatures fall below 10^oc, stems begin to elongate and flowering will occur. Long days alone will not induce flowering, but will speedup stem elongation (Delahaut and Newenhouse, 2003). Storage temperature is the main factor that influences storage life of shallot. Bulb onions and most shallots store well at low (0 °C) and high (roughly 25–30 °C) temperatures (peter, 2006).

2.2.1.2. Soil conditions

Soil type strongly influenced the bulb quality in terms of shape, firmness, skin color, and dry matter content alluvial soil is being the most suitable (Vetayasuporn, 2006). According to the author low soil organic matter and biological activity are major constraints of shallot production. Shallot is tolerant to a wide range of soils with a pH of 6.0 to 7.0. Loose, sandy soils with a high level of organic content are preferable, although silt-clay loams are often used. Bulb size and the number of cloves formed can often be increased by additional application of nitrogen and potash after planting. All members of the onion family grow best in light loam that is rich in organic matter and plant nutrients. The smaller onions like shallots yield reasonably well under many conditions, just so long as the soil is well-fertilized, well-drained and kept moist. However, waterlogged soil will make the bulbs rot or adversely affect their appearance and quality. In infertile soil the bulbs will be very small. Shallots like a rich, loose soil; mix plenty of compost, decomposed manure or other organic matter into bed before planting (Virginia Cooperative Extension, 2009). Shallots respond particularly to potash and phosphate fertilizers but soils should also be well supplied with organic material before planting. Application of excess nitrogen may lead to delayed bulb formation (Tindall, 1983). However, Kebede and Workneh (2010) reported that increasing nitrogen levels showed proportional increase in the bulb pungency levels but did not impact significantly the dry matter, total soluble solids, total sugars and reducing sugars of shallot bulbs. They explained that an increased level of pyruvate with nitrogen application could be partly by greater synthesis and accumulation of sulphur containing amino acids that are precursors of flavor compounds and pyruvate.

2.2.1.3. Moisture stress

Droughts may lead to plant water stress and growth may be impacted. Periods of even short drought stress can reduce crop growth and yields. The plant may adjust to short-term water stress by closing stomates and thereby reducing water loss through the leaves. When stomates are closed, the plant wilts, carbon dioxide from the atmosphere cannot enter the leaf photosynthesis is reduced or stopped. Growth will be slowed if such conditions are not corrected (Decoteau, 1998). Watering is very critical during the vegetative and bulb formation stages of shallot growth. The plants must be watered twice daily especially during the dry weather. Watering frequency is reduced once the bulb is near to maturity. Shallots need consistent watering to support their shallow root systems and require more frequent watering than do onions (Williams *et al*, 1991). The occurrence of early stage water stress reduced the formation of lateral branches, while mid-stage stress may affect both bulb numbers and bulb weights (Woldetsadik, 2003). Kebede *et al.* (2004) also reported that early and mid-growth stage stresses could reduce plant height, leaf number and bulb number of the field grown plants. The authors further explained mean bulb weight was reduced by about 20% as a result of the early and mid-growth stage stresses while late stage stress tended to increase mean bulb weight. The yield reduction amounted to 42% and 26% in the pot, and 46% and 52% in the field-grown plants due to early and mid growth stage stresses, respectively. When shallots planted during the dry season, proper irrigation water application is essential to ensure desired growth, yield and quality. Application of mulch and cover is essential for reduction of drought effects as mulch help to conserve moisture loss because of evaporation. Woldetsadik (2003) reported that black plastic mulch increased shallot yield three-fold in the short season and by one fourth in the main season compared to the bare ground treatment.

Watering has to be stopped completely one week prior to harvesting to avoid accumulation of water in the skin which will lead to easily deterioration of the bulbs *(*Relf and Daniel, 2009). Suitable environment for Shallot production in Ethiopia is the area which is situated in an altitude of 1800 to 2200 m. a.s.l, a temperature range of 15 to 30^{o}C, a soil with a pH of 6.0 to 7.0 and an annual rainfall of 600 to 700 mm (Getachew *et al.*, 2009).

2.2.2. Cultural practices

2.2.2.1. Planting time

Three shallot crops are grown a year, the major seasons being April to August, January to March, and September to December (Currah and Proctor, 1990). A few plantings are made in August, although the bulk of the crop is planted during October with little planting until January. Therefore, shallot can be cultivated under rain fed, supplemental irrigation or full irrigated conditions (Ali and Marta, 2007) and thus time of planting is not dependent on climatic conditions. However, cultivation of shallot during heavy rainy condition may result in the reduction of growth, yield and quality of shallot because of the prevalence of high downy mildew, difficulty of proper harvesting and curing and reduction of the color and pungency of the crop due to high moisture in the bulbs. A study conducted to see the effect of planting time on onion growth, yield and yield components at Rajshahi University revealed that onion planted at October 30 resulted in higher plant height, leaf number, bulb length and diameter, bulb weight per plant and bulb yield per ha than bulbs planted at November 15 and November

30 (UD-Deen, 2008). Therefore, selection of proper time of planting had a marked effect on shallot yield and quality.

2.2.2.2. Irrigation amount and method

Irrigation methods and water amount affect growth and yield of shallot. A study done on four different water application methods in Ghana viz., flooded, regular watering, and watering up to half and quarter the field capacity of the root medium showed that flooded shallots recorded the highest growth rate, leaf area, and green leaf number *(*Abbey and Fordham, 1998). They further explained that regularly watered and flooded shallots had the highest relative water contents of leaf tissue. The highest harvest index and bulb yield were obtained in the regularly watered shallots. Water stress, thus, adversely affected shallot growth, maturation, and bulb yield under 12-h photoperiod.

2.2.2.3. Harvesting time

Proper harvesting is also crucial for better yield and quality of harvested bulbs. Prior to harvesting of shallot bulbs, plants must mature in dry soil by stopping watering at least one week prior to harvest. Time of harvesting is known to affect quality and storability of onion and shallots. Kebede and Workneh (2010) reported that increasing nitrogen application up to 100 kg N ha^{-1} and delaying harvest up to 100% top fall resulted in an increasing trend in fresh bulb yield compared to 50% top fall. Shallots are ready to harvest when the leaves start to wither. Harvesting should be done when the weather is dry and let them cure outside for a few days out of direct sunlight. Their skins have not hardened yet so it is important to avoid bruising or tearing the skin. The bulbs, with their tops still attached should be air-dried for few days until the tops have completely shriveled. Then cut the tops off with sharp scissors or pruning shears about 2.5 cm above the bulb, spread the bulbs out on wire racks in the shade or in a garage to cure for 2-3 months.

2.2.3. Disease, insect pests and weed

Loss of shallot yield from pests and diseases is common all over the world, and chemical treatment is the major means currently used to reduce damage. However, good agricultural practices that are essential for high-quality long-keeping yields include crop rotation, suitable irrigation methods like drip system (which is preferred over sprinkler irrigation to maintain low air humidity) that helps to reduce air RH, proper spacing to allow free circulation of air, so as to reduce the relative humidity of the air, proper harvesting and curing practices are among the suitable and environmentally friendly pest and disease control methods (peter, 2006).

Onion thrips (Thrips tabaci) are the major pest of shallots. Their attack leaves results dramatic reduction in foliage quality. Use Malathion to control thrips at 0.75 - 1.5 kg per ha or Fenitrothion at 0.1 - 0.5 kg per ha. Downy mildew (*Peronosphora destructor*) and Purple Blotch (*Alternaria porri*) are the major leaf diseases in shallot. These diseases can be controlled using Copper fungicide at 0.2% active ingredient for treating the downy milder and for the purple blotch, Maneb, Mencozeb or Zineb could be used. Bulb rot which is caused by *Fusarium oxysporum* is becoming the most destructive disease in shallot producing areas of Ethiopia. It can be aggravated by the use of infected seed and planting on contaminated soils and it can be controlled by applying proper sanitation and soaking the 100 kg bulb seeds with 300ml Berate special or 200gm benomyl 15%. Moreover, avoiding planting during the wet season may also reduce the occurrence of it (Getachew and Asfaw, 2000; Relf and Daniel, 2009).

Weeds severely compete with shallot for light, nutrients, water, and space. In addition to reducing harvestable bulbs through competition, weeds interfere with the harvesting process by decreasing hand and machine harvesting efficiency. Weeds can also harbor destructive insects and diseases that can severely damage the present or following crop. Therefore, weeding should be practiced in regular days particularly at the early stage of the crop. Hand weeding and hoeing are the most familiar ways of weed removal in our condition (BoARD, 2002). Shallot roots are shallow so cultivation must be carried out with care.

2.2.4. Variety

The growth, yield, and quality of a given plant are affected by the genetic makeup. Shallots yield, like that of other crops, is affected by varieties which vary in bulb skin color, pungency, size and number of bulbs, total yield and overall productivity. Growers and consumers have special preference for a specific variety against the above characters. Getachew and Asfaw (2000) observed that shallot cultivars in Ethiopia varied in days to maturity, fresh bulb weight and number of bulbs per plant, bolting nature, foliar characteristics, bulb shape and skin color. Fasika *et al*. (2008) also reported highly significant genetic differences among Ethiopian shallot genotypes for plant height, number of leaves per plant, bulb splits, bulb diameter, total yield, marketable yield, biological yield, harvest index, total soluble solids, bulb dry weight and pungency. Jilani and Ghaffoor (2003) also reported a significant variability among ten onion varieties in the number of leaves per plant, leaf length, bulb diameter, weight of single bulb, bolting percentage, bulb survival percentage, yield, leaf color, leaf erectness, leaf waxiness, bulb skin color and flavor rating.

These results is evident that varieties within a crop have genetic differences that affect yield, yield components and quality traits which influence the ultimate value of that particular crop. Therefore, unless detail assessment is done before deciding which variety is suitable for the desired production, the final profit may not be feasible because of reduced yield and quality. In Ethiopia, there are three released varieties; '*Minjar'*, '*Negelle'* and '*Huruta'* which were released in 2009, 2004 and 1999, respectively (Getachew *et al.*, 2009). The varieties were developed for different agro-ecological zones; however, these varieties are not familiarized in the study area and farmers use local varieties which are not uniform in color, maturity and are low yielder. According to Getachew *et al. (*2009), the local varieties being used by farmers are very low yielder (6 t/ha) as compared to the average yield obtained from improved varieties (25 t/ha) hence improved varieties have had a main role in the increases in yield and quality of vegetable crops (Prohens and Nuez, 2008), and therefore, there is a need to evaluate the three released varieties in the western Amhara condition where yield of the cultivars is often less than 6 t/ha.

2.2.5. Plant population

Competition occurs when two or more plants are growing in an environment and the combined demands of the plants exceed the supply of one or more of the limiting factors (water, soil nutrients, soil oxygen, carbon dioxide and light) for growth and development. Space is frequently referred to as a limiting factor but in reality embraces two or more of factors already listed (Soffe, 1995; Taiz and Zeiger, 2002; Winch, 2006). Competition occurs between plants of the same species and is termed as intra-specific competition. In extreme cases of crop plant growing in complete isolation, its individual yield gives an indication of the maximum yield possible per plant (Robinson, 2001). Burton (1989) observed a strong intra-raw competition with closely planted potato tubers and yields decreased due to mutual shading of leaves resulting in high leaf area index reducing the total radiation intercepted and net assimilation. The author justified that in close spacing individual plants suffer much from competition and the crop may be impaired and in too wide spacing; however, the yield per hectare may be reduced because of reduction in plant number and the plants become too large and/or woody for consumption, and weeds allow to develop aggressively in the open space between crop plants (Winch, 2006).

Competitive demands in the crops are not constant but change with time which may lead to alterations in the density of the unit of population. Increasing plant population can also lead to higher mortality rates within a crop (thinning response). Usually, in a highly competitive situation, plants located in an unfavorable position will be disadvantaged and may die. This could be considered to be a waste of seed but may be a necessary loss to achieve the desired plant population (Soffe, 1995). Generally, competition between plants will increase with increase in population, which in turn leads to decrease in individual yield per plant; however, yield per unit area (crop yield) will increase until the maximum potential is attained (Fig.1).

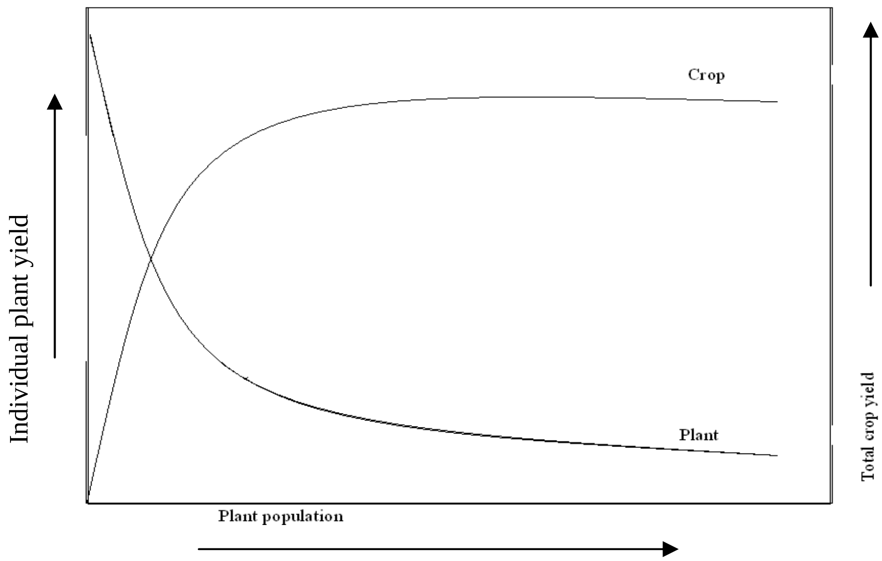

Fig. 1. Plant and crop yield in response to increasing plant population (source: Soffe, 1995)

This is because of an efficient light capturing and utilization ability of the crop canopy made by the community of plants (the crop) at higher populations despite each plant is not attaining its full potential production. As population increases, the yield response starts to diminish until the plateau is reached and no further response to plant population can be achieved (asymptotic response curve; Fig.2). In biological terms, the optimum plant population in such a case is a point where the plateau starts whereas in practice the optimum is lower than this when seed costs are taken into account. Often an asymptotic response curve is associated with total biomass production and crops grown for complete utilization of biological yield.

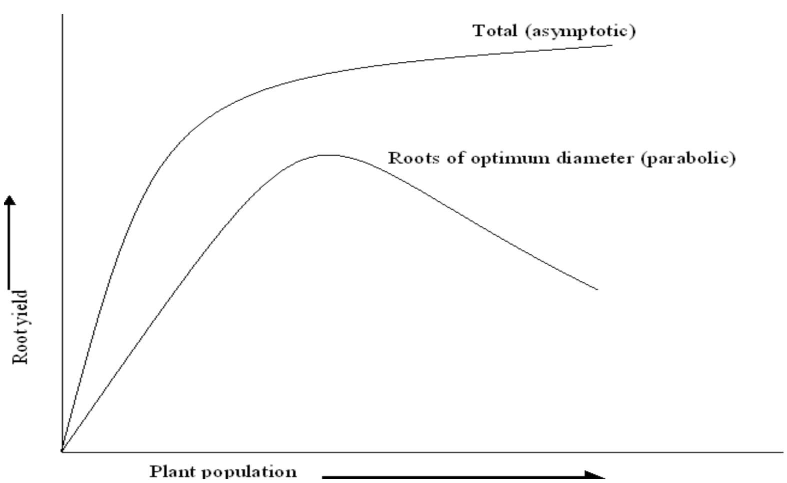

Fig.2. Response of root crops to increasing plant population (source: Soffe, 1995)

Plant density affects the partitioning of assimilates within the plant with high densities tending to lead to a greater vegetative component and a lower reproductive or storage component per plant. If the adverse effect of partitioning away from an economic portion is not out-weighed by the advantage of increased plants per unit area, then economic yield will decline beyond a certain point (parabolic response curve), and such response is associated with crops grown for economic yield (Soffe, 1995; Taiz and Zeiger, 2002).

When considering crops showing a parabolic yield response, obtaining the optimum plant population is very important. However, if a suboptimal population is established, then the compensatory growth may occur as individual plants can have a greater share of limiting resources. In crops with a high degree of compensatory growth, the parabolic curve becomes a wide flat topped response curve and the unit of population may not always be simple to define. For example in potatoes it is the stem population and in cereals the tiller population that is of the greatest value.

Optimum plant growth will be achieved when the leaves of crop plants cover the ground area as soon as possible after planting, which allows the plants to utilize the sun's energy more efficiently, shade out weeds more rapidly, and reduce soil moisture loss. Tabo *et al.* (2002) reported that leaf area index and radiation interception increased with increasing plant density and when the leaf area index (ratio of leaf area to ground area) at any period in the growing season is less than one, then some of the sun's energy is wasted because some falls onto either bare soil or weeds. On the other hand, if there is too much leaf area index, the lower leaves become too shaded, which also reduces yields because losses due to plant respiration begin to cancel out gains from photosynthesis as the heavily shaded lower leaves often consume more carbohydrates by respiration than they can manufacture by photosynthesis. Therefore, correct plant spacing ensures that the leaf area index is optimum for plant growth (Winch, 2006). Thus, the ideal spacing and plant population are those that maximize yield, vegetable quality and profits farmers without unduly 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 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 (AVRDC, 1990, 2004).

Burton (1989) reported that density of stems of potato influences stem height and with an increase of density, height increases, and there is much decrease in auxiliary branching, which in turn decreases the photosynthetic potential. Kanton *et al.* (2003) also reported the decrease in bulb weight of onion with increase in plant population due to competition associated with higher plant population resulting in lower bulb weight, however, the more number of bulbs obtained at higher densities at harvest compensated for lower bulb weight associated with higher plant population densities.

Internationally, the optimum intra-row spacing for shallot is arguable and is dependent on the experience of the country. Williams *et al.* (1991) and Tindall (1983) reported that shallots are usually planted at intra-row spacing of 12 to 15 cm. Similarly, Devi and Anal (2008) reported that shallot responded well to the 10 cm intra-row spacing in terms of number of bulbs per hill, bulb diameter, fresh weight and dry weight as compared to lower levels of intra-row spacings but failed to give the highest yield. The closest spacing gave the highest yield of 164.37 q/ha. Relf and Daniel (2009) also reported that shallots planted at 10-15 cm between the bulbs.

Stallen and Hilman (1991) obtained the highest total shallot yield from large bulbs planted at the highest density but 74% of the harvest consisted of small bulbs (less than 1 cm in diameter) whereas higher percentage of large bulbs but lower yield were obtained from lower plant density. They found that about 25 plants per square meter were optimum. Jadczak and Orlowski (2001) also reported significant effect of planting density on the yield and bulb size of shallot. The yield decreased with the increase in plant spacing but the share of bulbs smaller than 10 g decreased considerably. Under Debre Zeit (Ethiopia) condition, the intra-row spacing for shallot is between 15 and 20 cm (Getachew *et al.*, 2009). However, the optimum intra-row spacing for shallot is not yet investigated in the Amhara region in general and in the study area in particular.

The above facts indicate that the optimum planting density for any crop is usually depends on environment and cultural practices. As a result, optimum plant density for different crops is based on evidences accumulated from field trials which have been repeated over a number of seasons to account for annual variations in weather. The optimum planting density at one site may not be applicable to another location because of variations in growing season, soil type and fertility, variety, ecology, preferable quality or size of the crop, etc (AVRDC, 1990, 2004) and thus calls for further trials at each site to validate general recommendations (Ali and Squire, 2002).

2.2.6. Bulb treatment

Farmers in the study area in particular and in Ethiopia in general use one-third topped bulbs as planting material. They believe that planting topped bulbs could result in vigorous daughter bulbs, faster crop establishment, fast growth and early maturity and provide reasonable yield. Godfrey-Sam-Agrey *et al.* (1987), Rashid and Singh (2000), Gubb and MacTavish (2002), Robinowitch and Kamenetesky (2002), and Peter (2006) also reported that bulb topping is practiced to break dormancy, enhance early germination, and vigorous crop stand. When the apical narrow part of the bulb is removed during topping, all of the shoot buds would grow early, uniformly and vigorously which would later develop into healthy and bigger bulbs. This resulted in fast establishment and efficient utilization of growth factors, accumulate more dry matter and hence produce higher yield within relatively short period of time than whole bulbs. However, Getachew and Asfaw (2000) on shallot and Sharma *et al* (2008) on onion reported that bulb topping negatively affected yield because of loss of initial food reserves. An experiment conducted to see the effect of different bulb sizes as a planting material on yield of shallot showed that planting materials with size of greater than 2.5 g gave the highest yield and yield components (Devi and Anal, 2008). Getachew and Asfaw (2000) also reported that big and medium sized bulbs established significantly better crop stand and gave better yield than small sized ones which could be due to their capability to sprout and survive owing to their more reserve food than the small sized bulbs have. The authors also reported that topped medium sized bulbs had lower establishment (crop stand) and had less yield than whole bulbs of the same size and big sized bulbs due to their reduced initial food reserve. Moreover, the wound created during bulb topping might serve as avenue for disease causing organisms (Agrios, 2005) which result in bulb rotting and consequently reduced yield.

Beyond the inconsistency of research results, farmers in the study area prefer one-third topped bulbs as a planting material. In addition, Getachew and Asfaw (2000) also suggested bulb topping might be practiced in areas having less disease incidence. Moreover, the response of bulbs for bulb topping may vary with variety, environment, severity of disease and cultural practices. Thus there is still a gap between the research findings and the common propagation (production) practice of shallot.

Moreover, information on combined effects of variety, intra-row spacing and/or bulb topping on yield and yield components of shallot is scanty. According to Awase *et al.* (2010), however, unmarketable yield of onion is affected by the interaction between variety and intra-row spacing. Similarly, Kabir and Sarkar (2008) reported significant interaction effects between variety and plant spacing on plant height, dry matter content, number of branches per plant, number of pods per branch, number of pods per plant, pod length, thousand seed weight and seed yield of mungbean. The authors stated that the highest value for all the parameters were recorded at wider spacing having less population density with significantly different values among varieties.

Therefore, this study was conducted with the general aim of observing the individual and combined effects of different levels of intra-row spacing and bulb topping on yield components, yield and quality traits of four shallot varieties so as to exploit the maximum potential of shallot that enhance economic benefits for growers and nutritional benefits for consumers.

3. MATERIALS AND METHODS

3.1. Description of the Study Site

The study was conducted in 2009/10 from December 2009 to May 2010 under irrigated condition at Aneded Woreda, Eastern Gojam Zone of western part of Amhara National Regional State; 280 km northwest of Addis Ababa, Ethiopia. The experimental site is located at 10^0 14'N latitude and 37^0 52'E longitude and has an altitude of 2443 meters above sea level. The area is characterized by having an average annual rainfall of about 1102 mm, the mean maximum and minimum temperature of 23 ^oC and 10.6 ^oC, respectively (Appendix Figure 1, 2 and 3). Laboratory analysis results of the composite sample soil from the site showed that is has a pH (in water) of 5.7, percent organic matter of 4.7 and soil texture of silt clay (10% sand, 45% silt and 45% clay) indicating that the soil of the experimental site was ideal for the production of selected crop (Getachew *et al*,, 2009; Relf and Daniel, 2009).

3.2. Experimental Material and Treatments

The experiment consisted of a factorial combination of three factors viz; variety, intra-row spacing and bulb topping (Table 1).

Table 1. Details of the treatment combination of the study

Treatment	Description	Treatment	Description
T_1	Local + 10 cm + topped bulb	T_{13}	Huruta + 10 cm + topped bulb
T_2	Local + 10 cm + whole bulb	T_{14}	Huruta + 10 cm + whole bulb
T_3	Local + 15 cm + topped bulb	T_{15}	Huruta + 15 cm + topped bulb
T_4	Local + 15 cm + whole bulb	T_{16}	Huruta + 15 cm + whole bulb
T_5	Local + 20 cm + topped bulb	T_{17}	Huruta + 20 cm + topped bulb
T_6	Local + 20 cm + whole bulb	T_{18}	Huruta + 20 cm + whole bulb
T_7	Negelle + 10 cm+ topped bulb	T_{19}	Minjar + 10 cm + topped bulb
T^8	Negelle + 10 cm + whole bulb	T_{20}	Minjar + 10 cm + whole bulb
T_9	Negelle + 15 cm + topped bulb	T_{21}	Minjar + 15 cm + topped bulb
T_{10}	Negelle + 15 cm + whole bulb	T_{22}	Minjar + 15 cm + whole bulb
T_{11}	Negelle + 20 cm + topped bulb	T_{23}	Minjar + 20 cm + topped bulb
T_{12}	Negelle + 20 cm + whole bulb	T_{24}	Minjar + 20 cm + whole bulb

There were 24 treatment combinations, consisting of four varieties (*Negelle*, *Huruta*, *Minjar* and Local), three intra-row spacing (10, 15 and 20 cm) and two types of bulbs (one-third topped bulbs and whole bulbs). The varieties '*Negelle'*, '*Huruta'* and '*Minjar'* were released and obtained from Debrezeit Agricultural Research Center whereas the local variety was obtained from Sinan Woreda farmers and were stored at the same condition to maintain uniform resting period. Cured and medium sized (20-30 g) bulbs were selected for the experiment. Half of the bulbs from each variety and spacing combinations were topped to one-third of bulb height (based on the experience of farmers in the study area by measuring using caliper) and the lower two-third of the bulbs were planted, while the remaining half of them were planted as whole bulbs. The bulbs were planted on ridges and were spaced 30 cm between double rows, 30 cm between rows and 10 cm, 15 cm and 20 cm between plants based on the treatment combinations (Getachew *et al.*, 2009).

3.3. Experimental Design

The experiment was laid out in 4 x 3 x 2 factorial arrangement using a randomized complete block design with three replications. The size of each experimental plot was 3.6 m^2 (3 m wide and 1.2 m long). The distance between blocks and plots were 1 m and 0.5 m, respectively.

3.4. Management of the Experiment

The treatments received 69 kg/ha N and 92 kg/ha P_2O_5 (Getachew *et al*., 2009). All the P_2O_5 and half of N fertilizers were applied during planting and the remaining half N was applied after a month of 50% sprouting (BoARD, 2002). Irrigation water was applied for all plots on the day of planting to avoid desiccation on topped bulbs. There was occurrence of downy mildew (*Peronosphora destructor*) and Redomil gold 63.5 was sprayed four times at the rate of 3.0 kg per ha, mixing in 1000 liter water per ha. All other management practices including watering, hoeing and weeding were provided as per the recommendations (Getachew *et al.*, 2009).

3.5. Data Collected

Data were collected on vegetative growth, yield parameters, bulb quality and disease reaction using the standard procedures described by IPGRI (2001). Data on the following traits were recorded and analyzed from ten randomly selected plants and the mean was taken, except for yield in which the data was recorded on net plot bases and total soluble solid, bulb color, bulb shape, and dry matter in which the data was recorded from randomly selected bulbs from the sampled plants.

Days to emergence: The number of days from planting to sprouting of bulb was recorded at 50% sprouting in a plot.

Plant height (cm): It was measured using meter tape from the soil surface to the tip of the mature leaf at maturity and expressed in cm.

Number of leaves per plant: It was recorded at maturity and expressed as number of leaves per plant.

Leaf length (cm): It was measured using ruler from the sheath (pseudo stem) to the tip of the leaf (3^{rd} youngest matured leaf) at maturity and expressed in cm.

Leaf diameter (mm): It was measured at maturity using ruler at widest point of matured leaf (3^{rd} youngest matured leaf) and expressed in mm.

Leaf sheath length (cm): It was measured at maturity using ruler from the top of the bulb up to the neck of the bulb and expressed in cm.

Bulb diameter (cm): It was measured at harvest using caliper (obtained from Debre Zeit Agricultural Research Institute) at the widest point in the middle portion of the matured bulb and expressed in cm.

Bulb length (cm): It was measured at harvest using caliper from the bottom to the top of the matured bulb and expressed in cm.

Number of shoots per plant: It was measured at harvest and expressed as number of shoots per plant.

Number of flower stalks per plant: It was measured at maturity and expressed as number of flower stalks per plant.

Days to maturity: Number of days from planting to the day at which more than 75% of the plant's top fall in a plot.

Number of bulbs per plant: It was counted at harvest and expressed as number of bulbs per plant.

Number of marketable bulbs per plant: It was scored at harvest by counting bulbs which are healthy and greater than 25 mm in diameter (Prissana-nanthakul, 2008) and expressed as number of marketable bulbs per plant.

Number of unmarketable bulbs per plant: It was scored at harvest by counting bulbs which are sprouted, rotted, unhealthy, and less than 25 mm in diameter, and expressed as number of unmarketable bulbs per plant.

Weight of bulb per plant (g): It was measured after harvested and cured, using sensitive balance (model BP 16000-s, county in gram and precision 0.01) and expressed in gram.

Weight of marketable bulbs per plant (g): Average weight of healthy matured bulbs greater than 25 mm in diameter (Prissana-nanthakul, 2008) was measured after curing using sensitive balance and expressed in gram.

Weight of unmarketable bulbs weight per plant: Average weight of abnormal matured bulbs and less than 25 mm in diameter was measured after curing using sensitive balance and expressed in gram.

Biological yield per plant: It is the sum total of weight of aerial parts (shoot parts) and under ground parts (bulbs and roots) and was measured after the bulbs were lifted and all the soil was removed and was expressed in grams.

Harvest index per plant (%): It was computed by dividing mean weight of mature bulb of plants taken (economic yield) by the mean biological yield of plants taken using the equation (Pessarakli, 2001):

$$\text{Harvest Index (HI)} = \frac{\text{Economic yield (edible portion)}}{\text{Biological yield/total biomass}} \times 100$$

Total yield (t/ha): Sum total of marketable and unmarketable bulb yield. The total bulb yield (kg/plot) from the net plot was weighed after the bulbs cured for two days under shade, and was converted to t/ha.

Marketable yield (t/ha): Total weight of clean, disease and damage free bulbs with greater than 25 mm in diameter measured in kg/plot and converted in to t/ha.

Unmarketable yield (t/ha): Total undersized, defected and diseased bulb weight and expressed in kg/plot and converted in to t/ha.

Bulb dry weight (g): From each plot, bulbs of sample plants were lifted, 10 bulbs were randomly selected, and fresh weigh was recorded and then cut into smaller pieces, dried in oven at 105^{o}C for 60 hours to constant weight. Mean dry weight of bulbs was recorded in gram.

Bulb dry matter content (%): It was from the ratio of dry weight to fresh weight as follows and expressed in percent as the formula suggested by Undersander *et al*. (1993).

$$\text{Dry matter content (\%)} = \frac{m_b - m_e}{m_f - m_e} * 100$$

where: m_b = mass of the dish containing dry matter in grams

m_f = mass of the dish containing fresh weight in grams

m_e = the mass of the empty dish in grams

Total soluble solids (%): Total amount of soluble solids present in the bulb. It was recorded from the juice of five randomly sampled bulbs of each plot and was measured using an electrical bench refractometer (Model NAR-1T, made by Wagtech International Ltd, Atago digital thermometer) at Debre Zeit Agricultural Research Center horticulture section laboratory at a temperature of 20 ^{0}c and expressed in percent.

Shape of bulb: The shape of ten randomly selected mature bulbs per plot was classified based on IPGRI descriptors for Alliums species (IPGRI, 2001). The shape index (bulb length to bulb diameter ratio) was used for analysis.

Bulb color: Color of ten randomly selected bulbs from each plot was scored by experts of Debrezeit Agricultural Research Centre. The numbers were assigned as 1 for deep red, 2 for red and 3 for light red to quantify and analyze the data.

3.6. Statistical Analysis

The mean values of all the above parameters were subjected to analysis of variance (ANOVA) using the SAS package (SAS, 2002, version 9.2). Least Significant Difference (LSD) procedure was used to compare differences between treatment means at p=0.05 whenever the treatment effects were significantly different. Linear correlation was applied for all parameters to establish relationship between the parameters.

4. RESULTS AND DISCUSSION

4.1. Growth Parameters

4.1.1. Days to 50 percent emergence

The analysis of variance for the main effects of varieties and bulb topping showed a very highly significant ($p<0.001$) difference on days to 50% emergence (Fig. 3 and 4 and Appendix Table 1). Local variety had significantly more mean days (10) of 50% emergence followed by '*Negelle*' (8 days) and '*Huruta*' (7.33 days) and '*Minjar*' (7.00 days), both of which were statistically similar. However, other main and interaction effects showed non significant difference (Appendix Table 1).

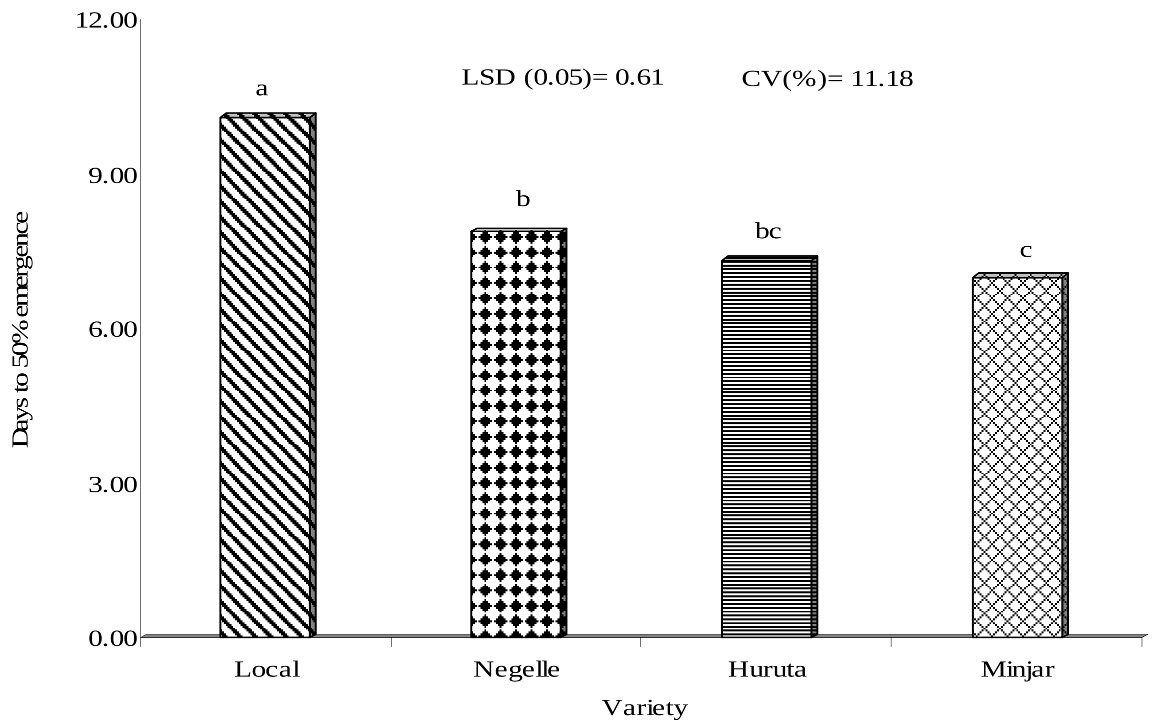

Fig.3. Differences in the days to 50% emergence of shallot varieties

Topped shallot bulbs had significantly ($p<0.001$) short 50% emergence date (7 days) where as whole bulbs had the longest 50% emergence date (9 days). This could be due to the fact that topping avoid mechanical resistance for leafing out, expose shoot buds to external climatic factors like temperature, aeration, and enhance respiration as a result of hormonal initiation all lead to dormancy breakage. This result is in agreement with the findings of Godfrey-Sam-Agrey *et al.* (1987) who reported emergence of topped bulbs 4-5 days earlier than whole bulbs. Rashid and Singh (2000), Gubb and MacTavish (2002), Robinowitch and Kamenetesky (2002), and Peter (2006) also reported that bulb topping practiced to break dormancy and enhance early sprouting and production of uniform and vigorous seedlings than whole bulbs leading to early maturity.

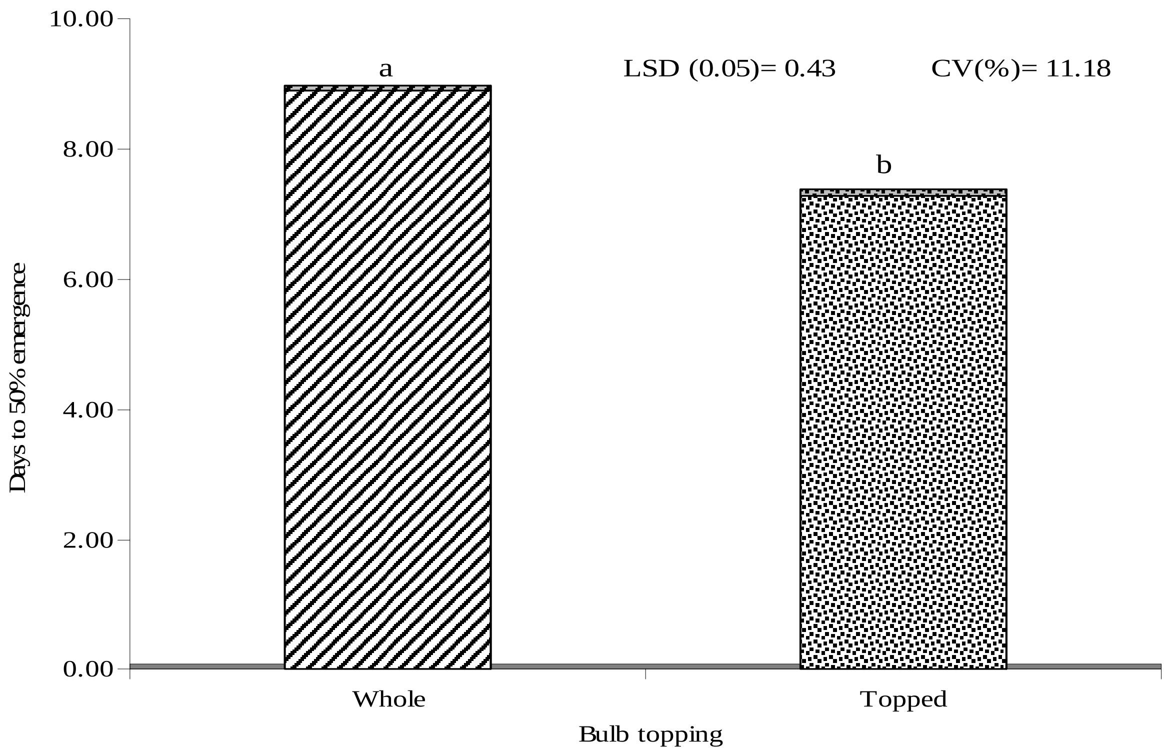

Fig.4. Effects of bulb topping on days to 50% emergence of shallot

4.1.2. Plant height (cm)

The main effects of intra-row spacing showed a highly significant ($p<0.01$) difference on plant height (Fig. 5 and Appendix Table 1). Shallot bulbs planted at 15 and 20 cm intra-row spacing produced significantly taller plants than bulbs planted at 10 cm intra-row spacing. Bulbs planted at 20 cm and 15 cm intra-row spacings had height advantage of 1.79 cm and 2.62 cm over those planted at 10 cm intra-row spacing, respectively. The reduction in plant height at higher plant population might be attributed to the possible competition for soil moisture and nutrients (Ibrahim, 1994; Bodnar *et al*., 1998; Karaye and Yakubu, 2006). The result is in accord with Kanton *et al. (*2003) who reported that plant height decreased as plant population density increased. These results are also in pact with the findings of Zamir *et al.* (1999) on maize, Khan *et al.* (2003) on onion, Agele *et al.* (2007) on sunflower, and Woldemariam (2009) on ginger but in contradiction with Burton (1989) who reported increase of density resulted in height increases and much decrease in auxiliary branching of potato.

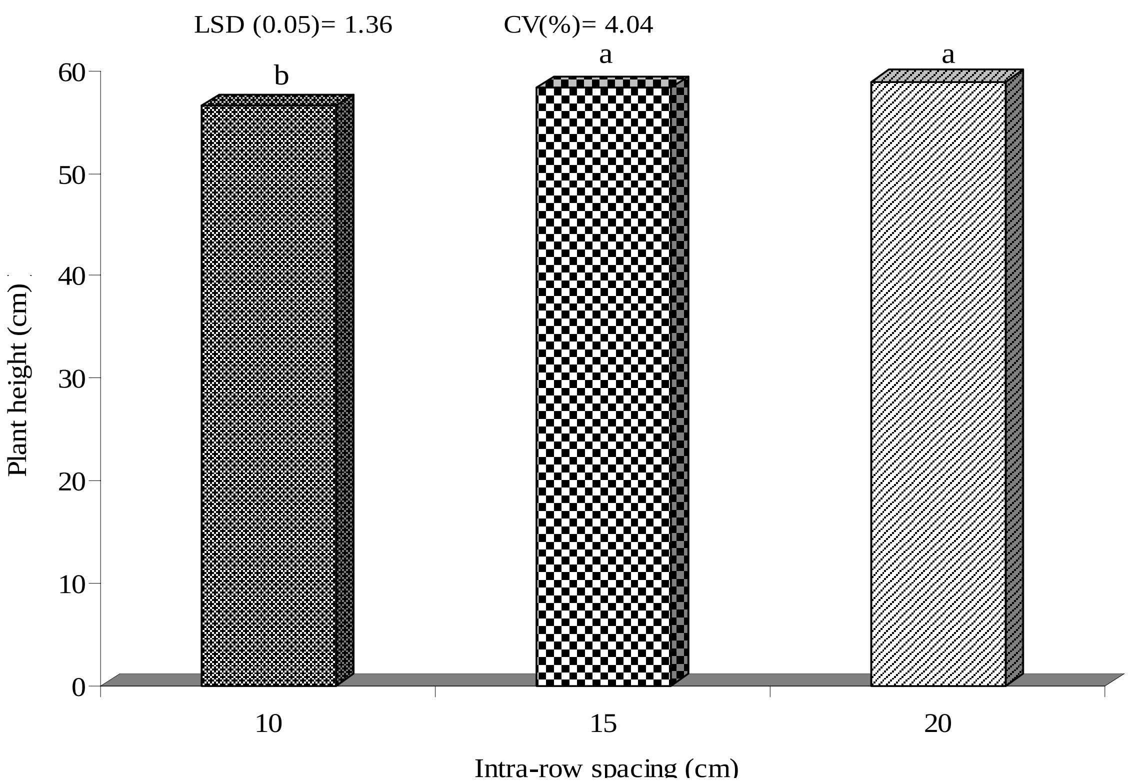

Fig.5. Effects of intra-row spacing on plant height of shallot

The interaction effects of variety with bulb topping showed a significant ($p<0.05$) difference on plant height of shallot (Fig. 6 and Appendix Table 1). Both bulb types of '*Negelle*' and '*Huruta*' varieties produced the highest and statistically similar height. The shorter plant height was recorded with local variety planted with both bulb types. However, height variation between bulbs planted as whole and topped was pronounced on different varieties and no height variation was observed between both bulb types on the same variety. The relatively slight height increment in whole bulbs might be due to the effect of bulb topping on mother bulb size. UD-Deen (2008) and Ashrafuzzaman *et al.* (2009) reported that plant height of onion was significantly affected by the size of the mother bulbs in which larger bulbs resulted in longer plants. Islam *et al.* (2007) also reported significant genotypic variation on onion in plant height.

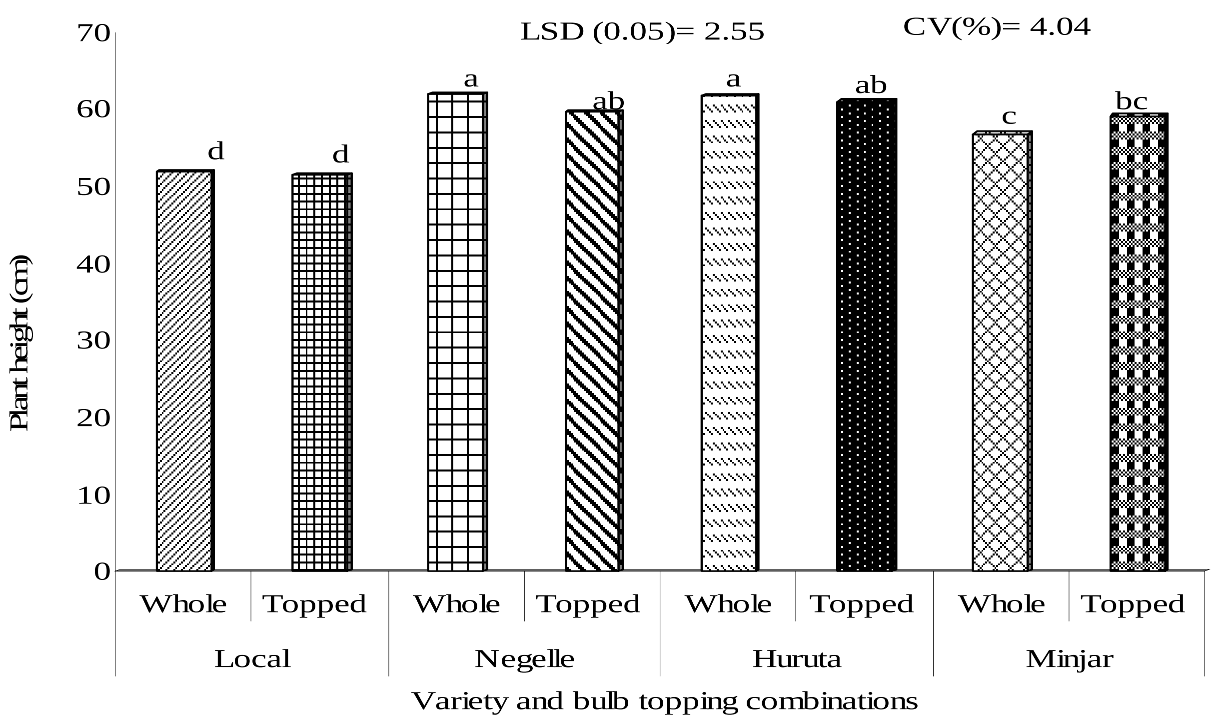

Fig.6. Plant height of shallot as influenced by interaction between varieties and bulb topping

4.1.3. Number of leaves per plant

Interaction effects of variety with intra-row spacing showed a highly significant (p<0.01) difference on the number of leaves per plant of shallot (Table 2 and Appendix Table 1). Local variety planted at 20 cm intra-row spacing produced the highest number of leaves per plant (81) whereas '*Huruta'* variety planted at 10 cm intra-row spacing produced the lowest number of leaves per plant (47). The variation in leaf number per plant on different varieties might be due to variations in gene composition. However, *'Minjar'* variety didn't respond for intra-row spacings. In agreement with this, Fasika *et al.* (2008) reported that Ethiopian shallot genotypes had highly significant genetic differences for number of leaves per plant. The higher number of leaves per plant at wider spacing could be explained by more space per plant and reduced competition.

Table 2. Number of leaves of shallot as influenced by the interaction effects between variety and intra-row spacing and bulb topping

Intra-row spacing (cm)	Variety			
	Local	Negelle	Huruta	Minjar
10	67.20[bc]	56.35[ef]	47.27[g]	48.22[g]
15	73.52[b]	56.40[ef]	56.95[ef]	51.13[fg]
20	81.38[a]	59.37[de]	64.20[cd]	52.75[efg]
LSD (0.05)	6.44			
CV (%)	7.01			
Bulb topping				
Whole	70.16[b]	56.80[cde]	52.32[def]	50.11[f]
Topped	77.91[a]	57.94[cd]	59.96[c]	51.29[ef]
LSD (0.05)	6.62			
CV (%)	7.01			

Means followed by the same letter(s) are not significantly ($p<0.05$) different

The presence of greater number of leaves for varieties planted at wider spacing might be due the possibility of greater shoot buds emergence as nutrient availability and other requirements are better condition and competition for space is low and all the emerged leaves can survive better at wider plant spacing. This observation is in agreement with that of Sarikhani and Razmjoo (2007) who reported significant influence of the interaction between plant spacing and cultivar on the number of leaf per square meter of sorghum. Kabir and Sakar (2008) also reported that the number of branches per plant of mungbean was significantly affected by the interaction effects between cultivar and spacing. However, Jilani *et al.* (2009) reported absence of interaction among onion cultivars and planting densities on number of leaves per plant.

Many investigations revealed that increased plant spacing increases the number of leaves per plant on different crops. Jilani *et al.* (2009) reported at wider plant spacing (25 cm) onion produced maximum number of leaves per plant as compared to closely spaced ones (10 cm). Karaye and Yakubu (2006) also reported that 15 cm and 20 cm intra-row spacings produced significantly higher number of leaves per plant than the 10 cm intra-row spacing on garlic. Ibrahim (1994) and Bodnar *et al.* (1998) also observed widely spaced garlic plants tend to grow more vegetatively and bear more leaves per plant. Burton (1989) also reported that decreasing density of potato resulted in an increase in auxiliary branching and number of leaves. Similarly, Woldemariam (2009) reported that intra-row spacing had significant ($p < 0.05$) effect on number of leaves per plant of ginger. The authors explained that under wider spacing, the plants did not experience stern competition for growth factors to the extent that can depress growth or alternatively the plants were favored to get a micro-environment that is more fertile than the rest portions of the land on which other plants grew.

Interaction effects of variety with bulb topping showed a significant ($p<0.05$) difference on number of leaves per plant of shallot (Table 2 and Appendix Table 1). Local variety planted with topping produced greater number of leaves per plant followed by the same variety planted with whole bulbs, whereas '*Minjar'* planted with both bulb types and '*Huruta'* planted as whole bulb produced statistically similar and the fewest leaf number per plant. However, only local and '*Huruta'* responded significantly to topping of bulbs. Getachew and Asfaw (2000) pointed out presence of wide variations of foliar characteristics among Ethiopian shallot cultivars. In the meantime, varieties have dormant shoot buds that could be stimulated by bulb topping (Gubb and MacTavish, 2002; Robinowitch and Kamenetesky, 2002; Peter, 2006) and accordingly respond differently. Leaf number variation due to different bulbs of local and '*Huruta'* varieties might be due to the fact that bulbs planted with topping produced more number of shoots and then more number of leaves per plant. The result is in support of Ashrafuzzaman *et al.* (2009) who observed that increase in the number of leaves of onion was directly related to the number of shoots and the more the number of shoots the more were the number of leaves. The highly significant positive correlation ($r = 0.69^{***}$) between number of leaves and shoots per plant in the present study also revealed the increase in number of leaves is accounted with the increase in shoot number (Appendix Table 7).

4.1.4. Leaf length (cm)

The interaction effects of varieties with bulb topping showed a significant ($p<0.05$) difference on leaf length (Table 3 and Appendix Table 1).

Table 3. Length of leaves (cm) of shallot as influenced by the interaction of variety and intra-row spacing and variety with bulb topping

Variety	Bulb topping	
	Whole	Topped
Local	43.54^{c}	42.61^{c}
Negelle	51.19^{a}	50.32^{ab}
Huruta	51.77^{a}	52.59^{a}
Minjar	44.62^{c}	48.01^{b}
LSD(0.05)	2.71	
CV (%)	5.05	
Intra row spacing (cm)		
10	44.98^{b}	47.72^{a}
15	49.04^{a}	48.41^{a}
20	49.32^{a}	49.03^{a}
LSD(0.05)	2.74	
CV (%)	5.05	

Means followed by the same letter(s) are not significantly ($p<0.05$) different

Both bulb types of ‘*Huruta’* and ‘*Negelle’* produced longer but statistically similar leaves. On the other hand, both bulb types of local and whole bulbs of ‘*Minjar’* produced the shortest but statistically similar length of leaves. The later variety, however, significantly improved leaf length when topped bulbs are used. The correlation coefficient (r=93***) between leaf length and plant height revealed that the variation in leaf length between these treatment combinations resulted in their height difference (Appendix Table 7). The production of a significantly longer leaves in '*Minjar'* planted with topped bulbs might be due to the slightly taller plants from topped bulbs (Fig. 4.4). Jelani *et al.* (2009) also reported that onion cultivars varied significantly from each other with respect to length of leaves from 27.12 cm to 39.74 cm.

A significant ($p<0.05$) difference was observed among interaction effects of intra-row spacing with bulb topping on leaf length (Table 3 and Appendix Table 1). Both bulb types planted at 20 cm and 15 cm intra-row spacings, and topped bulbs planted at 10 cm intra-row spacing produced plants with statistically similar and taller leaf length compared to whole bulbs planted at 10 cm intra-row spacing. This result is in agreement with Jelani *et al.* (2009) on onion who reported that lowest plant density (20 plants per square meter) gave maximum leaf length (37.99 cm) followed by 30 plants per square meter (35.44 cm). They also observed that all planting densities tested significantly differed from each other with regard to leaf length and this might be attributed to increased competition for nutrients and moisture at above certain plant density levels.

4.1.5. Leaf diameter (mm)

The effects of bulb topping showed a very highly significant ($p<0.001$) difference on leaf diameter (Fig. 7 and Appendix Table 2).

Topped bulbs of shallot produced wider leaves than whole bulbs. This might be due to the fact that early emergence of topped bulbs allowed the plants to take over the microenvironment and resulted in thicker leaves than plants from whole bulbs. Moreover, topped bulbs produced thicker shoots than whole which inturn produced thicker leaves.

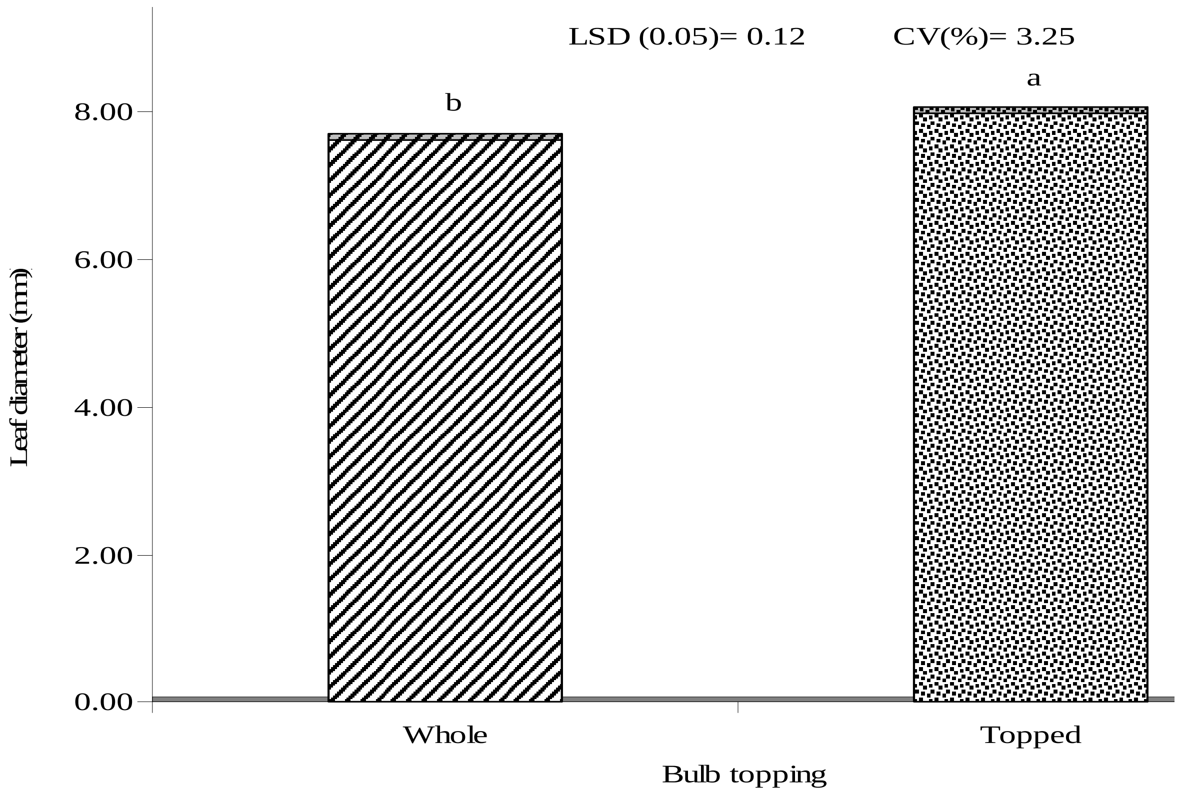

Fig.7. Effect of bulb topping on leaf diameter of shallot

Interaction effect of variety with intra-row spacing showed a very highly significant ($p<0.001$) difference on leaf diameter (Fig. 8 and Appendix Table 2). ‘*Negelle’* planted at 20 cm intra-row spacing produced widest leaf diameter whereas local planted at 10 cm intra-row spacing produced the narrowest leaf diameter. All varieties tended to increase in leaf diameter with increase in intra-row spacing. This might be due genetic difference as well as less competition among sparsely populated plants leading to vigorous vegetative growth. This result is in conformity with the findings of Broome (2009) that reported leaf diameter of different Allium species plants grown at 20 cm was larger than plants grown at 15 cm which in turn were larger than plants grown at 10 cm. Palada and Crossman (1998) also reported that leaf area of okra increased with increase in plant spacing linearly.

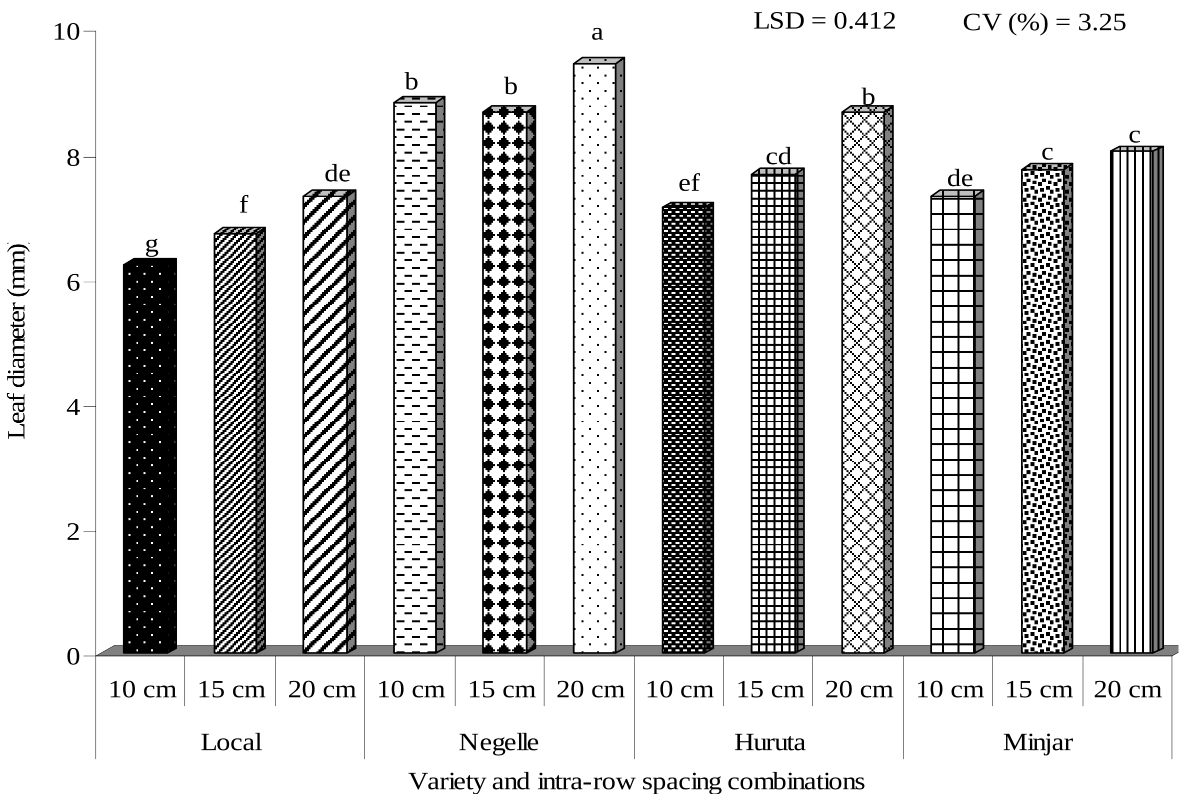

Fig.8. Leaf diameter of shallot as affected by variety and intra-row spacing combinations

4.1.6. Leaf sheath (shaft) length (cm)

The effects of bulb topping showed a highly significant (p<0.01) difference on leaf sheath length (Fig. 9 and Appendix Table 2).

Topped shallot bulbs produced plants with the shortest leaf sheath length whereas whole bulbs produced plants with the longest leaf sheath length. This might be due to the fact that when the top part of the bulb is removed, more shoots will emerge early and resulted in shorter glumes and associated pseudostem (Table 4).

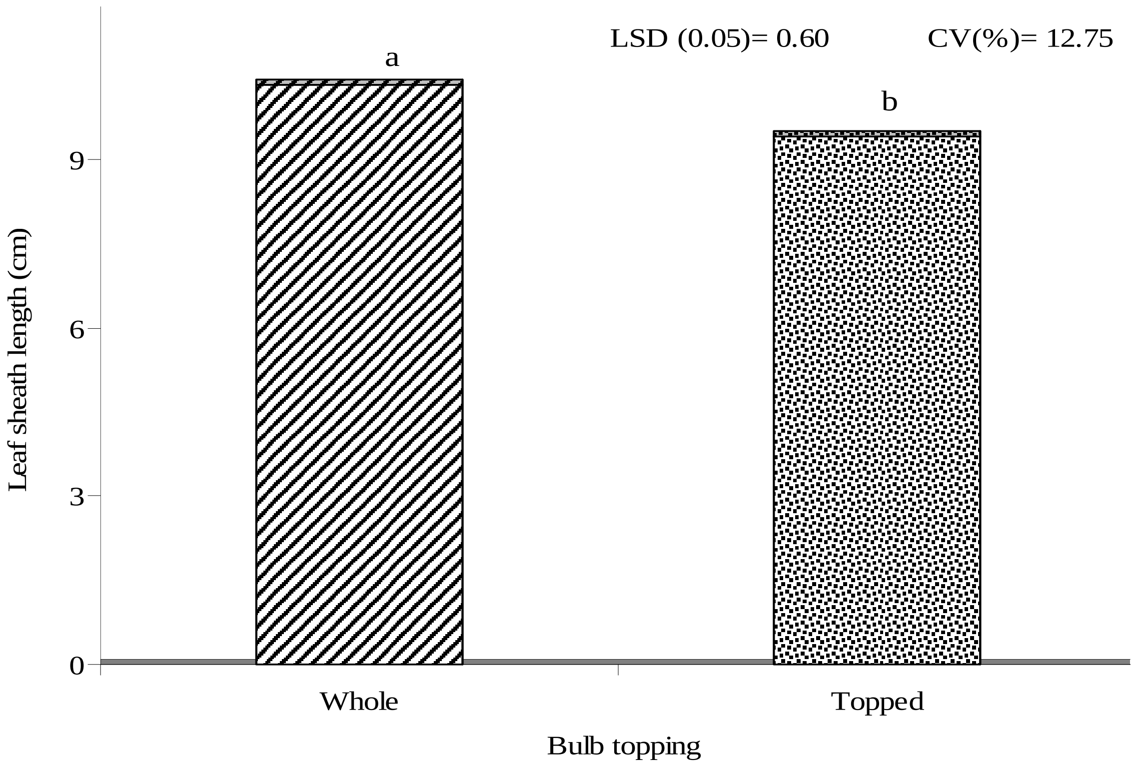

Fig.9. Effects of bulb topping on leaf sheath length of shallot

The influence of variety on leaf sheath length were very highly ($p<0.001$) significant (Fig. 10 and Appendix Table 2). '*Minjar*' produced longer leaf sheath followed by '*Negelle*', whereas '*Huruta*' and local had statistically similar short leaf sheath length. '*Minjar*' had leaf sheath length advantage of 1.66 cm, 2.42 cm and 3.09 cm over '*Negelle*', '*Huruta*' and local varieties, respectively. A significant and weak positive correlation (r = 0.30**) between sheath length and bulb length in the present study revealed that plants having long sheath length will produce large bulbs when adequate earthing-up is done (personal observation). However, the presence of highly significant negative correlation (r =-0.31**) between sheath length and bulb dry weight revealed that having of short sheath length would favor to high bulb yield through reduction in dry matter loss in the sheath and unmarketable bulb (Appendix Table 7).

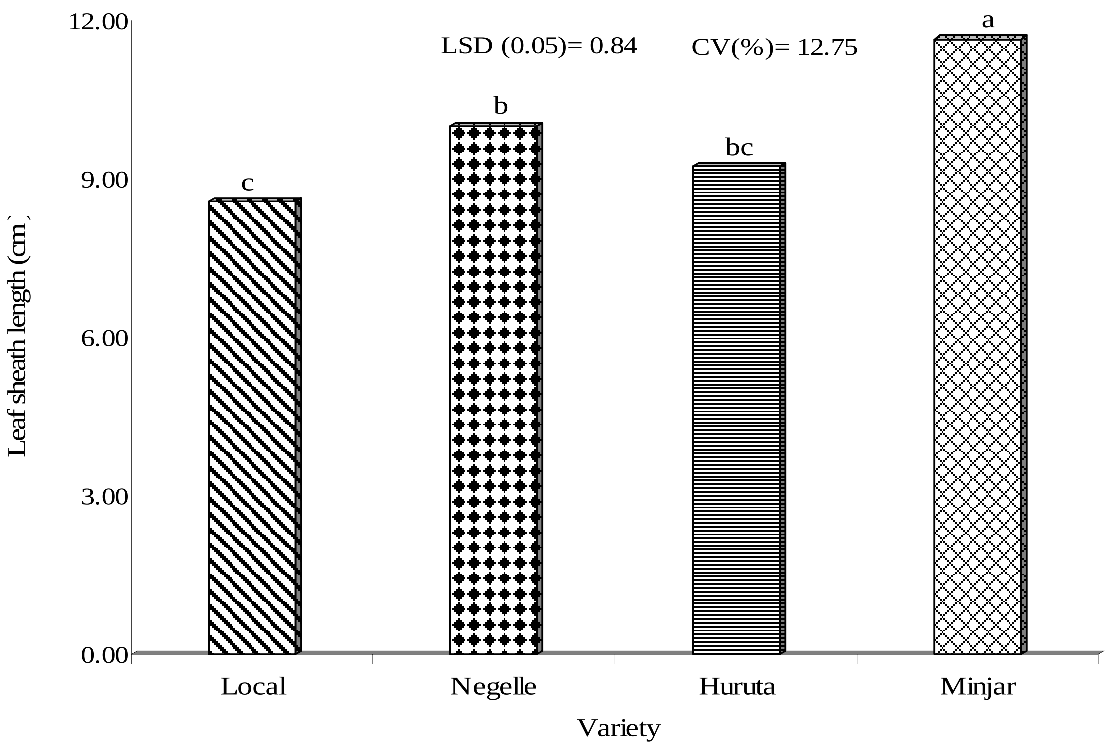

Fig.10. Effects of varieties on leaf sheath length of shallot

4.1.7. Number of shoots per plant

Interaction effects of variety, intra-row spacing and bulb topping showed a very highly significant ($p<0.001$) difference on number of shoots per plant (Table 4 and Appendix Table 2). Topped bulbs of the local variety planted at 20 cm intra-row spacing produced more number of shoots per plant followed by whole bulbs of the same variety planted at the same intra-row spacing and topped bulbs of the same variety planted at 15 cm intra-row spacing. Whereas, topped bulbs of '*Huruta'* planted at 10 cm intra-row spacing produced plants with the lowest number of shoots but not statistically different from whole bulbs of the same variety planted at 15 cm and 10 cm intra-row spacings and topped bulbs of '*Negelle'* planted at 10 cm intra-row spacing.

This might be due to the fact that different varieties with their genetic make up variation responded differently to different factors. When bulbs planted with topping the apical dominance removed and more buds emerge. Moreover, when the shoots emerge earlier, it produce more food and encourage the growth of more dormant shoots and resulted in more shoots per plant as there is enough space and resource in wider spacing than in closely spaced ones. This result is in consistent with Legesse *et al.* (2001) who reported that an increase in branch number was observed as planting density decreased on sweet potato.

Table 4. Numbers of shoots, and flower stalk per plant of shallot as affected by the interaction of variety, intra-row spacing and bulb topping

Variety	Spacing (cm)	Bulb topping	Number of shoots/plant	Number of flower stalk/ plant
Local	10	Whole	12.60^{fg}	1.00^{e}
		Topped	15.13^{cd}	0.57^{g}
	15	Whole	15.47^{c}	0.87^{ef}
		Topped	16.37^{bc}	0.63^{fg}
	20	Whole	16.80^{ab}	1.03^{e}
		Topped	17.73^{a}	0.53^{g}
Negelle	10	Whole	10.05^{jkl}	0.00^{h}
		Topped	9.57^{lm}	0.00^{h}
	15	Whole	10.97^{ijk}	0.00^{h}
		Topped	11.17^{hij}	0.00^{h}
	20	Whole	12.43^{fgh}	0.00^{h}
		Topped	12.67^{fg}	0.00^{h}
Huruta	10	Whole	9.77^{klm}	0.00^{h}
		Topped	8.63^{m}	0.00^{h}
	15	Whole	9.63^{lm}	0.00^{h}
		Topped	10.03^{jkl}	0.00^{h}
	20	Whole	11.60^{ghi}	0.00^{h}
		Topped	13.50^{ef}	0.00^{h}
Minjar	10	Whole	10.83^{ijkl}	3.50^{b}
		Topped	12.50^{fg}	4.17^{a}
	15	Whole	13.23^{ef}	2.40^{cd}
		Topped	11.40^{ghi}	3.97^{a}
	20	Whole	14.00^{de}	2.23^{d}
		Topped	13.67^{fe}	2.53^{c}
LSD (0.05)			1.272	0.24
CV (%)			6.20	15.20

Means followed by the same letters in a column are not significantly ($p<0.05$) different

4.1.8. Number of flower stalks per plant

Interaction effects of variety, intra-row spacing and bulb topping showed a significant ($p<0.05$) difference on number of flower stalks per plant (Table 4 and Appendix Table 2). Topped bulbs of '*Minjar'* planted at 10 cm and 15 cm intra-row spacing produced statistically similar and more number of flower stalks per plant whereas '*Negelle'* and '*Huruta'* varieties planted at all intra-row spacing with all bulb types produced null flower stalk. Bolting nature was manifested only on local and '*Minjar'* varieties. The more number of bolters in '*Minjar'* planted with closer spacing might be due to intense competition at high population density and forced the plants to enter more into reproductive phase than sparsely spaced plants.

4.1.9. Days to maturity

Variety and bulb topping showed a very highly significant ($p<0.001$) difference on days to maturity (Fig. 11 and 12 and Appendix Table 2).

'*Minjar*' had the shortest days to maturity (107 days). '*Huruta'*, '*Negelle'* and local varieties matured in 118, 119, and 125 days, respectively. However, '*Negelle'* and '*Huruta*' varieties had statistically similar days to maturity. These results are in agreement with the findings of Getachew and Asfaw (2000) who reported days to maturity of shallot showed variations from 95 to 126 days. Kimani *et al.* (1993) also observed variations in days to maturity among onion cultivars and the value affect by the growing environment.

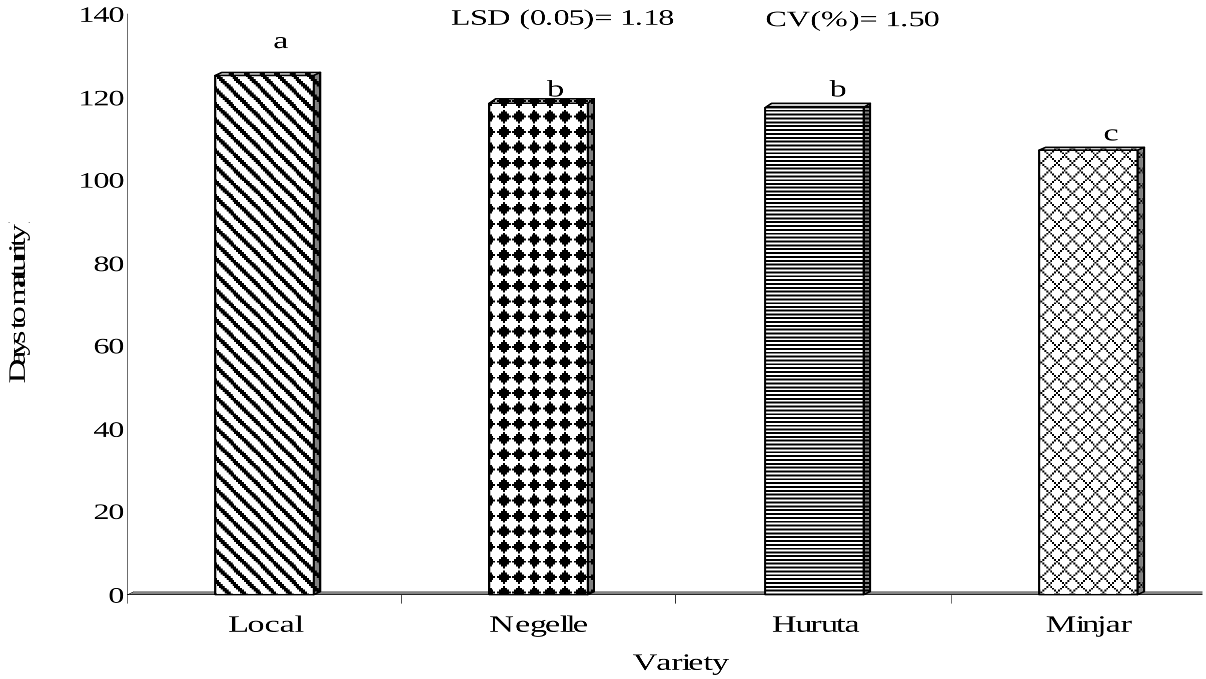

Fig.11. Effect of variety on days to maturity of shallot

Topped shallot bulbs had the minimum of days to maturity whereas whole bulbs had the maximum number of days to maturity.

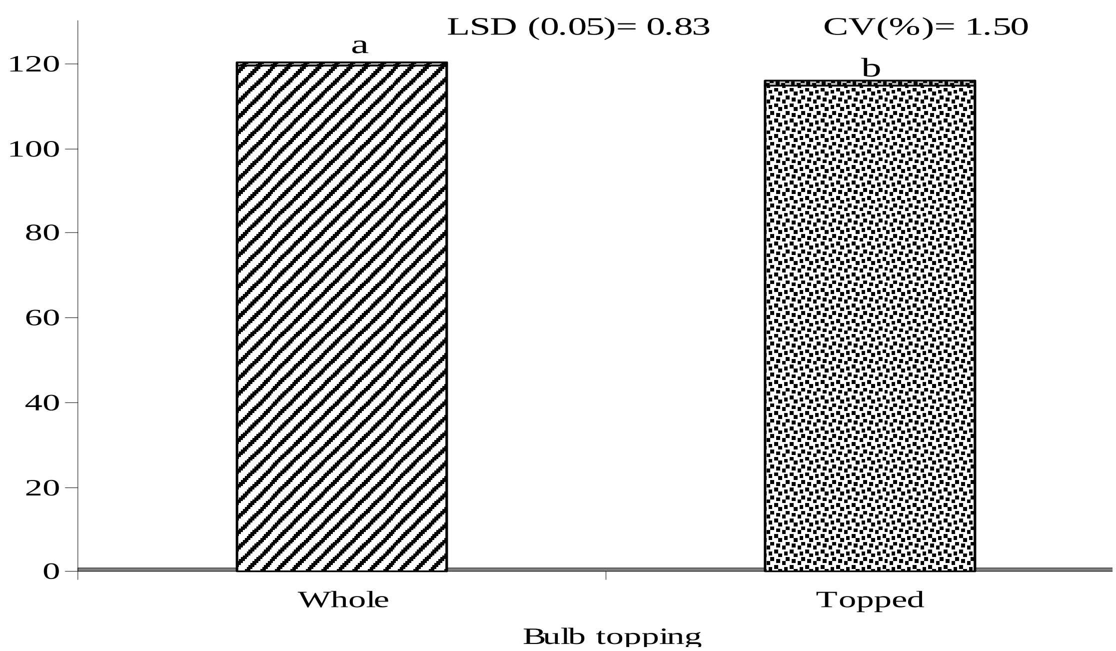

Fig.12. Effects of bulb topping on days to maturity of shallot

This might be due to bulb topping effect on days to emergence (Fig. 4). When topped bulbs emerge earlier, they can cope up with early carbon assimilation and the reach maximum growth earlier than whole bulbs. This result is sustaining Rashid and Singh (2000) who pointed out planting topped bulbs at one-third of height had enhanced early emergence and a consequence early maturity.

4.2. Yield Parameters

4.2.1. Bulb diameter (cm)

The effects of bulb topping showed a significant ($p<0.05$) difference on bulb diameter (Fig. 13 and Appendix Table 3).

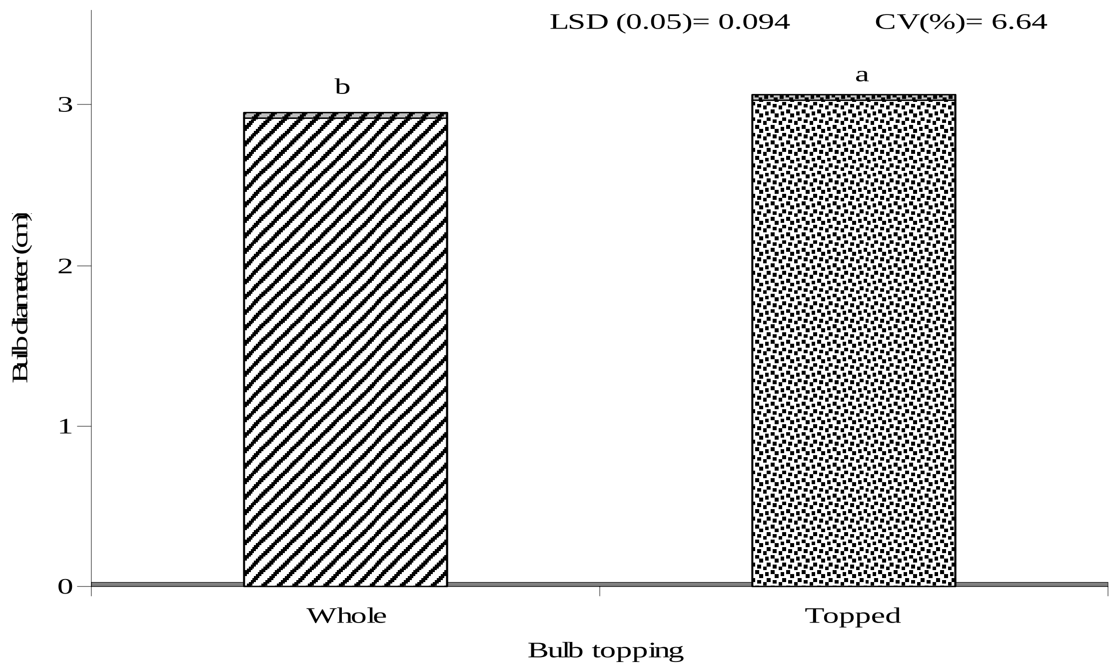

Fig.13. Effect on bulb topping on bulb diameter of shallot

Topped bulbs produced greater bulb diameter (3.03 cm) as compared to whole bulbs (2.92 cm). This might be due to the fact that topped bulbs produced more thick shoots and leaves that increase carbon assimilation (Winch, 2006) which in turn might lead to accumulation of high photosynthetic products and larger bulbs. The highly significant positive correlation of bulb diameter with leaf diameter (r =0.63***) and leaf length (r =0.74***) in the present study revealed the direct relationship between the photosynthetic area and the resulted sink (bulb) (Appendix Table 7).

The interaction effects of variety with intra-row spacing showed a significant ($p<0.05$) difference on bulb diameter (Fig. 14 and Appendix Table 3).

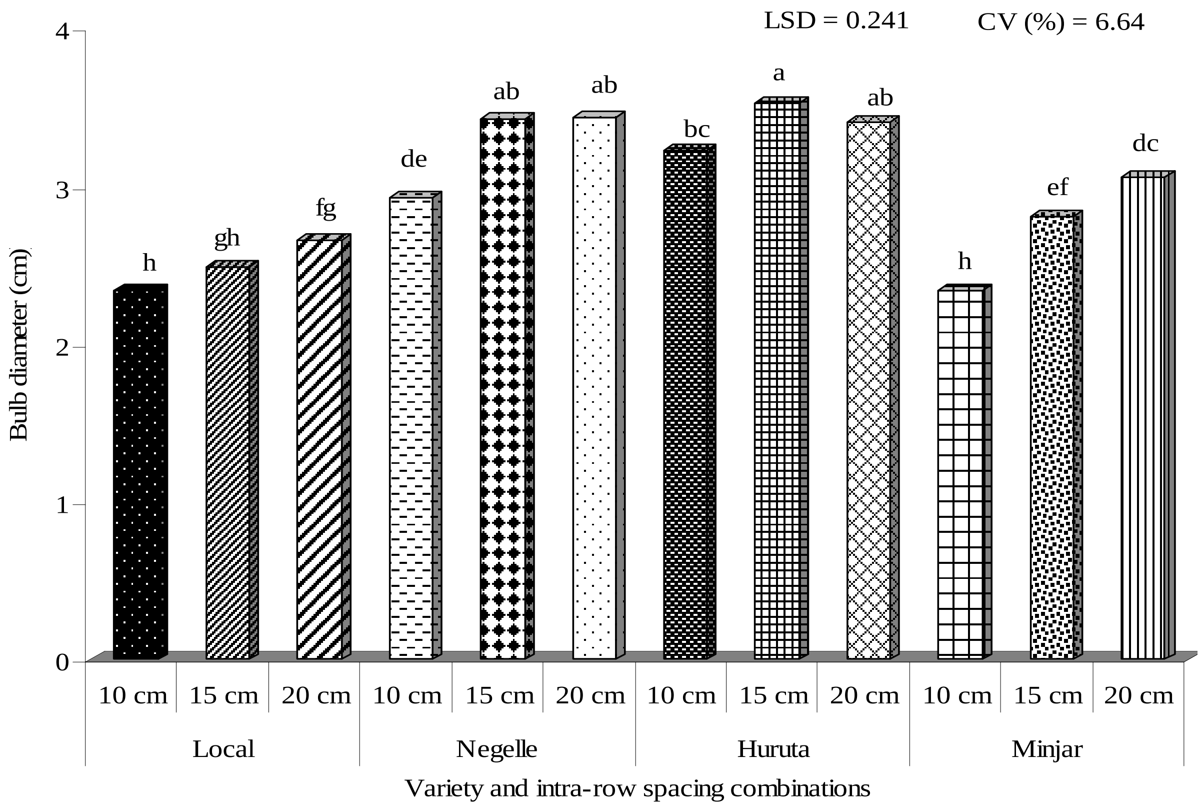

Fig.14. Effects of variety and intra-row spacing on bulb diameter of shallot

'*Huruta*' and '*Negelle*' varieties planted at 15 and 20 cm intra-row spacing produced higher and statistically similar bulb diameter, whereas local and '*Minjar*' varieties planted at 10 cm intra-row spacing produced the lowest and statistically similar bulb diameter. This might be due to the fact that closely spaced plants result in smaller bulbs because of intense competition than sparsely populated plants and the response is varied among varieties with variations in spacing levels. Comparing the average bulb weight of '*Huruta*' and '*Negelle*' under the three intra row spacings revealed wider spacings gave larger bulbs. These results are in agreement with the findings of Jilani *et al.* (2009) on onion who observed a significant decrease in bulb diameter with increased plant population with different values among cultivars. They explained minimum plant population (20 plants per square meter) had significantly larger bulb diameter than high planting density (40 plants per square meter). Nourai (1988) also reported progressive shift to smaller bulb size with increased plant populations of onion.

Moreover, the significant positive correlation of bulb diameter with leaf diameter (r =0.63***) and with leaf length (r =0.74***) in the present study reveal that production of longer and wider leaves at the sparsely populated plants contributed for the formation of larger sized bulbs as it enhanced accumulation of more assimilates (Appendix Table 7). However, the response is not equal for all varieties because of their genetic variation. Fasika *et al.* (2008) reported highly significant genetic differences among Ethiopian shallot genotypes for bulb diameter. Kimani *et al.* (1994) and Islam *et al.* (2007) also noticed difference in bulb diameter of onion due to genetic variation. Mohammedali (1989) also reported wider in-row spacing gave larger bulbs of onion. Tendaj (2005) reported an increase in intra-row spacing of shallot from 5 cm to 20 cm resulted in increment of percent share of bulbs having greater than 25 mm diameter from 13.70% to 47.20% and greatly affect the marketable yield.

4.2.2. Bulb length (cm)

The effects of varieties showed a highly significant ($p<0.01$) difference on bulb length (Fig. 15 and Appendix Table 3). Varieties 'Minjar', 'Huruta', and 'Negelle' produced highest and statistically similar bulb length than local and this variation might be due to the discrepancy among varieties inherent characteristics. This result is in agreement with Islam et al. (2007) that reported significant genotypic variation of bulb length on onion.

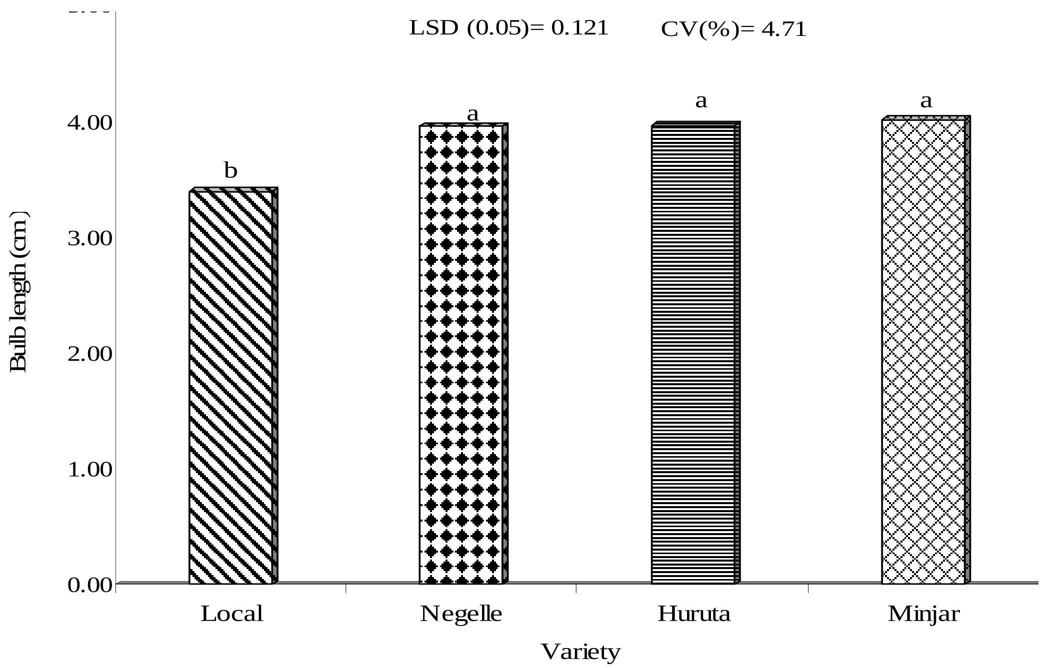

Fig.15. Effects of varieties on bulb length of shallot

The interaction effects of intra-row spacing with bulb topping showed a significant ($p<0.05$) difference on bulb length (Fig. 16 and Appendix Table 3).

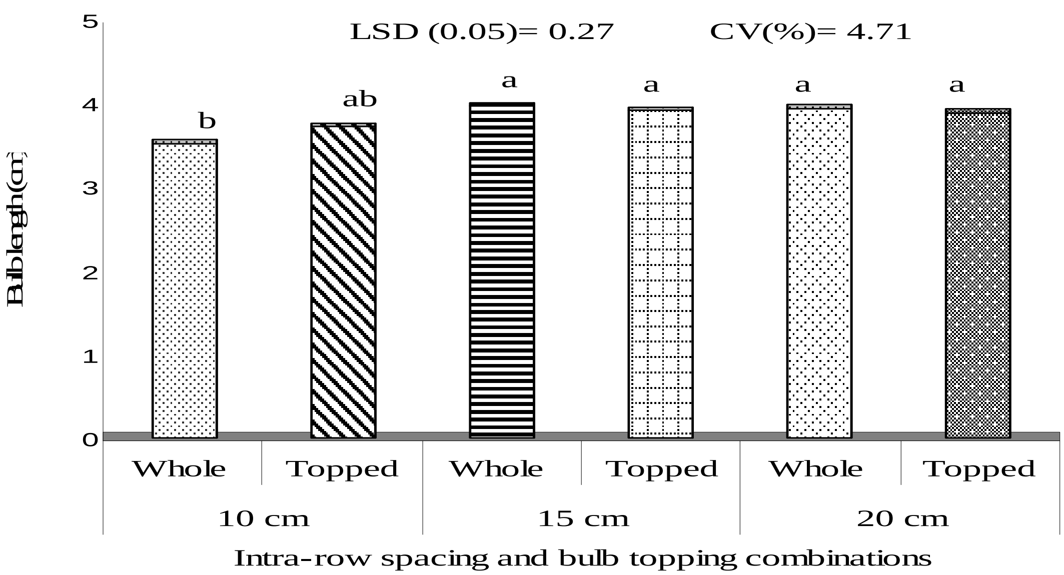

Fig.16. Intra row spacing and bulb topping effects on bulb length of shallot

Whole bulbs planted at 10 cm intra-row spacing produced the shorter bulbs than the rest of bulb treatment-intra-row spacings except topped bulbs planted at the same intra-row spacing. The production of shorter bulbs at densely populated plants might be due to competition effects. The highly significant positive correlation (r = 0.67***) between bulb diameter and bulb length of the present study revealed that as bigger bulbs developed from sparsely populated plants resulted in associated longer bulbs (Appendix Table 7).

4.2.3. Number of bulbs per plant

The interaction effects of variety, intra-row spacing and bulb topping showed a highly significant (p<0.01) difference on number of bulbs per plant (Table 5 and Appendix Table 3). Whole bulbs of '*Minjar'* planted at 20 cm intra-row spacing produced the highest number of bulbs per plant although it is not significantly different from its topped bulbs planted at 20 cm and whole bulbs planted at 15 cm and whole bulbs of local variety planted at 20 cm intra-row spacings, whereas both bulbs of *'Negelle'* planted at all intra-row spacings and both bulbs of *'Huruta'* planted at all spacings except the 20 cm intra-row spacing produced the lowest and statistically similar number of bulbs per plant. Getachew and Asfaw (2000) reported variation in average number of bulbs per plant from two to twelve among shallot varieties. When varieties with this variation planted at different spacing and bulb treatment (topping), they responded differently. Topped bulbs result in emergence of more and vigorous shoots (due to loss of apical dominance of main shoot) which in turn would develop into large bulbs reach at maturity with minimum loss when they are planted at wider spacings due to less competition and proper sanitation.

4.2.4. Number of marketable bulbs per plant

The interaction effects of variety, intra-row spacing and bulb topping showed a highly significant (p<0.01) difference on number of marketable bulbs per plant (Table 5 and Appendix Table 3). Topped bulbs of '*Huruta'* planted at 20 cm intra-row spacing produced the highest number of marketable bulbs per plant whereas topped bulbs of '*Minjar'* planted at

10 cm intra-row spacing produced the lowest number of marketable bulbs per plant. This might be due to the production of larger and healthy bulb at topped bulbs of *'Huruta'* planted at wider spacing which resulted in the absence of intense inter-plant competition. The highly significant and positive correlation (r = 0.51***) between number of marketable bulbs and bulb diameter in the present study also reveal the positive impact of topped bulbs planted at wider spacings on bulb diameter and associated marketability (Appendix Table 3).

Table 5. Number of total, marketable and unmarketable bulbs per plant of shallot as affected by the interaction of variety, intra-row spacing and bulb topping

Variety	Spacing (cm)	Bulb topping	Number of bulbs per plant		
			Total	Marketable	Unmarketable
Local	10	Whole	10.53^{f}	4.27^{jk}	6.27^{cd}
		Topped	11.27^{def}	4.83^{ij}	6.43^{bc}
	15	Whole	11.20^{ef}	5.93^{efgh}	5.27^{e}
		Topped	11.90^{cde}	6.43^{def}	5.47^{de}
	20	Whole	12.53^{abcd}	7.30^{bc}	5.23^{e}
		Topped	12.10^{bcde}	6.53^{cdef}	5.57^{de}
Negelle	10	Whole	7.60^{ij}	4.90^{ij}	2.70^{g}
		Topped	7.47^{ij}	5.43^{hi}	2.03^{ghij}
	15	Whole	7.83^{ij}	5.57^{ghi}	2.27^{ghi}
		Topped	8.43^{hij}	6.10^{defgh}	2.33^{gh}
	20	Whole	8.77^{hi}	6.90^{bcd}	1.87^{ghij}
		Topped	8.10^{hij}	6.77^{bcde}	1.33^{j}
Huruta	10	Whole	7.80^{ij}	4.13^{jk}	3.67^{f}
		Topped	7.43^{j}	5.93^{efgh}	1.50^{hij}
	15	Whole	7.30^{j}	6.10^{defgh}	1.20^{j}
		Topped	7.90^{hij}	6.73^{bcde}	1.17^{j}
	20	Whole	9.17^{gh}	7.47^{b}	1.70^{hij}
		Topped	10.57^{f}	9.17^{a}	1.40^{ij}
Minjar	10	Whole	10.20^{fg}	3.87^{k}	6.33^{bcd}
		Topped	12.13^{bcde}	2.97^{l}	9.17^{a}
	15	Whole	12.77^{abc}	4.23^{jk}	8.53^{a}
		Topped	11.37^{def}	5.83^{fgh}	5.53^{de}
	20	Whole	13.50^{a}	6.33^{defg}	7.12^{b}
		Topped	13.37^{ab}	6.17^{defgh}	7.2^{b}
LSD (0.05)			1.31	0.86	0.87
CV (%)			7.90	8.99	12.60

Means followed by the same letter(s) are not significantly ($p<0.05$) different

4.2.5. Number of unmarketable bulbs per plant

The interaction effects of variety, intra-row spacing and bulb topping showed a very highly significant ($p<0.001$) difference on number of unmarketable bulbs (Table 5 and Appendix Table 3). Topped bulbs of '*Minjar'* planted at 10 cm intra-row spacing produced the highest number of unmarketable bulbs per plant followed by whole bulbs of '*Minjar'* planted at 15 cm intra-row spacing. Topped bulbs of '*Huruta'* and '*Negelle'* planted at 20 cm intra-row spacing produced the lowest number of unmarketable bulbs per plant although not statistically different from all but whole bulbs of '*Huruta*' planted at 10 cm intra-row spacing and topped bulbs of '*Negelle*' planted at 10 cm spacing.

Generally, topped bulbs of '*Minjar'* planted at high population produced more number of unmarketable bulbs per plant whereas topped bulbs of '*Negelle'* and '*Huruta'* planted at wider spacing produced the lowest number of unmarketable bulbs per plant. This might be due to the fact that topped bulbs produced more number of vigorous shoots that bear thick leaves per plant which assimilate more photosynthetic product and produce large bulbs which could get adequate space and nutrients thus decreasing the number of unmarketable bulbs. In addition, sparsely populated plants have less chance of being exposed to sever disease which in turn maximizes the development of healthy and bigger bulbs; and the reverse happens when topped bulbs are planted at high density.

4.2.6. Total bulb weight per plant (g)

Interaction effects of variety, intra-row spacing and bulb topping showed a highly significant ($p<0.001$) difference on total bulb weight per plant (Table 6 and Appendix Table 4). Topped bulbs of '*Huruta'* planted at 20 cm intra-row spacing produced the highest bulb weight per plant followed by the same bulbs of '*Negelle'* planted at similar spacing, whole bulbs of '*Huruta'* planted at 15 cm and whole bulbs of local planted at 20 cm intra-row spacing, whereas both bulb types of '*Minjar'* planted at 10 cm intra-row spacing produced the lowest bulb weight per plant but not statistically different from each other.

Differences in shallot variety's responses to different intra-row spacings are manifested in differential ability to transform accumulated biomass to bulb production under different intensities of interplant competition. Differences in intra-row spacing enhanced plant-plant variation in terms of accumulated biomass and this phenomenon affected bulb yield and the stability of dry matter partitioning to bulbs. Large plants in wide in-row spacing have competitive advantage and could be identified with high capacity for resource capture and use for bulb production.

Table 6. Total, marketable and unmarketable bulb weight per plant of shallot as influenced by the interaction of variety, intra-row spacing and bulb topping

Variety	Spacing (cm)	Bulb topping	Weight (gram per plant)		
			Total bulbs	Marketable bulbs	Unmarketable bulbs
Local	10	Whole	160.04^{mn}	80.58^{m}	79.46^{bc*}
		Topped	168.57^{lm}	91.99^{m}	76.56^{c}
	15	Whole	198.97^{ij}	130.77^{jk}	68.20^{d}
		Topped	202.39^{hij}	138.89^{j}	63.50^{e}
	20	Whole	270.75^{b}	193.73^{fg}	77.03^{c}
		Topped	238.64^{de}	170.65^{hi}	67.99^{d}
Negelle	10	Whole	151.55^{n}	111.10^{l}	40.45^{f}
		Topped	169.68^{lm}	137.13^{j}	32.55^{g}
	15	Whole	191.05^{jk}	161.27^{i}	29.78^{gh}
		Topped	211.68^{ghi}	183.80^{gh}	27.89^{h}
	20	Whole	222.68^{fg}	217.33^{ed}	5.35^{kl}
		Topped	277.34^{b}	273.69^{b}	3.65^{l}
Huruta	10	Whole	146.86^{no}	117.94^{kl}	28.92^{gh}
		Topped	180.98^{kl}	157.83^{i}	23.15^{i}
	15	Whole	217.43^{gh}	204.36^{ef}	13.07^{j}
		Topped	234.98^{ef}	223.25^{d}	11.73^{j}
	20	Whole	263.24^{bc}	252.63^{c}	10.61^{j}
		Topped	308.85^{a}	299.48^{a}	9.38^{jk}
Minjar	10	Whole	132.69^{op}	63.60^{n}	69.09^{d}
		Topped	125.65^{p}	59.05^{n}	66.61^{de}
	15	Whole	182.53^{kl}	107.15^{l}	75.38^{c}
		Topped	209.77^{ghi}	127.65^{jk}	82.12^{b}
	20	Whole	252.37^{cd}	161.46^{i}	90.91^{a}
		Topped	223.97^{efg}	133.48^{j}	90.49^{a}
LSD (0.05)			15.81	14.72	4.21
CV (%)			4.67	5.56	5.37

Means followed by the same letter in a column are not significantly ($p<0.05$) different

This result is consistent with Tendaj (2005) who reported that shallot clusters varied in weight from 50.7 g to 342.7 g when shifted from high to low planting density. Kimani *et al.* (1993) also reported significant bulb yield variation among eight onion cultivars and this variation present among cultivars had different response to factors. Kanton *et al.* (2003) reported a decrease in bulb weight as the plant population per square meter increased from 50 to 200 plants likely due to competition associated with closely spaced plants that resulted in lower bulb weight per plant. Abubaker (2008) also reported that the highest yield per plant of bean was obtained from 20 and 30 cm spacings as compared to higher planting densities of 10 cm. Topped bulbs produced vigorous shoot and owing to optimum space, they would result in bulbs with wider diameter and higher yield. Moreover, better air circulation reduces disease occurrence which contributes to higher yield per plant. Palada and Crossman (1998) also reported that an increase in okra fresh weight per plant from 38 g to 70 g with the increasing in plant spacing from 31 cm to 41 cm due to increasing in the number of stem and wider leaf area per plant at wider spacing. In case of *'Minjar'* and local varieties, due to their bolting nature, they produced thinner bulb diameter and lower yield per plant.

The result is in agreement with Rashid and Singh (2000) who reported that bulb topping should be practiced to enhance vigorous sprouting. In contrast, Getachew and Asfaw (2000) and Sharma *et al.* (2008) reported topped bulbs produced low yield. The significant positive correlation between total bulb weight per plant and leaf number ($r = 0.43^{***}$), leaf length ($r = 0.34^{**}$), leaf diameter ($r = 0.41^{***}$), bulb diameter ($r = 0.54^{***}$), and marketable bulb number per plant ($r = 0.88^{***}$) in the present study revealed that the presence of high bulb weight per plant is associated with the positive influences of planting topped bulbs at wider spacing at the same treatment combinations (Appendix Table 7).

4.2.7. Weight of marketable bulbs per plant (g)

Interaction effects of variety, intra-row spacing and bulb topping showed a highly significant ($p<0.001$) difference on weight of marketable bulbs per plant (Table 6 and Appendix Table 4). Topped bulbs of '*Huruta'* planted at 20 cm intra-row spacing produced the highest weight of marketable bulbs followed by topped bulbs of '*Negelle*' with the same intra-row spacing, whereas both bulb types of '*Minjar*' planted at 10 cm intra-row spacing produced the lowest weight of marketable bulbs although not significantly different from each other. High marketable bulb weight in topped bulbs of '*Huruta*' and '*Negelle*' at wider spacing could be accounted by the production of larger and healthy bulbs at these treatments. The significant positive correlation between marketable bulb weight and leaf length (r = 0.59***), leaf diameter (r = 0.57***), bulb diameter (r = 0.76***), and marketable bulb number (r = 0.87***) in the present study revealed that the presence of high marketable bulb weight is associated with the positive influences of planting topped bulbs of '*Huruta*' and '*Negelle*' varieties at wider spacing on photosynthetic area and the resulted sink (Appendix Table 7).

4.2.8. Weight of Unmarketable bulbs per plant (g)

The interaction effects of variety, intra-row spacing and bulb topping showed a significant ($p<0.05$) difference on weight of unmarketable bulbs per plant (Table 6 and Appendix Table 4). Both bulb types of '*Minjar*' planted at 20 cm intra-row spacing produced the highest but statistically similar weight of unmarketable bulbs followed by topped bulbs of '*Minjar*' planted at 15 cm intra-row spacing and whole bulbs of local variety planted at 10 cm intra-row spacing. On the other hand, topped bulbs of '*Negelle*' planted at 20 cm intra-row spacing produced the lowest weight of unmarketable bulbs per plant followed by topped bulbs of '*Huruta*' planted at 20 cm intra-row spacing. Production of high unmarketable bulb weight in topped bulbs of '*Minjar*' at wider spacing might due to the production of high amount of bolters in these treatments (Table 4.3) which resulted in small sized bulbs. The significant positive correlation between unmarketable bulb weight per plant and number of flower stalks per plant (r = 0.82***), and unmarketable bulb number per plant (r = 0.90***) in the present study revealed that the presence of high unmarketable bulb weight is associated with the production of more unmarketable bulbs and high bolters in '*Minjar*' variety planted at narrow intra-row spacing (Appendix Table 7).

4.2.9. Biological yield per plant (g)

Interaction effects of variety, intra-row spacing and bulb topping showed a very highly significant ($p<0.001$) difference on biological yield per plant (Table 7 and Appendix Table 4).

Table 7. Biological yield and harvest index per plant of shallot as influenced by the interaction of variety, intra-row spacing and bulb topping

Variety	Spacing (cm)	Bulb topping	Biological yield/plant (g)	Harvest index/plant (%)
Local	10	Whole	201.15[kl]	79.71 (8.93[abcd])
		Topped	214.51[jk]	78.60 (8.87[abcd])
	15	Whole	255.22[i]	78.28 (8.84[abcd])
		Topped	249.56[i]	81.27 (9.01[abc])
	20	Whole	345.46[cd]	78.42 (8.86[abcd])
		Topped	284.03[fg]	84.01 (9.16[a])
Negelle	10	Whole	194.94[kl]	77.84 (8.82[abcd])
		Topped	210.93[jk]	80.42 (8.97[abcd])
	15	Whole	257.16[hi]	74.28 (8.62[dc])
		Topped	278.77[g]	75.99 (8.62[bcd])
	20	Whole	300.84[ef]	74.13 (8.60[d])
		Topped	363.08[c]	76.45 (8.74[bcd])
Huruta	10	Whole	184.98[l]	79.33 (8.91[abcd])
		Topped	226.13[j]	80.11 (8.95[abcd])
	15	Whole	282.37[fg]	76.98 (8.77[abcd])
		Topped	287.47[fg]	82.06 (9.06[ab])
	20	Whole	341.65[d]	77.04 (8.78[abcd])
		Topped	406.13[b]	76.05 (8.72[bcd])
Minjar	10	Whole	275.95[gh]	48.20 (6.94[g])
		Topped	314.20[e]	40.06 (6.33[h])
	15	Whole	388.97[b]	46.94 (6.85[g])
		Topped	387.73[b]	54.13 (7.36[f])
	20	Whole	494.41[a]	50.99 (7.13[fg])
		Topped	340.23[d]	66.05 (8.11[e])
LSD (0.05)			19.76	6.54 (0.392)
CV (%)			4.07	5.55 (2.83)

Means followed by the same letter in a column are not significantly ($p<0.05$) different

Numbers in parenthesis are square root transformations

Whole bulbs of '*Minjar*' planted at 20 cm intra-row spacing produced the highest biological yield per plant whereas whole bulbs of '*Negelle*' and '*Huruta*' planted at 10 cm intra-row spacing produced the lowest biological yield per plant though they were statistically akin. The production of higher biological yield in '*Minjar*' could be because of more flower stalks. Bulbs planted at wider spacing grow more vigorously and obtained more biological yield per plant.

The significant positive correlation between biological yield and total bulb weight (r = 0.63***), leaf diameter (r = 0.34**), number of shoots (r = 0.31**), number of flower stalks (r = 0.38**), number of bulbs (r = 0.50***), marketable bulb weight (r = 0.39**), bulb length (r = 0.53***), and number of marketable bulbs (r = 0.40**) in the present study revealed that the presence of high biological yield per plant is associated with both aboveground and underground biomass (Appendix Table 7).

4.2.10. Harvest index per plant (%)

The interaction effects of variety, intra-row spacing and bulb topping showed a very highly significant ($p<0.001$) difference on harvest index per plant (Table 7 and Appendix Table 5). Both bulbs of local, '*Negelle*' and '*Huruta*' varieties planted at all intra-row spacings produced the highest and statistically similar harvest index per plant except both bulb types of '*Negelle*' planted at 15 and 20 cm intra-row spacing and topped bulbs of '*Huruta*' planted at 20 cm intra-row spacing. Whereas, topped bulbs of '*Minjar*' planted at 10 cm intra-row spacing produced the lowest harvest index per plant. Higher harvest index was more pronounced in local, '*Huruta*' and '*Negelle*' varieties planted almost at all bulb types and intra-row spacings. This might be, in case of local presence of shorter leaf and plant height and thin leaf diameter will reduced the above ground biomass and resulted in higher harvest index, whereas in case of '*Negelle*' and '*Huruta*', production of smaller number of leaves and relatively larger bulbs accounted the highest harvest index per plant.

The lower harvest index in '*Minjar*' might be due to the production of more flower stalks which diverted assimilates away from the economically important bulbs. Agele *et al.* (2007) also reported a significant interaction effect between sun flower varieties and intra-row spacing in terms of total biomass accumulation. Kabir and Sarkar (2008) also reported a significant interaction effect on harvest index of mungbean and the highest value recorded from varieties at closer spacing probably due to the reduced vegetative biomass. The significant positive correlation between harvest index and total bulb weight (r = 0.33**), marketable bulb number (r = 0.48***), and weight of marketable bulbs (r = 0.49***) in the present study also revealed that the presence of high harvest index is associated with the production of high bulb weight relative to the other biomass. On the other hand a highly significant negative association between harvest index and number of flower stalks (r = -0.77***) also indicate the production of lower harvest index in '*Minjar'* variety (Appendix Table 7).

4.2.11. Total yield (t/ha)

The interaction effects of variety, intra-row spacing and bulb topping showed a significant ($p<0.05$) difference on total yield per hectare (Table 8 and Appendix Table 5). Topped bulbs of '*Huruta'* planted at 10 cm intra-row spacing produced the highest yield per hectare but not statistically different from the same variety and bulb type planted at 15 and 20 cm and topped bulbs of '*Negelle'* planted at 15 cm intra-row spacing. The higher number of bulbs obtained from '*Huruta'* and '*Negelle'* at higher densities (10 cm and 15 cm) at harvest compensated for the lower bulb weight associated with higher plant population densities. Whereas, topped bulbs of '*Minjar'* planted at 10 cm intra-row spacing produced the lowest total yield per hectare although it was not statistically different from whole bulbs of the same variety planted at the same spacing and both bulb types of local planted at 10 cm and whole bulbs of '*Negelle'* planted at 15 cm and 20 cm intra-row spacings. Although the narrow spacing produced smaller plants with lower leaf length and diameter per unit area more plants in narrow spacing resulted in higher leaf area index. This indicates that higher number of plants per unit area in the narrow spacing compensating for the lower leaf area per plant resulting in higher leaf area index and higher total yield.

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. This result is in agreement with Tendaj (2005) who reported that an increase in intra-row spacing of shallot from 5 cm to 20 cm resulted in reduction of total yield from 36.0 t/ha to 23.9 t/ha but the majority (86%) of the bulbs are undersized and then unmarketable in case of 5 cm intra-row spacing. Rekowska and Skupien (2007) also observed that significantly higher yield of bulbs and green leaves of garlic was collected when the highest clove planting density in the row has been used (2 cm).

Table 8. Total, marketable, and unmarketable yield (t/ha) of shallot as affected by the interaction effect of variety, intra-row spacing and bulb topping

Variety	Spacing (cm)	Bulb topping	Yield (qt/ha)		
			Total	Marketable	Unmarketable
Local	10	Whole	27.54[ghi]	13.80[m]	13.74[a]
		Topped	26.51[hi]	14.27[m]	12.24[b]
	15	Whole	31.65[e]	20.79[ij]	10.86[c]
		Topped	34.63[cd]	23.63[fg]	11.00[c]
	20	Whole	32.56[de]	23.41[g]	9.15[ef]
		Topped	30.48[ef]	22.15[ghi]	8.33[g]
Negelle	10	Whole	31.86[f]	23.24[gh]	8.62[fg]
		Topped	28.28[fgh]	22.92[gh]	5.36[i]
	15	Whole	27.46[hi]	23.02[gh]	4.44[j]
		Topped	36.39[abc]	32.39[bc]	4.00[jk]
	20	Whole	26.37[hi]	24.00[fg]	2.37[l]
		Topped	35.26[bc]	33.50[ab]	1.76[l]
Huruta	10	Whole	31.78[e]	25.60[f]	6.18[h]
		Topped	38.08[a]	28.56[e]	9.52[de]
	15	Whole	35.06[cd]	29.80[de]	5.26[i]
		Topped	37.74[ab]	32.08[bc]	5.66[hi]
	20	Whole	34.72[cd]	31.25[de]	3.47[k]
		Topped	36.21[abc]	35.48[a]	0.73[m]
Minjar	10	Whole	26.52[hi]	12.55[mn]	13.97[a]
		Topped	24.92[i]	10.97[n]	13.95[a]
	15	Whole	30.10[efg]	16.56[l]	13.54[a]
		Topped	34.70[dc]	21.17[hij]	13.53[a]
	20	Whole	28.53[fgh]	18.40[kl]	10.13[d]
		Topped	30.56[ef]	19.26[jk]	11.30[c]
LSD (0.05)			2.63	2.07	0.68
CV (%)			5.07	5.42	4.98

Means followed by the same letter in a column are not significantly ($p<0.05$) different

Kanton *et al.* (2003) also reported onion yield increased from 17.4 t/ha to 39.5 t/ha as plant population per square meter increased from 50 to 150. Carlson *et al.* (2009) reported plant density did impact the yield of two potato varieties and both varieties produced highest total yields at the closest plant spacing 17.75 cm. Hemphill (1987) also reported that a fourfold increase in planting density doubled the yield of shallot. Yield per unit area did not increase proportionally to the increase in planting density since both bulb weight and the number of bulbs produced per plant decreased at higher densities. The author further explained that low planting density and small planting stock size favoured production of large bulbs required for some markets, but with greatly reduced total yield.

In contrast to the results of the present study, Kabir and Sarkar (2008) also reported that interaction effects between variety and spacing were significant for seed yield of mungbean and the highest value was recorded at wider spacing which has less population density. Sharma *et al.* (2008) and Getachew *et al.* (2000) also reported that planting topped bulbs resulted in reduced yield. The significant positive correlation between total yield per hectare and plant height (r = 0.25*), leaf length (r = 0.38**), marketable bulb number per plant (r = 0.55***), bulb diameter (r = 0.53***), and weight of marketable bulbs per plant (r = 0.60***) in the present study also revealed that the presence of higher yield per hectare is associated with the presence of maximum interception and the obtained high bulb weight form topped bulbs planted at wider spacings (Appendix Table 8). As compared with the national average yield of shallot (25.00 t/ha, Getachew *et al*,.2009), except topped bulbs of '*Minjar*' planted at 10 cm intra-row spacing, all the treatments gave higher yield and '*Huruta*' planted at 10 cm intra-row spacing gave 66% more yield as compared to the yield obtained from improved varieties. This variation might be due to the suitability of the experimental site in terms of soil pH (5.7) and organic matter (4.7%).

4.2.12. Marketable yield (t/ha)

The interaction effects of variety, intra-row spacing and bulb topping showed a highly significant ($p<0.01$) difference on marketable yield per hectare (Table 8 and Appendix Table 5). Topped bulbs of '*Huruta*' planted at 20 cm intra-row spacing produced the highest marketable yield per hectare but not statistically different from topped bulbs of '*Negelle*' planted at 20 cm intra-row spacing. On the other hand, both bulbs of '*Minjar*' planted at 10 cm intra-row spacing produced the lowest and statistically similar marketable yield per hectare. Production of high amount of marketable yield in topped bulbs of '*Huruta*' and '*Negelle*' at wider spacings might be due to the advantage of producing larger and healthier bulbs per plant on those treatments.

This result is in agreement with Tendaj (2005) who reported that an increase in intra-row spacing of shallot from 5 cm to 20 cm resulted in increase in marketable yield from 21 q/ha to 104 q/ha. Stoffella (1996) also observed that as in-row spacing increased, marketable onion yield increased. Tendaj and Kuzyk (2001) also observed among the intra-row spacings observed (30, 40, 50 and 60 cm) the 40 and 50 cm spacings produced the highest marketable yield of cabbage. Carlson *et al.* (2009) also reported that the wider spacing of 32.50 cm between plants increased in the production of large sized tubers. The highly significant positive correlation between marketable yield per hectare and plant height (r = 0.50***), leaf length (r = 0.64***), leaf diameter (r = 0.53***), marketable bulb number per plant (r = 0.68***), bulb diameter (r = 0.81***), and weight of marketable bulbs per plant (r = 0.72***) in the present study also revealed that the presence of higher marketable yield per hectare is associated with the presence of maximum interception and production of larger and healthy bulbs form topped bulbs planted at wider spacings (Appendix Table 7).

4.2.13. Unmarketable yield (t/ha)

The interaction effects of variety, intra-row spacing and bulb topping showed a highly significant ($p<0.01$) difference on marketable yield per hectare (Table 8 and Appendix Table 5). Whole bulbs of '*Minjar*' planted at 10 cm intra-row spacing and produced the highest unmarketable yield per hectare but not statistically different from topped bulbs of '*Minjar*' planted at 10 cm intra-row spacing and both bulb types of '*Minjar*' planted at 15 cm intra-row spacing and whole bulbs of local planted at 10 cm intra-row spacing. Whereas, topped bulbs of '*Huruta*' planted at 20 cm intra-row spacing produced the lowest unmarketable yield per hectare followed by topped bulbs of '*Negelle*' planted at 20 cm intra-row spacing and whole bulbs of '*Negelle*' planted at 20 cm intra-row spacing. High unmarketable yield in closely spaced plants could be due to inter-plant competition resulted in a fewer large sized bulbs than wider spacings that negatively affected the marketable yield and favored the production of small sized bulbs which are unmarketable.

Results of the present study are in consistence with Awase *et al*. (2010) who pointed out that unmarketable yield of onion is affected by the interaction between variety and intra-row spacing. The authors observed that Bombey Red planted at 10 cm intra-row spacing produced the highest unmarketable yield (89.87 q/ha). The significant positive correlation between unmarketable yield per hectare and number of flower stalks per plant (r = 0.79***) and weight of unmarketable bulbs per plant (r = 0.88***) in the present study also revealed that the presence of higher unmarketable yield per hectare is associated with the presence of flower stalks and more unmarketable bulbs per plant at closer spacings (Appendix Table 7).

4.3. Quality parameters

4.3.1. Dry matter content (%)

The varietals effect showed a very highly significant ($p<0.001$) difference on dry matter content (Fig. 17 and Appendix Table 6).

However, none of the main and interaction effects other than variety were significant. Local variety produced the highest dry matter content followed by '*Minjar*'. The Local variety had 1.56%, 3.23% and 3.27% more dry matter than '*Minjar*', '*Negelle*' and '*Huruta*', respectively which might be attributed to their genetic variation. Kimani *et al.* (1993) reported a dry matter content variation from low levels of 7-10% to high levels of 15-20% in onion varieties. The authors further suggested that onions with high dry matter are preferred for processing. They further showed that onions with high dry matter content tend to yield less than those with low dry matter content and the latter also exhibit rapid bulbing.

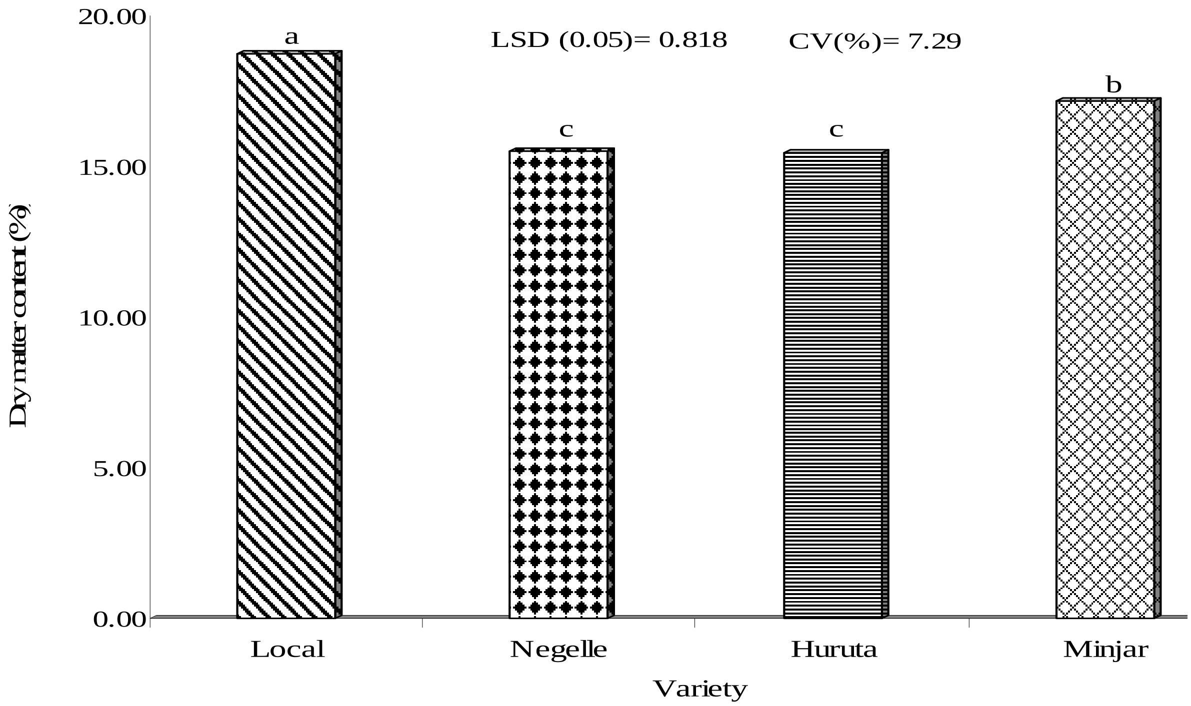

Fig.17. Effects of varieties on percent dry matter content of shallot

4.3.2. Bulb dry weight (g)

The effects of intra-row spacing on bulb dry weight was very highly significant (p<0.001) (Fig. 18 and Appendix Table 6) and bulbs planted at 20 cm intra-row spacing produced greater bulb dry weight per plant than those planted at 15 cm and 10 cm intra-row spacings.

Shallot bulbs planted at 20 cm intra-row spacing had bulb dry weight advantage of 8.7 g and 17.25 g over crops planted at 15 cm and 10 cm intra-row spacings, respectively. The results of this study is in concurrent with Mohammedali (1989) that reported the different in-row spacings had no effect on the dry matter content of onion and so provision of high fresh bulb yields per plant could ultimately lead to high total dry weight production and dehydrated product. Abubaker (2008) also reported that pod dry weight of bean tended to be higher under the lower planting densities.

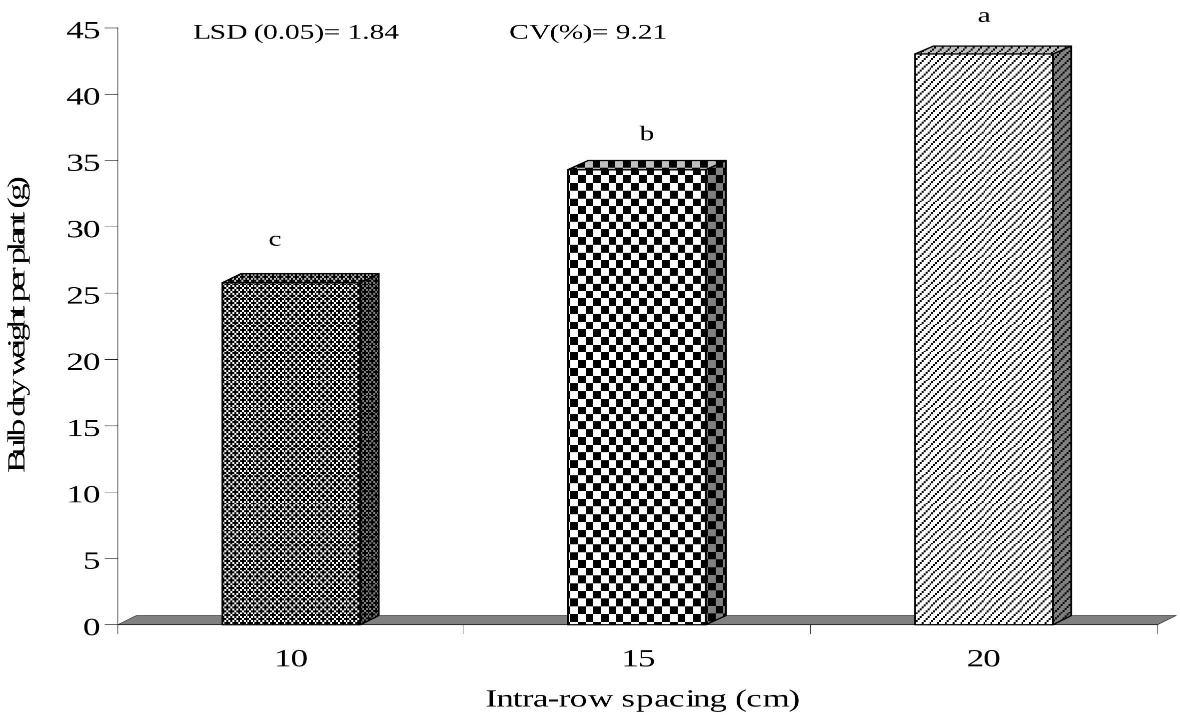

Fig.18. Effect of intra-row spacing on bulb dry weight per plant of shallot

Interactive effects of variety and bulb topping revealed a significant ($p<0.05$) difference on bulb dry weight per plant (Fig. 19 and Appendix Table 6).

Whole bulbs of '*Negelle*' had the lowest dry weight, but not significantly different form its topped bulbs, whole bulbs of '*Huruta*' and '*Minjar*'. The highly significant positive correlation between bulb dry weight per plant and marketable bulb number per plant (r = 0.78***), weight of marketable bulbs per plant (r = 0.68***), total bulb fresh weight per plant (r = 0.90***), and dry matter content (r=0.35**) in the present study also revealed that the presence of higher bulb dry weight per plant is associated with the higher bulb fresh weight (incase of '*Huruta*' and '*Negelle*') as well as with the higher dry matter content (incase of local and '*Minjar')* (Appendix Table 7).

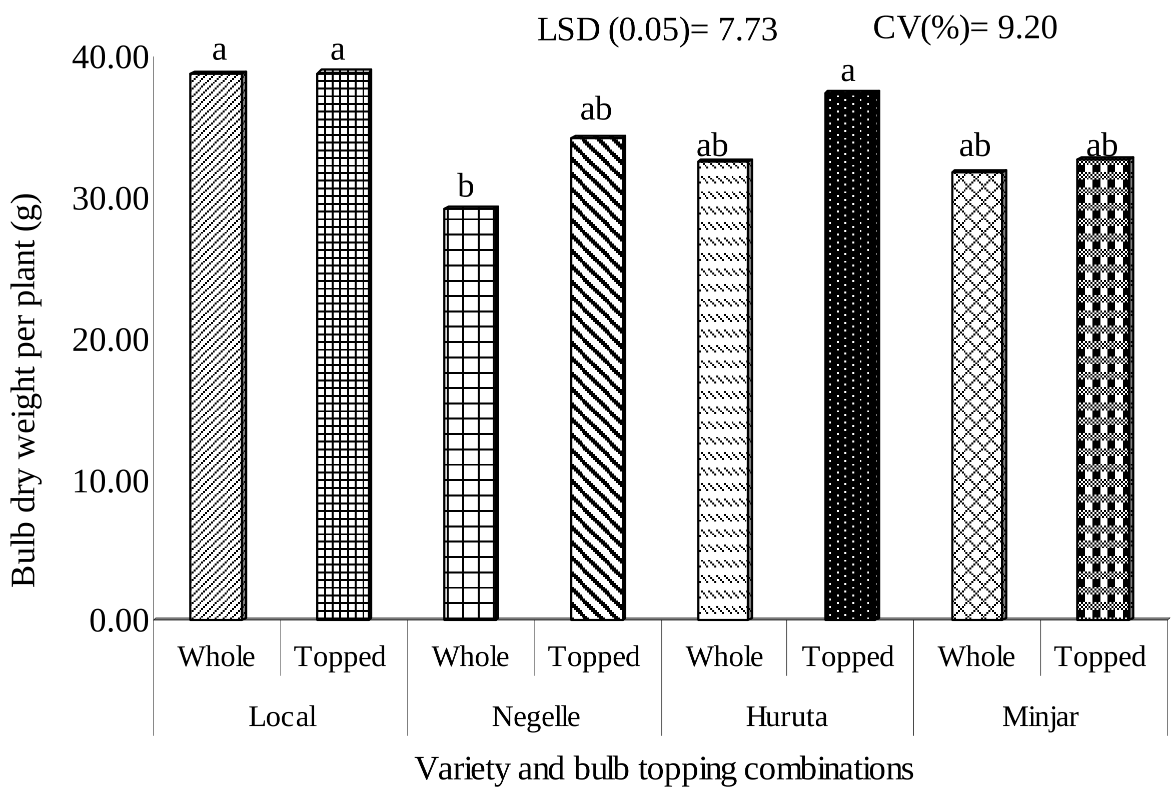

Fig.19. Effects of variety and bulb topping on bulb dry weight per plant of shallot

4.3.3. Total soluble solid (%)

The interaction effects of variety, intra-row spacing and bulb topping showed a very highly significant ($p<0.001$) difference on total soluble solid (Table 9 and Appendix Table 6).

Topped bulbs of Local variety planted at 20 cm intra-row spacing and whole bulbs of the same variety planted at 15 cm intra-row spacing produced the highest total soluble solid. Whereas both bulb types of '*Huruta*' planted at 10 cm intra-row spacing produced the lowest but statistically similar total soluble solid. The higher amount of total soluble solid in local and '*Minjar*' might be associated with the presence of small sized bulbs. This result is in consistency with Rajcumar (1997) who reported that a total soluble solid variation of about 4.0% to 16.3% and the maximum was recorded from the Local cultivar onion. He further suggested cultivars with high bulb yields have lower total soluble solids content as compared to the cultivars with lowest yields and a negative correlation (r=-0.85) between bulb yield and soluble solids content was found, suggestive of a strong association between these two character.

Table 9. Interaction effects of variety, intra-row spacing and bulb topping on total soluble solid of shallot

Variety	Spacing (cm)	Bulb treatment	
		Whole	Topped
Local	10	13.40^{bc}	13.87^{b}
	15	15.00^{a}	13.00^{cd}
	20	13.67^{bc}	15.17^{a}
Negelle	10	12.00^{efgh}	12.33^{def}
	15	11.07^{i}	11.23^{hi}
	20	11.33^{ghi}	12.33^{def}
Huruta	10	10.67^{i}	10.83^{i}
	15	11.50^{fghi}	12.90^{cd}
	20	12.17^{defg}	12.17^{defg}
Minjar	10	13.33^{bc}	12.35^{de}
	15	12.17^{defg}	12.17^{defg}
	20	12.27^{def}	12.87^{cd}
LSD (0.05)		0.84	
CV (%)		4.07	

Means followed by the same letter(s) are not significantly ($p<0.05$) different

Mallor *et al.* (2010) also reported significant negative correlation found between bulb weight and soluble solids content. They elaborate these results indicate a trend in larger onions to contain lower rates of both organosulfur derivatives and carbohydrates; therefore, suggesting that bulb size increase was because of higher water content. Walsh *et al.* (2007) also reported that higher total soluble solid obtained from fruits of plum, peach and nectarine harvested from higher canopy positions with the increase availability of photo assimilates at higher canopy positions due to higher level of irradiation.

In the present study, total soluble solid was also negatively correlated with bulb diameter (r = -0.58***), bulb length (r = -0.52***) and positively correlated with unmarketable bulb number per plant (r = 0.44***) that indicating high total soluble solid content is associated with smaller bulbs (Appendix Table 7).

4.3.4. Shape of bulb

The interaction effects of variety and intra-row spacing showed a highly significant ($p<0.01$) difference on bulb shape index (Fig. 20 and Appendix Table 6). '*Minjar*' planted at 10 cm intra-row spacing produced a higher and undesirable bulb shape index (1.61). Whereas '*Huruta*' planted at 15 cm and 20 cm intra-row spacings produced small bulb shape index. As the bulb shape index become higher, it shows the presence of longer bulb length which result in more cylindrical/oval shape. When bulbs of different varieties planted at closer spacing, competition between bulbs result is longer bulbs with slim diameter (high bulb shape index).

Bulb shape depends on variety, depth of planting and soil type. Heavier soils and shallow setting produce a more flattened bulb. Kimani *et al.* (1993) reported bulb shape difference among onion cultivars and was affected by environmental conditions. They further explained globe shaped (shape index = 1) are preferred by consumers.

Bulb shape and size may also be related to the length of growing period with rapid growth resulting in elongated bulbs while long growing periods produce larger bulbs (Delahaut and Newenhouse, 2003) which was true in the case of '*Minjar*'. The result is also in conformity with the work of Grant and Carter (2010) that pointed out increasing plant density of onion from 50 to 100 plants per square meter increased the percentage of shape rejects due to increased bulb shape index from 7.9 to 15.3%. Crowding plants will produce smaller and slimmer bulbs. According to the authors, bulbs having a shape index of >1.2 were regarded as having an unacceptable shape for New Zealand export grade onions as European markets demand a flattened globe (shape index of nearly one) shaped onion for ease of packaging. Kanton *et al.* (2003) also reported the increase in bulb shape index of onion with increasing in plant population.

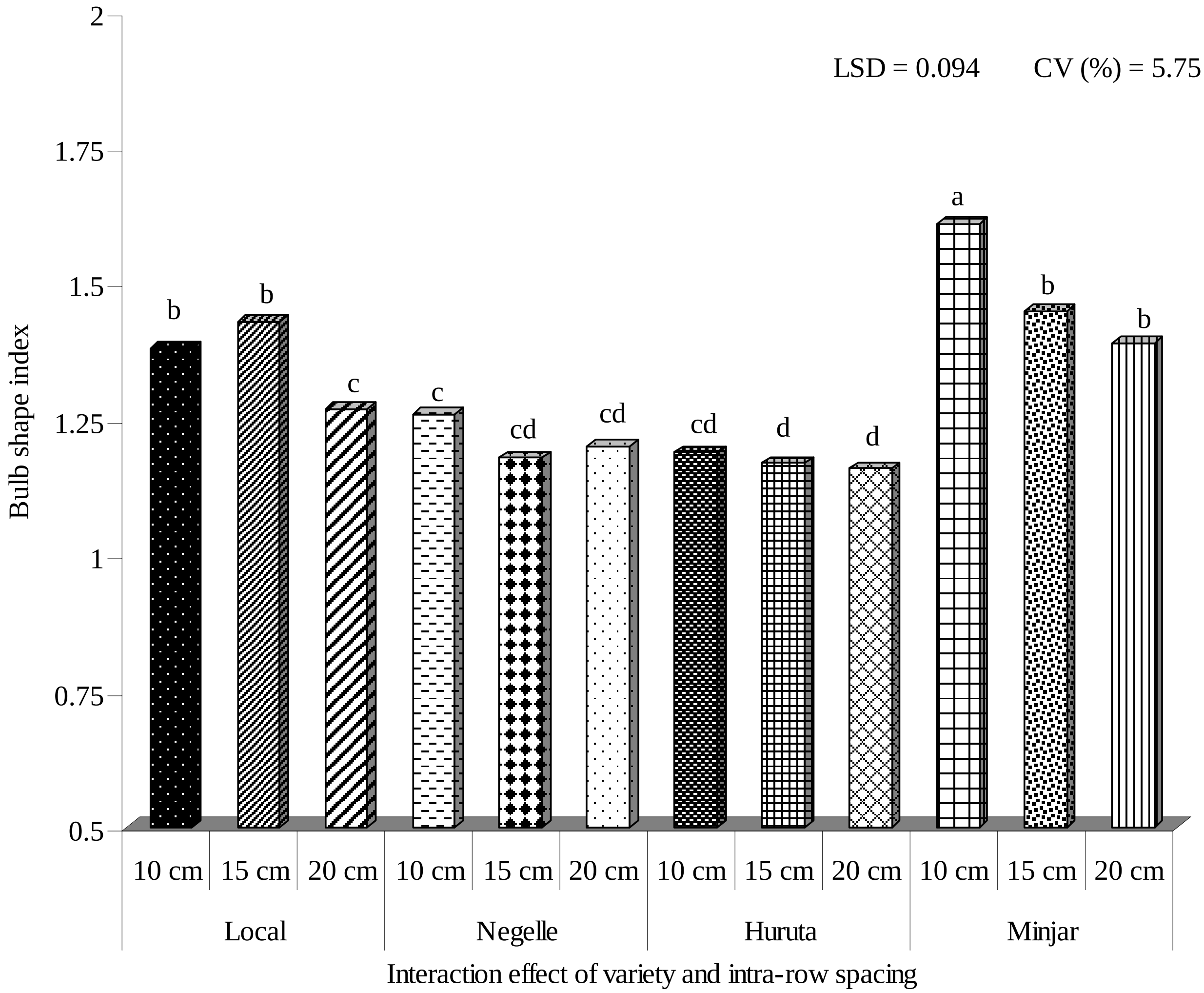

Fig.20. Interaction effect of variety and intra-row spacing on bulb shape index of shallot

4.3.5. Bulb color

The main effects of variety on bulb skin color was very highly significant ($p<0.001$; Fig. 21 and Appendix Table 7).

'*Minjar*' produced deep red bulb skin color followed by the local variety that produced red bulb skin colour. '*Negelle*' and '*Huruta*' produced similar light red bulb skin color. The red and deep red skin color bulbs are more demanded by the consumers in the market. This result is substantiating Getachew and Asfaw (2000) who reported bulb shape and skin colour variations were observed among the Ethiopian shallot cultivars.

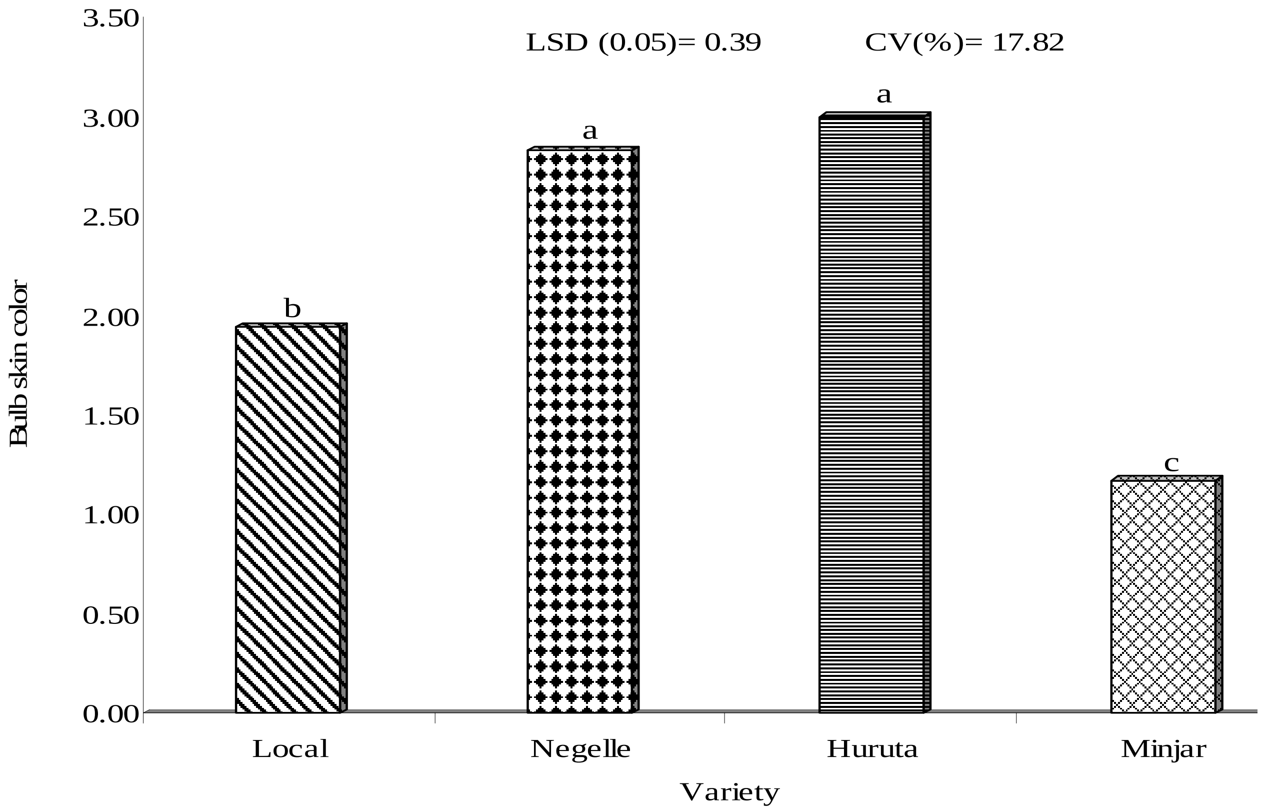

Fig.21. Effects of variety on bulb skin color of shallot

5. SUMMARY AND CONCLUSIONS

Shallot is one of the popular and the most cultivated vegetables in Ethiopia in general and in Amhara region in particular. Farmers in the study area produce shallot as a cash crop using topped bulbs of local varieties with non-uniform plant spacing based on the existing indigenous knowledge. The present study was thus conducted to investigate the effect of different intra-row spacings and bulb topping on yield and yield components of four shallot varieties and to recommend options for farmers in and around the study area. It was conducted under irrigation condition at East Gojam Zone, Aneded Woreda agriculture and rural development office nursery site (Gudalima) in 2009/2010 off season. The experiment consisted of factorial combinations of three intra-row spacings (10, 15 and 20 cm), two types of bulbs (whole bulb and topped at one-third of bulb height) and four varieties (Local, '*Negelle', 'Huruta'* and *'Minjar'*) designed in Randomized Complete Block with three replications. Data on days to emergence were collected at 50 percent emergence. Data on growth parameters were collected at maturity before harvest. Data on yield and quality parameters were collected at harvest.

Results of the study showed that main effects of intra-row spacing, bulb topping and varieties as well as their interactions had substantial influences on different parameters. Plant height and bulb dry weight per plant were increased with increase in intra-row spacing from 10 to 20 cm. Thus it is advisable to produce shallot at 20 cm intra-row spacing to fetch maximum bulb dry weight per plant. Topped bulbs emerged and matured earlier than whole bulbs. In addition, leaf and bulb diameter were increased when topped bulbs were planted. However, leaf sheath length decreased when topped bulbs were planted. The results suggested that both early emergence and maturity and larger leaf and bulb diameter could be obtained if topped bulbs are planted. '*Minjar'* was superior in terms of days to 50 percent emergence, leaf sheath length, bulb length, maturity date, and bulb skin color. On the other hand, local variety was superior in dry matter content but it was inferior in earliness and leaf sheath length. Therefore, the pronounced variability of the four varieties might suggest that they are distinct in their genetic makeup and in their response to the environmental conditions of the study area.

The combined effects of varieties with intra-row spacing were also significant for bulb diameter, and bulb shape index. Thus, '*Huruta'* and '*Negelle'* planted at 15 and 20 cm intra-row spacings produced the highest bulb diameter and the lowest bulb shape index. Therefore, it is advisable to plant '*Negelle'* and '*Huruta'* varieties at wider spacing for bigger bulb with desirable bulb shape index. The combined effects of variety with bulb topping were significant for plant height, leaf number, leaf length, and bulb dry weight per plant. Topped bulbs of '*Huruta'* produced the highest leaf length and bulb dry weight per plant. Therefore, to have vigorous plants with maximum height and leaf length, topped bulbs of '*Huruta'* is recommended followed by '*Negelle'* variety with the same bulb type. The combined effect of intra-row spacing with bulb topping was also significant for leaf length and bulb length. Whole bulbs of all the four varieties bulbs planted at 15 and 20 cm intra-row spacing produced higher leaf and bulb length.

In addition, the mutual effect of variety, intra-row spacing and bulb topping were significant for number of shoots and bolters per plant, total, marketable and unmarketable bulb numbers per plant, bulb fresh weight, biological yield and harvest index per plant, total, marketable and unmarketable yield per ha and total soluble solid. Topped bulbs of '*Huruta'* planted at 20 cm intra-row spacing produced the highest marketable bulb number per plant. Therefore, for production of high number of marketable bulbs and associated yield per plant, planting topped bulbs of '*Huruta'* at wider intra-row spacing (20 cm) is advisable. Topped bulbs of '*Huruta'* planted at all intra-row spacings and '*Negelle'* planted at 15 and 20 cm intra-row spacings produced higher and statistically similar total yield. On the other hand topped bulbs of '*Huruta'* and '*Negelle'* planted at 20 cm intra-row spacing produced the highest marketable yield and the lowest unmarketable yield per hectare. The ultimate goal of shallot production is for commodity exchange/ source of cash. The acceptance of the produce in the market (marketability) is dependent on its health, size and shape. It is therefore recommended to the growers to use topped bulbs of '*Huruta'* and '*Negelle'* planted at 20 cm intra-row spacing for production of better marketable yield per hectare followed by bulbs of the same varieties planted at 15 cm intra-row spacing. Topped bulbs of local variety planted at 20 cm intra-row spacing resulted in the highest total soluble solid. It is generally observed that local and

‘*Minjar’* varieties had high total soluble solid and dry matter content. Therefore, these verities are recommended to produce dehydrated products.

Generally, the present study showed that planting topped bulbs of ‘*Huruta’* and ‘*Negelle’* at 20 cm intra-row spacing had positively influenced the majority of yield parameters evaluated and thus it is advisable to use these for the production of bigger bulbs with desirable bulb shape index and higher marketable yield. In addition, it is also advisable to use local variety for high dry matter content, total soluble solid, and better bulb skin color. However, production of ‘*Minjar’* is not advisable in areas having similar conditions with the study area because of its high bolting nature and the consequent yield reduction though it had the best bulb skin color, dry matter content, and total soluble solid. On the other hand, *Minjar* can be produced for its above mentioned qualities by discouraging the flower stalk production using different cultural practices.

However, further investigation must be made under different seasons in order to fully recommend the results of the present study which is based on one season and location. In addition, it is better to assess the potential of ‘*Minjar*’ for botanical seed production as it has high bolting nature. This would be a prospect to solve the problems in shallot production expansion by alleviating the shortcomings of using bulbs as a planting material; large quantity, bulkiness, short shelf-life, and source of inoculum for diseases and pests.

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7. APPENDICES

Appendix Table 1. Mean square values for days to 50% emergence, plant height, number of leaves per plant and leaf length per plant as affected by varieties, spacing and bulb topping at Aneded Woreda, 2010

Source	Degree of freedom	Mean Square Values			
		Days to 50% Emergence	Plant Height	Number of leaves per plant	Leaf Length
Variety	3	35.31***	358.13***	1826.80***	312.49***
Spacing	2	0.38ns	37.70**	560.73***	55.19***
Variety*Spacing	6	0.02ns	10.46ns	74.95**	8.22ns
Bulb topping	1	46.72***	1.65ns	352.89***	6.54ns
Variety*Bulb topping	3	0.20ns	16.61*	64.04*	18.49*
Spacing*Bulb topping	2	0.10 ns	10.97ns	26.02ns	20.60*
Variety*Spacing*Bulb topping	6	0.08 ns	9.29ns	18.16ns	8.95ns
Block	2	1.54ns	1.43ns	230.64ns	1.42ns
Error	46	0.82	5.47	17.45	5.89

Ns=non significant, *, **, and *** indicates significant difference at probability levels of 5%, 1% and 0.1%, respectively

Appendix Table 2. Mean square values for leaf diameter, leaf sheath length, number of shoots and flower stalk per plant and days to maturity as affected by varieties, spacing and bulb topping at Aneded Woreda, 2010

Source	Degree of Freedom	Mean Square values				
		Leaf Diameter	Leaf Sheath Length	No of Shoots/ plant	No of flower stalk/plant	Days to maturity
Variety	3	14.86^{***}	31.77^{***}	95.27^{***}	1.48^{***}	1005.35^{***}
Spacing	2	6.09^{***}	2.13^{ns}	51.73^{***}	0.009^{***}	0.29^{ns}
Variety*Spacing	6	0.37^{***}	0.61^{ns}	1.19^{ns}	0.009^{***}	1.25ns
Bulb topping	1	2.31^{***}	14.76^{**}	3.10^{*}	0.00003^{ns}	364.50^{***}
Variety*Bulb topping	3	0.069^{ns}	3.85^{ns}	2.41^{*}	0.076^{***}	5.80^{ns}
Spacing*Bulb topping	2	0.01^{ns}	1.67^{ns}	1.12^{ns}	0.0035^{**}	1.63^{ns}
Variety*Spacing*Bulb topping	6	0.13^{ns}	0.49^{ns}	2.84^{***}	0.0015^{*}	1.48^{ns}
Block	2	0.69^{***}	1.01^{ns}	1.97^{ns}	0.0001^{ns}	10.67^{*}
Error	46	0.06	1.58	0.60	0.0052	3.09

Ns=non significant, *, **, and *** indicates significant difference at probability levels of 5%, 1% and 0.1%, respectively

Appendix Table 3. Mean square values for total, marketable, unmarketable number of bulbs per plant, bulb diameter and bulb length per plant as affected by varieties, spacing and bulb topping at Aneded Woreda, 2010

Source	Degree of Freedom	Mean Square Values				
		Bulb Diameter	Bulb Length	Total number of bulbs per plant	Number of marketable bulbs per plant	Number of unmarketable bulbs per plant
Variety	3	3.27***	1.56***	84.04***	8.74***	134.18***
Spacing	2	1.28***	0.76***	18.33***	38.66***	5.26***
Variety*Spacing	6	0.11*	0.06ns	1.32ns	0.93**	0.57ns
Bulb topping	1	0.23*	0.02ns	1.00ns	4.35***	1.18*
Variety*Bulb topping	3	0.05ns	0.07ns	0.31ns	1.60**	0.95*
Spacing*Bulb topping	2	0.02ns	0.13*	0.43ns	0.65ns	0.89ns
Variety*Spacing*Bulb topping	6	0.05ns	0.02ns	2.09**	1.17**	4.71***
Block	2	0.06ns	0.16*	1.02ns	0.55ns	0.12ns
Error	46	0.04	0.032	0.63	0.27	0.28

Ns=non significant, *, **, and *** indicates significant difference at probability levels of 5%, 1% and 0.1%, respectively

Appendix Table 4. Mean square values for total, marketable and unmarketable bulb weight and biological yield per plant as affected by varieties, spacing and bulb topping at Aneded Woreda, 2010

Source	Degree of Freedom	Mean Square Values			
		Total bulb weight per plant	Marketable bulb weight per plant	Unmarketable bulb weight per plant	Biological yield/plant
Variety	3	4262.64***	36748.40***	19048.93***	43883.38***
Spacing	2	63319.62***	73163.33***	379.24***	104139.86***
Variety*Spacing	6	539.66***	1078.85***	917.03***	1723.79***
Bulb topping	1	3294.29***	4750.69**	132.90***	196.55ns
Variety*Bulb topping	3	2012.50***	2136.54***	37.77**	6408.09***
Spacing*Bulb topping	2	79.21ns	46.50ns	30.42*	3674.46***
Variety*Spacing*Bulb topping	6	920.25***	738.42***	16.10*	5461.47***
Block	2	133.13ns	103.17ns	1.92ns	158.87ns
Error	46	92.59	77.53	6.55	144.57

Ns=non significant, *, **, and *** indicates significant difference at probability levels of 5%, 1% and 0.1%, respectively

Appendix Table 5. Mean square values for harvest index per plant, total yield per ha, marketable yield per ha and unmarketable yield per ha as affected by varieties, spacing and bulb topping at Aneded Woreda, 2010

Source	Degree of freedom	Mean Square Values			
		Harvest index per plant	Total yield	Marketable yield	Unmarketable yield
Variety	3	3397.83***	139.11***	727.22***	308.39***
Spacing	2	35.12ns	98.63***	338.14***	124.96***
Variety*Spacing	6	111.01***	12.52***	6.99**	2.52***
Bulb topping	1	136.79**	109.74***	144.02***	2.33***
Variety*Bulb topping	3	8.17ns	19.71***	27.48***	3.47***
Spacing*Bulb topping	2	82.75**	34.23***	30.07***	0.89**
Variety*Spacing*Bulb topping	6	52.69**	26.16***	13.31***	6.16***
Block	2	8.83ns	0.24ns	0.28ns	0.016ns
Error	46	15.82	2.57	1.59	0.17

Ns=non significant, *, **, and *** indicates significant difference at probability levels of 5%, 1% and 0.1%, respectively

Appendix Table 6. Mean square values for dry matter content, bulb dry weight per plant, total soluble solid, bulb shape index, and bulb skin color as affected by varieties, spacing and bulb topping at Aneded Woreda, 2010

Source	Degree of Freedom	Mean Square Values				
		Dry matter content	Bulb dry weight per plant	Total Soluble Solid	Bulb shape index	Bulb skin color
Variety	3	43.79***	187.96***	21.27***	0.36***	13.01***
Spacing	2	0.09ns	1785.42***	1.18*	0.07***	0.01ns
Variety*Spacing	6	0.74ns	20.05ns	2.05***	0.02**	0.24ns
Bulb topping	1	1.16ns	132.19***	0.88ns	0.02ns	0.13ns
Variety*Bulb topping	3	0.57ns	30.27*	0.52ns	0.01ns	0.16ns
Spacing*Bulb topping	2	2.28ns	5.03ns	1.40**	0.01ns	0.04ns
Variety*Spacing*Bulb topping	6	0.78ns	22.64ns	1.86***	0.01ns	0.08ns
Block	2	1.69ns	4.14ns	0.01ns	0.0002ns	0.01ns
Error	46	1.49	10.02	0.26	0.006	0.16

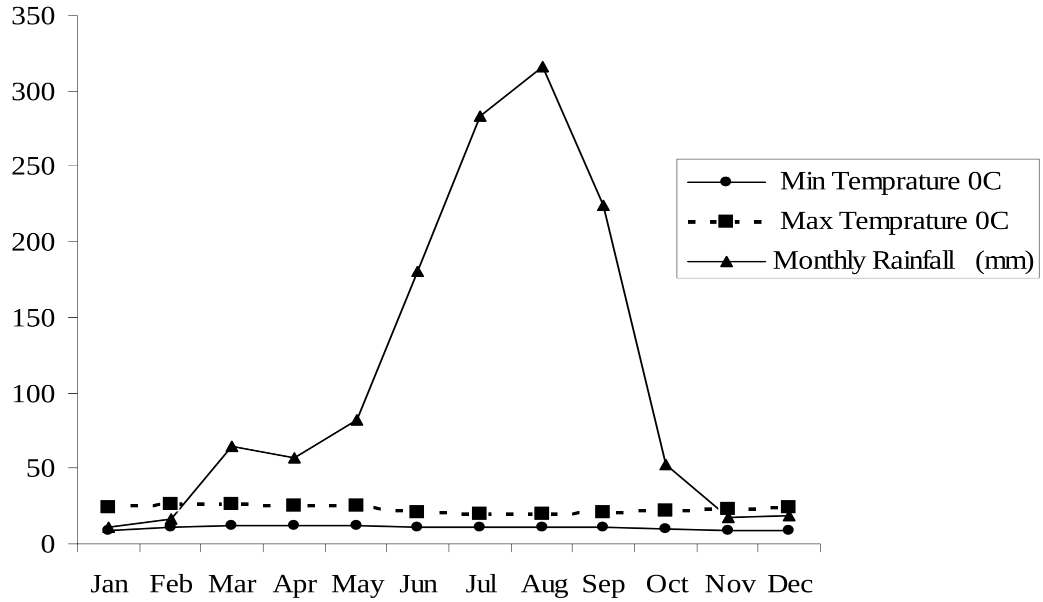
Ns=non significant, *, **, and *** indicates significant difference at probability levels of 5%, 1% and 0.1%, respectively

Appendix Table 7. Correlation coefficients among parameters in shallot varieties at Aneded, Ethiopia during 2009/10

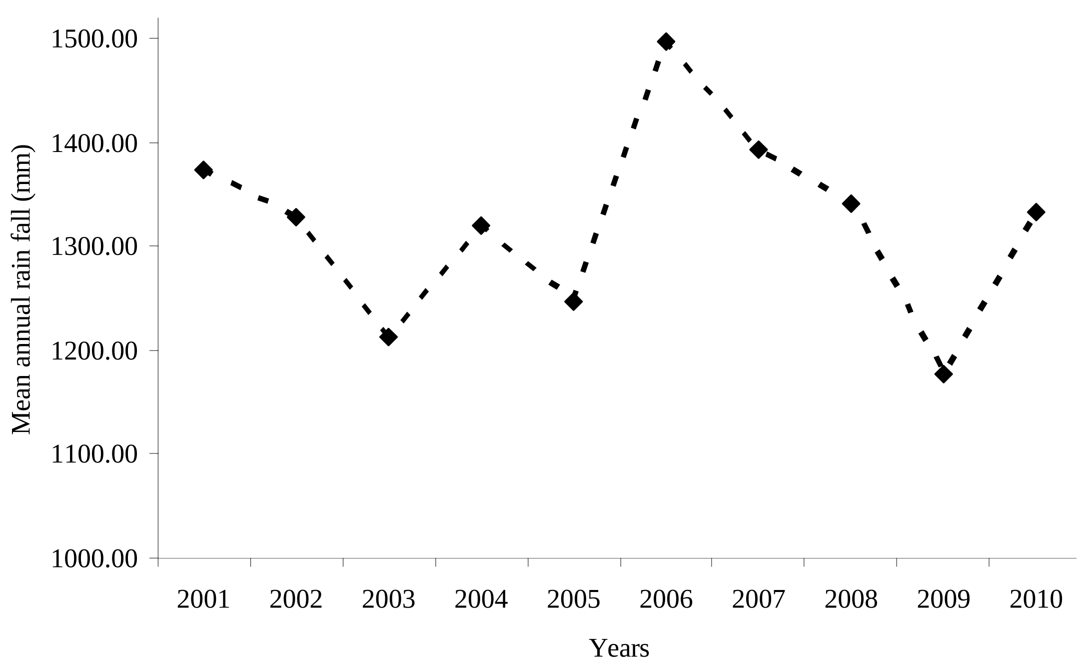
	PH	LN	LL	LD	LSL	SN	Fn	BN	MB	UMB	BD	BL	mbw	umbw	BW	BY	HI	TY	MY	UY	DM	BDW
PH	1																					
LN	-0.46***	1																				
LL	0.93***	-0.27*	1																			
LD	0.64***	-0.14	0.61***	1																		
LSL	0.26*	-0.55***	-0.11	0.16	1																	
SN	-0.53***	0.69***	-0.46***	-0.26*	-0.25*	1																
Fn	-0.41***	-0.12	-0.56***	-0.41***	0.36**	0.37**	1															
BN	-0.43***	0.27*	-0.46***	-0.34**	0.05	0.77***	0.76***	1														
MBN	0.27*	0.48***	0.45***	0.42***	-0.44***	0.26*	-0.44***	0.03	1													
UBN	-0.55***	-0.01	-0.67***	-0.54***	0.28*	0.52***	0.88***	0.83***	-0.52***	1												
BD	0.69***	-0.21	0.74***	0.63***	-0.06	-0.45***	-0.63***	-0.53***	0.52***	-0.76***	1											
BL	0.68***	-0.49***	0.59***	0.58***	0.30**	-0.33**	-0.09	-0.13	0.19	-0.28*	0.67***	1										
MBW	0.45***	0.28*	0.59***	0.57***	-0.32**	0.03	-0.63***	-0.26*	0.87***	-0.72***	0.76***	0.40***	1									
UBW	-0.57***	0.09	-0.67***	-0.60***	0.21	0.47***	0.82***	0.73***	-0.43***	0.90***	-0.74***	-0.37**	-0.72***	1								
TBW	0.22	0.43***	0.34***	0.41***	-0.29**	0.36**	-0.27*	0.15	0.88***	-0.37**	0.54***	0.32**	0.89***	-0.35**	1							
BY	0.21	-0.01	0.14	0.34**	0.21	0.31**	0.38***	0.50***	0.40***	0.15	0.24*	0.53***	0.39**	0.05	0.63***	1						
HI	-0.02	0.48***	0.2	0.01	-0.57***	0.02	-0.77***	-0.44***	0.48***	-0.58***	0.30*	-0.29*	0.49***	-0.42***	0.33**	-0.52***	1					
TY	0.25*	0.09	0.38***	0.19	-0.32**	-0.17	-0.42***	-0.28*	0.55***	-0.54***	0.53***	0.23*	0.60***	-0.42***	0.51***	0.12	0.41***	1				
MY	0.50***	0.12	0.64***	0.53***	-0.33**	-0.24*	-0.77***	-0.52***	0.72***	-0.84***	0.79***	0.36**	0.88***	-0.78***	0.65***	0.10	0.59***	0.82***	1			
UY	-0.55***	-0.08	-0.65***	-0.69***	0.22*	0.21	0.79***	0.53***	-0.62***	0.82***	-0.74***	-0.37**	-0.85***	0.88***	-0.59***	-0.13	-0.46***	-0.35**	-0.80***	1		
DM	-0.59***	0.41***	-0.57***	-0.52***	-0.09	0.60***	0.48***	0.57***	-0.13	0.59***	-0.62***	-0.45***	-0.37***	0.63***	-0.08	-0.03	-0.05	-0.19	-0.46***	0.56***	1	
BDW	-0.04	0.58***	0.08	0.17	-0.31**	0.59***	-0.06	0.38**	0.783	-0.1	0.25*	0.12	0.68***	-0.06	0.90***	0.58***	0.29*	0.40***	0.43***	-0.32**	0.35**	1
TSS	-0.67***	0.63***	-0.61***	-0.42***	-0.23*	0.67***	0.38**	0.50***	0.01	0.44***	-0.58***	-0.52***	-0.19	0.49***	0.09	0.02	0.05	-0.19	-0.36**	0.38**	0.64***	0.34**

***, **, and *= indicate significant correlation at 0.001, 0.01 and 0.05 probability level, respectively

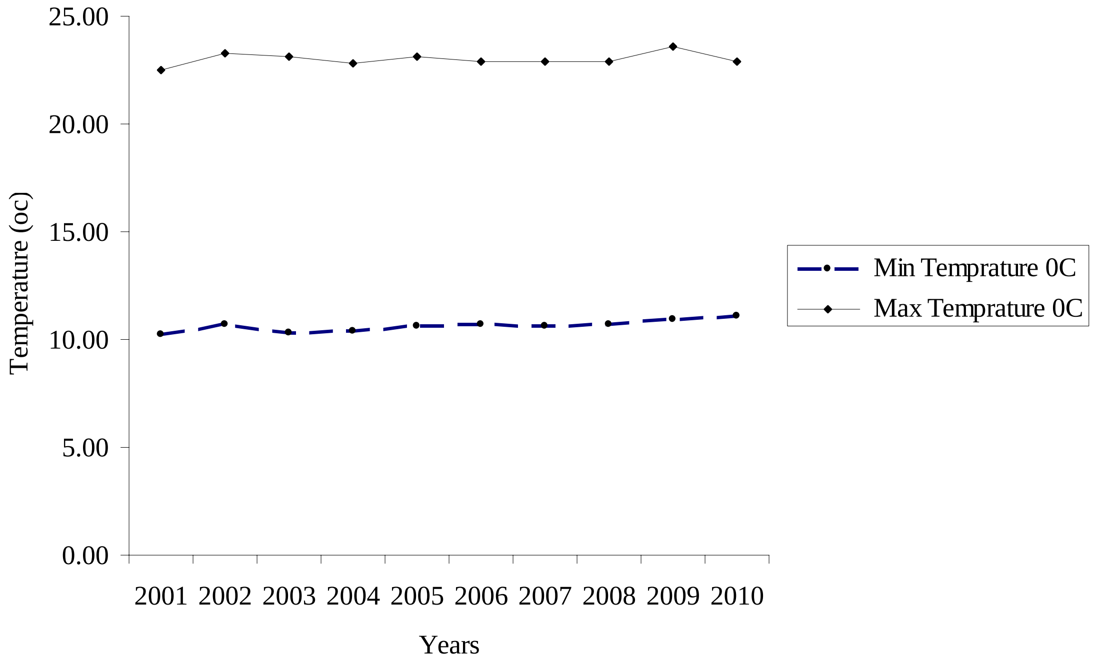
PH= plant height, LN= leaf number, LL= Leaf diameter, LSL= leaf sheath length, SN= shoot number/plant, BN= Bulb Number/plant, MBN= marketable bulb number/plant, UBN= unmarketable bulb number/plant, BD= bulb diameter, BL= bulb length, BW= bulb weight/plant, HI= harvest index, TYH= total yield/ha, MYH= marketable yield/ha, UYH= unmarketable yield/ha, DM= % dry matter content, BDW= bulb dry weight/plant, TSS= total soluble solid



Appendix Figure 1. Mean monthly maximum and minimum temperature (^oC) and rain fall (mm) at the study area from 2001 to 2010 average data (Source: Ethiopian National Meteorology, Bahir Dar Branch Office)



Appendix Figure 2. Mean annual rain fall (mm) at the study area from 2001 to 2010 (Source: Ethiopian National Meteorology, Bahir Dar Branch Office)



Appendix Figure 3. Mean annual maximum and minimum temperature (^oC) at the study area from 2001 to 2010 (Source: Ethiopian National Meteorology, Bahir Dar Branch Office)