EFFECTS OF NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZATION ON GROWTH, YIELD, QUALITY AND STORAGE LIFE OF ONION (*Allium cepa* L.) AT JIMMA, SOUTHWESTERN ETHIOPIA

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EFFECTS OF NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZATION ON GROWTH, YIELD, QUALITY AND STORAGE LIFE OF ONION (*Allium cepa* L.) AT JIMMA, SOUTHWESTERN ETHIOPIA

A Thesis Submitted to the Department of Horticulture and Plant Science,
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In Partial Fulfillment of the Requirements for the Degree of
Master of Science in Horticulture
(Vegetable Science)

By

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As Thesis Research advisor, we hereby certify that we have read and evaluated this thesis prepared under our direction by Muluneh Bekele, entitled **'Effects of Nitrogen, Phosphorus and Potassium Fertilization on Growth, Yield, Quality and Storage Life of Onion (*Allium cepa* L.) at Jimma, SouthWestern Ethiopia'.** We recommend that it be accepted as fulfilling the thesis requirement.

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As member of the *Board of Examiners* of the *M.Sc. Thesis* Open Defense Examination, We certify that we have read, evaluated the Thesis prepared by Muluneh Bekele and examined the candidate. We recommended that the Thesis be accepted as fulfilling the *Thesis* requirement for the *Degree of Master of Science* in Horticulture (Vegetable Science).

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DEDICATION

I dedicate this Thesis work to my mother Tilaye Shiferaw and my father Bekele Etana for nursing me with affections and love and their dedicated partnership for success in my life!!!

STATEMENT OF THE AUTHORS

I, the undersigned, declare that this Thesis is my work and is not submitted to any institution elsewhere for the award of any academic degree, diploma or certificate and all sources of materials used for this Thesis have been duly acknowledged. This Thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to borrowers under the rules of the library. Brief quotations from this Thesis are allowable without special permission provided that an accurate acknowledgment of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the Dean or Coordinator of the School of Graduate Studies or Head of the Department of Horticulture when the proposed use of material is in the interest of scholarship. In all other cases, however, permission must be obtained from the authors.

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BIOGRAPHICAL SKETCH

The author, Muluneh Bekele Etana was born at Oromia region, Addis Ababa Liyu Zone, Welmera Woreda on June 15, 1986. He attended his Elementary School and Junior School education in the same district and later attended his High-school education at Sebeta Compressive Secondary School. After completion his High-School education, he joined Jimma University College of Agriculture and Veterinary Medicines and graduated with a Bachelor of Science degree in Horticulture in 2008.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
AVRDC	Asian Vegetable Research and Development Center
°Brix	Degree of Brix
CIMMYT	International Maize and Wheat Improvement Centre
CSA	Central Statistical Authority
DAP	Diammonium Phosphate
DMC	Dry matter content
EARO	Ethiopian Agriculture and Research Organization
EC	Exchangeable Cation
ETB	Ethiopian Birr
FAO	Food and Agriculture Organization of United Nation
HI	Harvest index
LD	Leaf diameter
LL	Leaf length
LSD	Least Significance Difference
m.a.s.l	Meter above sea level
meq	Milliequivalent
MoARD	Ministry of Agriculture and Rural Development
NFIA	National Fertilizers Industry Agency
pH	Power of hydrogen ion
PPM	Parts per Million
PWL	Physiological weight loss
REML	Residual Maximum Likelihood
RH	Relative Humidity
RCBD	Randomized Complete Block Design
TSP	Triple Super Phosphate
TSS	Total Soluble Solid

TABLE OF CONTENTS

Contents **Page**

TABLE OF CONTENTS *(CONTINUED)*

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF TABLES IN THE APPENDICES

Appendix Table **Page**

LIST OF PLATES IN THE APPENDICES

Appendix Plate **Page**

EFFECTS OF NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZATION ON GROWTH, YIELD, QUALITY AND STORAGE LIFE OF ONION (*Allium cepa* L.) AT JIMMA, SOUTHWESTERN ETHIOPIA

ABSTRACT

Onion (Allium cepa L.) *is one of the most important vegetable crops produced in Ethiopia. Yield and productivity of the crop has been far below the national standards owing to several factors; absence of location specific fertilizer recommendation being the major among others. Thus, field and laboratoty experiments were conducted at Jimma University College of Agriculture and Veterinary Medicine Research field and department of post-harvest management laboratory during 2010/2011 in dry season to study the effects of Nitrogen (N), Phosphorus (P) and Potassium (K) fertilization on growth, yield, quality and storage life of irrigated onion under Jimma conditions, Southwestern Ethiopia. The treatments consisted of factorial combinations of four levels of Nitrogen (0, 50, 100 and 150 kg* ha^{-1}*) as Urea, three levels of Phosphorus (0, 46 and 92 kg* ha^{-1}) as TSP *and four levels of Potassium (0, 40, 80, and 120 kg* ha^{-1}*) as Potassium sulphate which were laid out in a Randomized Incomplete Block Design with three replications. Data on growth, yield, quality and storage life parameters were recorded and analyzed using GenStat 12.1 version computer software packages. Results of the study revealed that; N, P and K had shown a highly significant difference on growth, yield and quality parameters like: plant height, leaf diameter, leaf length, number leaves per plant, leaf sheath length, bolters percentage, days to physiological maturity, harvest index, mean bulb weight, bulb length, bulb diameter, TSS (*^{o}*Brix), DMC(%) and bulb shape index. Similarly, keeping quality of the onion bulbs like bulb sprouts (%), weight loss (%), weeks to 50% bulb sprouts and storage rots (%) were highly influenced by application of N, P and K at different levels. The highest total bulb yield per hectare (18.78 t/ha) was recorded with the plot that received the maximum combined applications of N-P-K (150:92:120kg* ha^{-1}*) and on par with the results obtained in the combined applications of N-P-K at 150:46:120 and 150:46:80kg* ha^{-1} *which were significantly superior to the rest of other treatments. Maximum (150kg* ha^{-1}*) application of Nitrogen caused higher bulb rots (%), bulb sprouts (%) and weight loss (%) over the others while, maximum (120kg* ha^{-1}*) application of potassium significantly decreased bulb rots (%), bulb sprouts (%), weight loss (%) and prolonged weeks to 50% bulb sprout during the two month storage time at ambient storage temperature and humidity. However, according to the partial budget analysis; the highest economic benefit level was obtained in the combined applications of N-P-K (150:46:80kg* ha^{-1}*) whereas the lowest net benefit was obtained from the control treatment. This could be recommended for the uses by potential onion investors or farmers with high initial capital in the study area. Nevertheless, more researches are needed in different locations and on different soils in various season to come up with specific soil test based fertilizer recommendation.*

Key words: Fertilization, Nitrogen, Onion, Phosphorus, Potassium, Quality, Storage life, Yield.

1. INTRODUCTION

Onion (*Allium cepa* L.) is an important vegetable crop worldwide, ranking second among all vegetables in economic importance next to tomato. Onion contributes a significant nutritional value to the human diet and has medicinal properties and is primarily consumed for its unique flavor or ability to enhance the flavor of other foods (Randle and Ketter, 1998).

The genus Allium which belongs to family Alliaceae is diverse and comprises of over 600 species. Only seven of them are widely cultivated in different parts of the world. The species which are significantly important in the Ethiopian national economy are onion (*Allium cepa* L.), shallot (*Allium cepa var. ascalonicum* L.), garlic (*Allium sativum* L.) and leek (*Allium ampeloprasum* L.). The first three are diploid with the basic chromosome number of 2n=16 where as Leek is tetraploid with 2n=32 (Jones, 1990).

The primary center of origin for onion is Central Asia with secondary center being in Near East and the Mediterranean region. From these centers, the onion has spread widely to other many countries of the world (Astley *et al.,* 1982). Onion is different from the other edible species of alliums for its single bulb and is usually propagated by true botanical seed.

A global review of major vegetables shows that onion ranks second to tomatoes in area under cultivation. According to FAO, (2008) amongst the onion producing countries in the world the first is China followed by India in terms of area of production. The highest productivity of onion in the world is from Korea Republic (67.25 t/ha) followed by USA (53.91 t/ha), Spain (52.06 t/ha) and Japan (47.55 t/ha). India being the second major Onion producing country in the world has a productivity of 10.16 t/ha only.

Onion was introduced to the agricultural community of Ethiopia in the early 1970’s when foreigners brought it in. Though shallots were traditional crop in Ethiopia, Onion is becoming more widely grown in recent years. Currently, the crop is produced in different parts of the country for local consumption (Lemma and Shimelis, 2003).
Onion is considerably important in the daily Ethiopian diet. All the plant parts are edible, but the bulbs and the lower stem sections are the most popular as seasonings or as vegetables in

stews (MoARD, 2009). It is one of the richest sources of flavonoids in the human diet and flavonoid consumption has been associated with a reduced risk of cancer, heart disease and diabetes. Flavonoids are not only anti-cancer, but also are known to be anti bacterial, antiviral, anti-allergenic and anti-inflammatory. Onion quality parameter, the percentage of single center bulbs, has become important to meet demands of both processing and fresh market buyers (Brewster, 1990 and Pelter *et al.* 2004).

Tropical countries, having about 45% of the world's arable land, grow about 35% of the world's onions (Pathak, 1994). About 8% of the total area was in Africa. Ethiopia has high potential to benefit from onion production. The demand for onion increases from time to time for its high bulb yield, seed and flower production potential (Lemma and Shimelis, 2003). Over the last 15 years the total area dedicated to onion crop in the world has doubled and presently reaching 2.74 million hectares. Average world yield increased from 12 t/ha in the early 1960s to 17 t/ha in 2001. As a result, the increase in cultivated area and the yield obtained, the world production of onion is about 3944 millions tonne per year (FAOSTAT, 2011). In Ethiopia, the total area under production reaches 15,628 hectares and the production was estimated to be over 1, 488,549 quintals (MoARD, 2009).

Different cultural practices and growing environments are known to influence yield and quality of dry bulb. So far, research in the country was mainly focused on the identification of superior cultivars of onions and adopting improved management practices. Mineral nutrition is main factor that affects yield and quality of onion (Chung, 1989). Nitrogen (N), Phosphorus (P) and Potassium (K) are often referred to as the primary macronutrients because of the probability of plants being deficient in these nutrients and because of the large quantities taken up by plants from the soil relative to other essential nutrients (Marschner, 1995). Nitrogen comprises 7% of total dry matter of plants and is a constituent of many fundamental cell components (Bungard *et al.*, 1999). It is one of the most complexes in behavior, occurring in soil, air and water in organic and inorganic forms. For this reason, it poses the most difficult problem in making fertilizer recommendations (Archer, 1988). Plant demand for N can be satisfied from a combination of soil and fertilizer to ensure optimum growth.

Three major essential plant nutrients N, P and K were found increasingly in short supply in the soils of Eastern, Western and Southern Africa (Rao *et al.*, 1998). Particularly N and P are deficient in many soils of tropical Africa (Richardson, 1968). Nitrogen is required in much greater quantities than most other nutrients. It is an important component of proteins, enzymes and vitamins in plants, and is a central part of the essential photosynthetic molecule, chlorophyll (Marschner, 1995). Plant demand for nitrogen can be satisfied from a combination of soil and fertilizer N to ensure optimum growth. It is also important to ensure that mineralized N is available within the rooting zone of onion plants, particularly during the early stages of growth (Brewster, 1994; Rahn *et al.*, 1996).

Phosphorus deficiency is one of the largest constraints to crop production in many tropical soils, owing to low native content and high P immobilization within the soil (Fairhust *et al.*, 1999). Accordingly, P fertilization is usually recommended in these soils. Phosphorus is essential for root development and when the availability is limited, plant growth is usually reduced. In onions, P deficiencies reduce root and leaf growth, bulb size, yield and can also delay maturation (Brewester, 1994). In soils that are moderately low in P, onion growth and yield can be enhanced by applied P.

In Ethiopia, so far there was a general understanding that Ethiopian soils are rich in K and there was no need for its application based on the research conclusion of Murphy (1968) some 50 years ago. However, Wassie *a*nd Shiferaw, (2009) reported that K is removed through deforestation, crop export, leaching of cations and other possible reasons, especially in some highland areas of Southern Ethiopia and possibly in other similar areas of the country. Yadav *et al*. (2002) also noticed that a significant higher bulb yield (247.79 q ha^{-1}) and fresh bulbs weight (49.53g) were registered with application of 150 kg K ha^{-1} over other levels.

Onion is more susceptible to nutrient deficiencies than most crops because of their shallow and un-branched root system; hence they require and often respond well to addition of fertilizers (Brewester, 1994). *Allium cepa* as bulb onion and/or shallot is probably cultivated in all countries of tropical Africa including Ethiopia (Grubben and Denton, 2004). Proper management techniques such as fertilizers, soil moisture and disease control, harvest time and curing enhance onion produce (Kabir, 2007). Optimization of such practices results in significant decrease in post-harvest losses and increases bulb yield in onion. Decrease in post-harvest losses will be instrumental in market stability and exploiting opportunities to export onion and earn foreign exchange. Best quality onion can be produced through application of well balanced fertilizers (Murashkina *et al*., 2006).

Worldwide, post-harvest losses in fruits and vegetables range from 24 to 40% (Raja and Khokhar, 1993) or even greater, reaching up to 50% in developing tropical countries (Anon, 1989). A post-harvest loss in onion has been estimated to reach 30% in Sudan (Hayden, 1989) and 50 to 76% in Nigeria (Dento and Ojeifo, 1990). A comprehensive statistics for such losses is not available for Ethiopia; however, it has been estimated that up to 30% of vegetable crops harvested in Ethiopia are reported to be lost due to poor post-harvest handling (Fekadu and Dandena, 2006). The principal aim of onion bulb storage is to maintain the quality capital present at harvest (Gubb and Tavis, 2002) and to satisfy consumer demand for extended availability of onions of satisfactory quality.

A number of production constraints are responsible for such reduced bulb yield, quality and storage life of which lack of specific fertilizer recommendation for the area is in the top list. Better understanding of the nutrient requirements of onion plant is needed in order to develop management strategies, which optimize fertilizer use of the crop and thereby increase returns with premium bulb qualities to the producers. Hence, there is an urgent need to identify the optimum N, P and K level for better productivity, bulb quality and storage life of onion in the area. In the light of the above aspects, the present research work was initiated to determine the optimum doses of N, P and K fertilizer for onion (*Allium cepa* L.) optimum growth, yield, quality and storage life under Jimma conditions, Southwestern Ethiopia.

2. LITERATURE REVIEW

2.1. The Onion Crop

Onion (*Allium cepa* L.) is an herbaceous biennial monocot cultivated as an annual. Onion being a biennial crop, takes two seasons for seed production. During the first season bulbs are formed while flower stalks and seeds are developed in the second season. Onion is grown mainly for its bulbs; although the green shoots of salad onion is also an important part. It can be grown in all types of soils. But, for higher yield drained friable loam soil with a pH of 6.0 to 6.8 is good (Brewster, 1994).

The Onion bulb consists of the swollen bases (sheaths) of bladed leaves surrounding swollen bladeless leaves. Each leaf consists of a blade and sheath; the blade may or may not be distinctive. The sheath develops to encircle the growing point and forms a tube that encloses younger leaves and the shoot apex. Collectively, the grouping of these sheaths comprises the pseudostem. Leaves arise from the short, compressed, dislike stem which continues to increase in diameter with maturation and resembles an inverted cone. The onion skin is formed from the dry paper like outer most leaf scales that lose their freshness during bulbing. Major bulb features are uniformity of shape, size and skin color, pungency and dry matter content (Brewster and Rabinowitch, 1990; Rubatzky and Yamaguchi, 1997).

The test and odor characteristics of the alliums are their major attribute. Other features are the umbel inflorescence, flower with nectaries, a three-chambered ovary and a basic chromosome number of eight for the cultivated species. The major flavor of alliums results from the activity of the enzymes, alliinase, acting on certain sulfur-containing compounds (S. alkyl cysteine sulfoxides) when tissues are broken or crushed. Onion roots are shallow, mostly occur within 15 to 20 cm of the surface, and seldom extend horizontally beyond 50 cm. Onion roots are short lived, being continuously produced. Roots rarely have branch and root hairs and rarely increase in diameter. The terminal inflorescences develops from the ring like apical meristem scapes and several, generally elongate well above the leaves and ranges in height from 30 to more than 100 cm. The scape is the stem internodes between the spathe and the last foliage leaf. At first, the scape is solid but, by differential growth, becomes thin walled and hollow. The number of scapes that develop depends on the number of sprouted lateral buds. A spherical umbel is borne in each scape and can range from 2 to 15 cm in diameter.

2.2. Importance and Production Perspective of Onion in Ethiopia

Onion (*Allium cepa* L.) is an important bulb crop in Ethiopia. Onion was introduced to the agricultural community of Ethiopia in the early 1970's when foreigners brought it in. Though shallots are traditional crop in Ethiopia, onion is becoming more widely grown in recent years (Table 1). It is widely produced by small farmers and commercial growers throughout the year for local use and export market. Onion is valued for its distinct pungency and form essential ingredients for flavoring varieties of dishes, sauces, soup, sandwiches, snacks as onion rings etc. It is popular over the local shallot because of its high yield potential per unit area, availability of desirable cultivars for various uses, ease of propagation by seed, high domestic (bulb and seed) and export (bulb, cut flowers) markets in fresh and processed forms.

Ethiopia has high potential to benefit from onion production. The demand for onion increases from time to time for its high bulb yield, seed and flower production potential (Lemma and Shimelis, 2003). Over the last 15 years the total surface area dedicated to onion crop in the world has doubled and presently reaching 2.74 million hectares. Average world yield increased from 12 t/ha in the early 1960s to 17 t/ha in 2001. As a result of the increases in cultivated area and the yield obtained, the world production of onion is about 3944 million tons per year (FAOSTAT, 2011).

Table 1. Area harvested and production of onion by year in Ethiopia for the last five years

Year	Area of production (ha)	Production (ton)
2005	16579	175919
2006	21392	178474
2007	21392	178474
2008	18013	175106
2009	17588	169317

Source: FAOSTAT, 2011 and MoARD, 2006.

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

Irrigation development is part of the strategy designed to ensure food security and alleviate poverty in Ethiopia including Jimma Zone. In 2009/10 production season there was about 79.52 ha of land covered by onion production in the zone. There are 9, 146 holders, who took part in the development activities. The total yield obtained was 6,599.86 quintals with average yield of 8.3t/ha (BoARD, 2010).

The use of appropriate agronomic management has an undoubted contribution in increasing crop yield. The optimum level of any agronomic practice such as plant population, planting date, harvesting date and fertilizer of the crop varies with environment, purpose of the crop and variety. Package technologies have been developed on edible and seed production of Tomatoes, Hot pepper, Onion, Garlic and Shallot. Production guidelines, leaflets and comprehensive research reports have been developed and are available for distribution. Due to the unique production nature of vegetable crops, one has to be aware on nursery, field management and Post-harvest handling practices to succeed in the development effort (EARO, 2004).

Produce marketing and preservation is facing heavy losses that are caused mainly due to price fluctuations, lack of guaranteed prices and unplanned planting patterns. Such constraints are aggravated by underdeveloped infrastructure and weak transportation facilities. Vegetables are yet transported to market as bad packs on animals and human load. This causes heavy Post-harvest losses. Trucks and private buses are also, used by traders between local market, regional and terminal markets which, are not also designed for the purpose. Noteworthy is the lack of processing facilities because the existing processing facilities are not easily accessible to producers. Most vegetables are sold in unprocessed form and there are poor storage facilities, poor traditional storage system, because of which the crops are prone to storage pests and diseases. Packing facilities are also not well developed to bridge gab between growers and shorten the time interval between harvesting and consumption (Fekadu and Dandena, 2006).

2.3. Agronomic Characteristics of Onion

The onion root system is fibrous, spreading just beneath the soil surface to a distance of 30 to 46 cm. It has few laterals, and total root growth is sparse and not especially aggressive. Competition from aggressive root systems (as from weed growth) severely limits onion growth (Kalb, 2001). Onion can grow in all types of soils in Ethiopia from sandy loam to heavy clay, but it prefers well drained sandy loam with high content of organic matter. Highest yield can be obtained from freely drained friable loam soil with pH of 6 to 6. 8. Due to build up of soil borne diseases, it should be rotated with unrelated crops such as beans, and cereals. Onion could be planted at an interval of 3 to 4 years (Lemma, 2004). The best growing altitude for onion under the Ethiopian condition is between 700 to 2200 m.a.s.l and the optimum growing temperature ranges between 15^{o}C and 23^{o}C (EARO, 2004; MoARD, 2006).

Onion dry bulb can be produced throughout the year if dependable irrigation water, and diseases and insect pests control measures are available. However, the yield and quality of dry bulbs seem to vary from season to season due to diverse climatic conditions prevailing in the production areas. Findings of the research done by Melkassa Agricultural research center at the upper Awash rift valley revealed that 20 cm between rows on the bed and 10 cm between plants with 333,300 plants per hactare gave high yield (150 q/ha) and was easy to manage the plant. This is suitable for small-scale hand operated production system for the Melkassa and other areas with similar agro-ecologies. The spacing could be adjusted depending on the availability of facilities especially for tractor operated large scale production (Lemma, 2004).

2.4. Climatic Requirements of Onion Crop

Onion requires moist soil throughout the growing period. Moderate rainfall is preferable since excessive soil water and high humidity encourage diseases. The optimum water requirement for yield is between 350 to 550mm of water (AGL, 2002). A cool period promotes early leaf development, while high temperatures encourage bulb development but flower and seed production is only possible where the bulbs are subjected to low temperatures. Bulb setting in any onion variety is determined by day length and temperature. The optimum temperature for bulb setting is 20 to 25^{o}C. At 10 to 15^{o}C bulbs do not develop well regardless of day length. Temperature can also have another effect on plant development, and therefore production. Once an onion plant reaches a certain physiological age (50 to 80 days old) it may respond to certain temperature conditions (below 14 to 10^{o}C) by initiating a flower head, which then develop flower stalk up to 1m high.

2.5. Nutritional Requirements of Onion Crop

2.5.1. Roles of nitrogen in onion plants nutrition

Plant tissues usually contain more Nitrogen than any other nutrient normally applied as a fertilizer. Nitrogen is an integral component of many essential plant compounds. Nitrogen is needed to form chlorophyll, proteins and it is a major part of all amino acids and many other molecules essential for plant growth and other critical nitrogenous plant components such as the nucleic acids and chlorophyll. Nitrogen is also essential for carbohydrate use within plants. A good supply of nitrogen stimulates root growth and development as well as the uptake of other nutrients (Brady and Weil, 2002).

Plants respond quickly to increased availability of Nitrogen, their leaves turning deep green in color. Nitrogen increases the plumpness of cereal grains, the protein content of both seeds and foliage, and the succulence of such crops as lettuce and radishes. It can dramatically stimulate plant productivity (Sopher and Baird, 1982).

Under sub-optimal supply of N, onions can be severely stunted, with bulb size and marketable yields reduced. By contrast, too much nitrogen can result in excessive vegetative growth, delayed maturity, increased susceptibility to diseases, increased double centers in onions, reduced dry matter contents and storability and, thus, result in reduced yield and quality of marketable bulbs (Brewster & Butler, 1989; Singh & Dankhar, 1991; Batal *et al.*, 1994; Brewster, 1994; Henriksen & Hansen, 2001; Sørensen & Grevsen, 2001). The amount of N applied and onion crop responses vary from place to place. Accounting for soil N and expected release from the soil, additional N application may be necessary in order to meet the crop N requirements. The amount of nitrogen needed is usually based on soil organic matter content, crop uptake and yield levels. Nitrogen uptake levels by onion crops may vary from less than 50 kg to more than 300 kg per hectare, depending on cultivar, climate, plant density, fertilization and yield levels (Hegde, 1986; Sørensen, 1996; Suojala *et al.*, 1998; Salo, 1999 and Pire *et al.*, 2001). High yielding varieties usually require more N than low yielding. Results from different climatic regions of the world also show varying responses of onions to applied N. On a sandy loam soil in a semi-arid region of Ethiopia, irrigated onion plants benefited from application of 90 to120 kg ha^{-1} N compared to unfertilized crops (Aklilu, 1997). On a tropical Ultisol in Nigeria, Asiegbu (1989) found onion yield increases from applying N up to 150 kg ha^{-1}. Increased onion yields were also obtained from N fertilization of 143 to 246 kg ha^{-1} on loamy soils in Egypt (Haggag *et al.*, 1986) whereas 200 kg ha^{-1} N was required on sandy soils in Saudi Arabia (Al-Moshileh, 2001).

2.5.2. Roles of phosphorus in onion plants nutrition

Neither plants nor animals can grow without phosphorus. It is an essential component of the organic compound often called the energy currency of the living cell: adenosine tri-phosphate (ATP). Synthesized through both respiration and photosynthesis, ATP contains a high-energy phosphate group that drives most energy-requiring biochemical processes. For example, the uptake of nutrients and their transport within the plant, as well as their assimilation into different bio-molecules are energy-using plant processes that require ATP as stated by Sopher and Baird, (1982).

Phosphorous is an essential component of deoxyribonucleic acid (DNA), the seat of genetic inheritance, and of ribonucleic acid (RNA), which directs protein synthesis in both plants and animals. Phospholipids, which play critical roles in cellular membranes, are another class of universally important phosphorus-containing compounds. For most plant species, the total P content of healthy leaf tissue is not high, usually comprising only 0.2 to 0.4% of the dry matter (Brady and Weil, 2002).

Phosphorus is essential for numerous metabolic processes. Among the significant function and qualities of plants on which P has an important effects are, enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, reproduction, nitrogen fixation, flowering, fruiting (including seed production) and maturation. Root growth, particularly development of lateral roots and fibrous rootlets, is encouraged by P. In cereal crops, good P nutrition strengthens structural tissues such as those found in straw or stalks, thus helping to prevent lodging (falling over). Improvement of crop quality, especially in forages and vegetables, is another benefit attributed to this nutrient (Brady and Weil, 2002).

Phosphorus deficiency is one of the largest constraints to crop production in many tropical soils, owing to low native content and high P fixation capacity of the soil (Barber, 1995; Fairhust *et al.,* 1999; Marschner, 1995; Norman *et al.,* 1995). P is essential for root development and when the availability is limited, plant growth is usually reduced. The movement of P in soils is very low and its uptake generally depends on the concentration gradient and diffusion in the soil near to roots (Marschner, 1995; McPharlin & Robertson, 1999).

In onion, P deficiencies reduce root and leaf growth, bulb size and yield and can also delay maturation (Ojala *et al.,* 1983; Brewster, 1994; Greenwood *et al.,* 2001). In soils that are moderately low in P, onion growth and yield can be enhanced by applied P. Results of long-term fertilizer trials on loamy sand soils in Germany have shown a strong response of onions to P fertilization in the range 0 to 52 kg P ha^{-1} (Alt *et al.*, 1999). Depending on yield levels, P uptake rates in onion are estimated to be about 15 to 30 kg ha^{-1} (Hegde, 1988; Alt *et al.*, 1999; Salo *et al*., 2002). For a yield of 6.6 tone ha^{-1} shallots grown on peat soil in Malaysia, the estimated P uptake was about 5 kg ha^{-1} (Vimala and Yeong, 1994).

Depending on soil P status, cultivar and plant density, P application rates of up to 200 kg ha^{-1} was found to maximize onion yields and bulb weights (Haggag *et al.*, 1986; Vachhani & Patel, 1993; McPharlin & Robertson, 1999; El-Rehim, 2000; Singh & Singh, 2000 and Singh and verma, 2001) and reduce storage loss of bulbs. Increased P levels are also known to improve bulb size and the number of marketable bulbs in shallots (Zahara *et al.,* 1994; Nagaraju *et al.*, 2000). Regardless of the P status of the soil, placement of P-fertilizers in the soil near to the plant would be the most effective method of P supply to onion plants (Brewster, 1994; Henriksen and Hansen, 2001).

To optimize P availability through P additions, many factors must be considered. Because of the immobility of P in most soils, the timing of fertilizer P application is less critical than placement. Even though, small amounts of placed starter fertilizer for vegetable crops have successfully reduced the need for much larger broadcast applications of P (Costigan, 1988). Several additional factors influence P availability. These include temperature, compaction, moisture, aeration, pH, type and amount of nutrient (including P) status of soil (Sumner *et al.,* 1986).

2.5.3. Roles of potassium in onion plants nutrition

Potassium plays a pivotal role in plant growth and development. Like other tuber and root crops, onion is very responsive to potassium. It has a crucial role in the energy status of the plant, translocation and storage of assimilates and maintenance of tissue water relation. Also K plays a key role of crop quality. It improves size of fruit and stimulates root growth. It is necessary for the translocation of sugars and formation of carbohydrates.

Potassium also provides resistance against pest and diseases and drought as well as frost stresses (Marschner, 1995). With the exception of N, K is required by plants in much greater amounts than all other soil supplied nutrients (Tisdale *et. al.,* 1985). Potassium uptake by plants from the soil solution is regulated by several factors including soil texture, moisture conditions, pH, aeration and temperature. Therefore, during growth development soil K supply is seldom adequate to support crucial processes such as sugar transport from leaves to bulbs, enzyme activation, protein synthesis and cell extension that ultimately determine bulb yield and quality (Williams and Kafkafi, 1998).

Many studies reported several roles of K element in onion plant growth such as plant height, number of leaves per plant, fresh and dry weight of whole plant, total yield and its components. On the other hand the high levels of potassium fertilization resulted in bulbs with higher quality and higher TSS (Geetha *et al.*, 2000). Also El-Bassiouny (2006) found that using potassium Sulfate plus a suplemental dose of potassium oxide as foliar application resulted in the highest plant growth (plant length, number of leaves per plant, and fresh weight of leaves) and also the highest yield and bulb quality.

Similarly, a study conducted at Southern Ethiopia comparing N-P with N-P-K application on potato revealed that the tuber yield of potato was increased from 11.77 tone ha^{-1} in the N-P treatments to 34.93 tone ha^{-1} in the N-P-K treatments, which means N-P-K application increased the tuber yield by 197% over the N-P treatments suggesting that K is critically deficient in the area and disproved the long standing conclusion by Murphey (1986) that Ethiopian soil are rich in potassium (Wassie & Shiferaw, 2009). Potassium (K) is an essential nutrient which is vital in photosynthesis activity of leaf, as it helps in translocation of food. Besides, plants require large amount of K than the soil can supply (Thompson and Troeh, 1978). However, only limited studies are conducted so far in Ethiopia to investigate the yield and quality effect of K application on different crops.

Generally, onion takes up K in quantities nearly equivalent to N (Haggag *et al.*, 1986; Singh and Verma, 2001; Salo *et al.*, 2002). Moreover, like N, K is easily leached from soils and fertilization may be needed for high yields (Brewster, 1994; Marschner, 1995). The K requirement of onion plants increases with yield and its functions are linked to photosynthesis (Marschner, 1995; Greenwood and Stone, 1998). If K is deficient or not supplied in adequate amounts, onion plants can be stunted, become susceptible to disease and have reduced yields (Singh and Verma, 2001).

2.6. Responses of Onion Bulb Yield to N, P and K Fertilizers

There is a significant response of onion to inorganic fertilizers play an important role in onion production. Like other root and tuber crops, onion is very responsive to N-P-K fertilizer application. Among the various nutrients required to produce high yield of onion. Potassium is considered to be very important element due to it is influence for translocation of photosynthates, storage quality, bulb size, bulb numbers and yield per plant (Sangakkara, and Piyadasa, 1993).

Nitrogen is known to be most essential during the initial stages of plant growth. A deficiency of this element at this stage causes stunted growth, general yellowing, and weak plants. Low nitrogen levels have been associated with early bulb formation in onion. Under sub-optimal supply of N, onions and shallots can be severely stunted, with bulbs size and marketable yields reduced. On the other hand, too much nitrogen can result in excessive vegetative growth, delayed maturity, increased susceptibility to diseases, increased double centers in onions, reduced dry matter contents and storability and, thus, results in reduced yield and quality of marketable bulbs (Brewster and Buttler, 1989; Dankhar and Singh, 1991; Batal *et al.,* 1994).

Madan and Sandhu (1983) indicated that trials with Onion cv. Punjab 48 with the application of 185:117:105 kg N, P and K ha^{-1} gave the maximum bulb yield. Singh and Dhankar (1989) noticed that application of K alone and in combination with zinc (100 kg K + 25 kg Zn) increased plant height (61.62, 64.9 cm) yield and dry matter of bulbs (15.05 g and 14.9 g), respectively. Salimath (1990) also reported that dry matter production, bulb size and bulb yield increased with the increase in levels of K from 0 to 150 kg ha^{-1}. The similar results again observed by Nandi and Nanda (1992) indicated that significant differences among the fertilizer doses with respect to onion plant height. Plants were the tallest when 90 kg N and 120 kg K ha^{-1} were applied. Vacchani and Patel (1993) recorded the higher number of leaves per plant (11.56, 11.68), weight of bulb (50.42 from 51.83 g) and bulb yield (226.66 from 227.66 q/ha) with increase in Potassium application from 100 to 150 kg ha^{-1}. Singh *et al*. (1993) encountered a reduced in the bolting percent, which was lowest (1.29%) when 50 kg potassium was applied. Mallangowda *et al*. (1995) observed that the higher dry matter production, bulb diameter and yield of onion with the application of 150:50:125 kg N, P and K ha^{-1}.

Kumar *et al*. (2001) observed that the increase in K fertilizer nutrient application significantly increased the dry weight of tops and bulbs, bulb diameter, 100 bulb weight and bulb yield up to 40 kg K ha^{-1}. Sharma *et al.* (2002) also noticed that the application of fertilizers at (125 kg N, 33 kg P and 50 kg K ha^{-1}) and (187 kg N, 49 kg P and 75 kg K ha^{-1})

registered 42 and 56% increases in bulb yield of onion, respectively. Yadav *et al*. (2002) noticed a significantly higher yield of bulb (247.79 q ha^{-1}) and fresh weight of bulbs (49.53g) with application of 150 kg K ha^{-1} over other potassium levels. Increased bulb yield of garlic (97.24 q ha^{-1}) was obtained with 150:80:50 kg N, P and K ha^{-1} application. However, considering economics of crops balanced use of N, P and K fertilizers at 100:40:50 gave optimum returns (Tiwari and Agarwal, 2003). Hariyappa (2003) reported that, the application of Potassium at 125 kg ha^{-1} recorded significantly highest plant height, total dry matter production which was on par with 150 kg ha^{-1}. Same treatment recorded significantly higher bulb weight (106.44 g/plant), bulb length (4.68 cm), bulb diameter (5.32 cm) and bulb yield (22.87 t/ha) over control.

Singh *et al*. (2004) noticed that the maximum plant height, fresh weight of leaves and total chlorophyll content at 45 and 90 days after transplanting were noticed with application of K at 120 kg ha^{-1}. The maximum yield attributes *viz*., neck thickness (0.92 cm), number of scales (7.73), bulb diameter (5.03 cm), fresh weight of bulb (48.89 g) and bulb yield (211.50 q/ha) were also recorded with the same level of Potassium. On the other hand, Girigowda *et al*. (2005) reported that the higher bulb yield (41.69 t/ha) was recorded with fertilizer level of (188:75:188, N, P and K kg ha^{-1}) and was on par with fertilizer level of 156:63:156 kg N, P and Kha^{-1}.

2.7. Responses of Onion Bulb Quality to N, P and K Fertilizers

High quality Onions should have mature bulbs with good firmness and compactness of fleshy scales. The size, shape and color of the dry skin should be typical for the variety. They should be free of mechanical or insect damage, decay, sunscald injury, greening of fleshy scales, sprouting, bruising, doubles, bottlenecks (onions which have abnormally thick necks with only fairly well developed bulbs) and any other defects (Franciszek,1997).

In Ethiopia, little research had been conducted in relation to Onion nutrition requirement from storability and quality point of view. In some areas, however, farmers apply DAP (Diammonium Phosphate) fertilizer to their onion crop whereas in most areas of the country fertilizer is not used. A fertilizer trial at Adet indicated that combined application of N and P at a rate of 46/46 N/P kg ha^{-1} would be adequate for a good crop of Shallot. In addition, depending on its availability, manure could be applied liberally as high as 10 ton or more per hectare (Getachew and Asfaw, 2000).

Singh and Dhankar (1989) recorded that higher ascorbic acid (12.50 and 13.43 mg/100 g), TSS (14.23, 14.54%) and sugar content (55.78, 56.32%) were recorded with the application of 100kg K ha^{-1} alone and in combination with zinc (100 kg/ha K + 25g Zn ha^{-1}). The rotting, sprouting and loss in total weight was also reduced considerably during storage in the bulbs produced by the application of 100 kg K ha^{-1}. Vachhani and Patel (1993) also observed that the highest TSS content in onion bulbs with the application of Potassium at 100 and 150 Kg ha^{-1}. Singh and Singh (2000) again noticed that the maximum TSS (12.1%) and bolting (1.5%) were recorded with application of 50 kg K ha^{-1}.

Yadav *et al*. (2002) recorded that significantly higher TSS (12.47%) and all-yl-propyl disulphate (6.94 mg /100g) with the application of 150 kg K ha^{-1}, while maximum ascorbic acid content (9.93 mg/100g) was recorded with K application at 50 kg ha^{-1}. Increasing levels of potassium significantly increased the TSS and pyruvic acid content of onion bulb. Higher TSS (11.99%) and pyruvic acid (2.32 μ mol/g) content of onion bulb was obtained in the treatment receiving K at 125 kg ha^{-1} which was on par with K at 150 kg ha^{-1}. Same treatment recorded lowest total weight loss (41.35%) of onion bulb (Hariyappa, 2003).

On the average dry matter content of 13% has been found with a variation from 11 to 14% in shallot cultivars (Hansen and Henriksen, 2001). They found that as in other crops, increasing the N-supply to onion crops resulted in the percentage of N in dry bulbs increasing significantly while the percentage of dry matter in the bulbs and the percentage of minerals did not change. However, increasing the nitrogen supply above 200 kg N ha^{-1} decreased dry matter content in mature bulbs. High dry matter content is considered to be of importance for good storage ability (Hansen and Henriksen, 2001). Dry matter measurements also provide information on environmental factors and cultural management procedures during the production season (Ruthford and Wittle, 1982).

2.8. Responces of Onion Bulb Storage life to N, P and K Fertilizers

From its morphological and physiological characteristics, onion is a vegetable bulb crop for extended post-harvest life and storage. In order to maintain and improve such post-harvest keeping ability of the crop, special cultural practices should be taken in to consideration for maximum exploitation of such a feature. Both physical and chemical parameters have to be preserved during the post-harvest life of this crop. For persisted quality nature of onion crop in shelf life both pre-harvest and post-harvest management practices should be given due attention. Storage of bulbs after harvest is crucial to ensure availability during off season. Many cultivars do not keep long in ambient storage because they tend to sprout and rot shortly after harvest. In addition, due to poor storage facilities, onion breakdown within 2 to 4 months after harvest is a common phenomenon (Brewster and Rabinowitch, 1990).

Storage extends the availability of bulbs over long periods. The disadvantages of storage are dry matter and moisture losses. Following dormancy breaking, they normally resume growth and lose their food value. The onset of dormancy is thought to be caused by translocation of growth inhibitory substances from the leaves to the bulbs as the crops mature (Komochi, 1990). Stow (1976) found inhibitors in the leaves of onions approaching maturity and showed that defoliation at this stage shortened dormancy. Abscissic acid was identified but was accounted for only 10 to 20% of the growth inhibitory activity. During subsequent storage there was a progressive decline in inhibitory activity extractable from bulbs, followed by increase first in cytokines activity and then by gibberellins and auxin activity (Isenberg *et al.,* 1974).

Other possible losses include decay, sprouting, and rooting (Rubatzky and Yamagunchi, 1997). The later maturing, pungent, globe types, which tend to have more bulb dry matter, can be stored and can be held for no longer than 2 months; however, these types are usually consumed soon after harvest. As a rule, bulbs started from sets generally do not store well and should be used soon after harvest (John, 1992). Storage quality is also reported to be negatively correlated with certain bulb morphological traits such as bulb and neck diameter (Rivera *et al.*, 2005).

Sprouting is the major factor limiting storage life of onion and shallot bulbs. At harvest bulbs are in a state of innate dormancy and dormancy terminates when inner sprout growth begins (Brewster, 1987). High dose on N produced quick sprouting of thick-necked bulbs during storage. Moreover, greater percentage of open thick-necked bulbs resulted with increased sprouting due to increased access of oxygen and moisture to the central growing point (Dankhar and Singh, 1991).

Bhalekar *et al*. (1987) reported that 6.7, 11.6, and 13.1% sprouting in Onion plants fertilized with 0, 75, and 150 kg N ha^{-1}, respectively, during periods under common storage condition. Similarly, Celestino (1961) also found that bulbs grown with 60 or 120 kg/ha sprouted twice as much under common storage compared to those, which were not fertilized. Application of N had no significant effect on the percentage of sprouted bulb under cold storage condition. Another factor that could be attributed to the increment in sprouting of bulbs is due to higher concentration of growth promoters than inhibitors in the bulbs of N fertilized plants that keep it growing (Dankhar and Singh, 1991).

Adequate N supply promotes rapid and complete bulb maturity which is essential for good storage. It is known that reasonably high levels of nitrogenous fertilizers result in reduced onion storage life (Kato *et al.,* 1987). However, bulb form plants with higher tissue N levels often are of poor quality and do not store well for longer periods (Henriksen, 1987). Jones and Mann, (1963) concluded that excessive application of N in the growing season results in the production of bulbs with thick necks that do not store well. However, the levels that adversely affect storability of bulbs vary with species and cultivars.

Excessive N fertilization and late irrigation resulted in higher levels of neck rot in onion cv. Sweet Spanish (Vaughan, 1960). The effect of N and late irrigation were attributed to an increase in the succulence and diameter of the onion necks which made them more difficult to dry. Bhalker *et al.* (1987) showed that total loss (sprouting + rotting) on number bases was 9.7%, 15.4% and 18.5% at 0, 75, and 150 kg N ha^{-1}, respectively. Dankhar and Singh (1991) again reported that the rotting of bulbs increased with increased doses of Nitrogen.

Nandi *et al*. (2002) recorded that the lowest sprouting (20.00%), rotting (7.60) %) and weight loss (9.21%) were recorded with application of K at 180 kg ha^{-1} compared to control. Onion bulbs produced without nitrogen application resulted in lowest rotting (22%), while highest rotting (36 to 54%) was recorded in bulbs produced under higher dose of Nitrogen (Jones and Mann, 1963). Reports by Celestino (1961) shows that N application increased rotting of bulbs under both common and cold storages.

On the other hand, Narang and Dastane (1972) reported that onion bulbs grown under low Nitrogen and moisture regime, which were small in size and less in dry matter content, were liable to dry-out earlier than those grown under adequate moisture and nutrition. They showed that the loss in storage up to five months was mainly due to drying of bulbs. On the other hand, studies show that application of N reduces post harvest loss. Wayse (1977) indicated that for the Rabi onion crop, N fertilizer at 45 and 90 kg ha^{-1} resulted in the lowest post harvest weight loss. The author indicated that loss in weight 15 days after harvest was significantly decreased with these levels of N fertilization in his two seasons study.

3. MATERIALS AND METHODS

3.1. Description of the Experimental Site

The experiment was conducted under field condition at Jimma University College of Agriculture and Veterinary Medicine research field in the year 2003 E.C. under irrigation condition. Jimma University College of Agriculture and Veterinary Medicine is geographically located 346 km southwest of Addis Ababa at about 7^0, 33' N latitude and 36^0, 57' E longitude and an altitude of 1710 meter above sea level (Appendix Plate 1). The analysis of soil samples from the top 30 cm depth of the experimental site before transplanting revealed that the soil contains 1.46% organic carbon; 1.42% total nitrogen; 2.80ppm available phosphorus; 0.83 meq/100g exchangeable potassium; 53.1µS/cm electrical conductivity; pH value of 5.94 (Table 2).The mean maximum and minimum temperatures are 26.8^0C and 11.4^0C, respectively and the mean maximum and minimum relative humidity are 91.4% and 39.92%, respectively. The mean annual rainfall of the area is 1500mm (BPEDORS, 2000).

Table 2. Soil physical and chemical properties of the experimental site

Characteristics	**Status**
Sand (%)	8
Silt (%)	44
Clay (%)	48
Textural class	Silty clay
Organic carbon (%)	1.46
Total nitrogen (%)	0.142
Exchangeable K	0.83 meq/100 g
Available P (ppm)	2.80ppm
pH 1:1 water	5.94
Electric conductivity (1:1)	53.1(µS/cm)
Bulk density (g/cm3)	1.58

Note: The soil physical and chemical properties of experimental site were determined at Jimma Agriculture Research Center and Jimma University College of Agriculture and Veterinary Medicine soil laboratory.

3.2. Experimental Materials

Onion (*Allium cepa* L.) variety Bombay Red which is released by Melkassa Agricultural Research Center in 1980 through selection was used as a planting material for the study (Table 3). The treatments used consisted of combination of four levels of N (0, 50, 100, 150 kg ha^{-1}), three levels of P (0, 46, 92 kg ha^{-1}) and four levels of K (0, 40, 80, 120 kg ha^{-1}).

Table 4. Details of Onion variety used in the study

Variety Name	Year of release	Area of adaptation		Days to maturity	Yield (t/ha)
		Altitude(m)	Rain fall(mm)		
Bombay Red	1980	700-2000	Irrigated	<120	25-30

Source: EARO (2004)

3.3. Experimental Design and Layout

The experiment was laid out in a 4x3x4 factorial arrangement in a Randomized incomplete Block Design (RIBD) with three replications. The treatments were randomly assigned to the experimental plots. The details of the treatment combinations are indicated in Table 4 below.

Table 5. Details of the treatment combinations of the study

Treat-ment	Description	Treat-ment	Description	Treat-ment	Description	Treat-ment	Description
1	$N_0P_0K_0$	**13**	$N_{50}P_0K_0$	**25**	$N_{100}P_0 K_0$	**37**	$N_{150}P_0K_0$
2	$N_0P_{46}K_0$	**14**	$N_{50}P_{46}K_0$	**26**	$N_{100}P_{46} K_0$	**38**	$N_{150}P_{46} K_0$
3	$N_0P_{92}K_0$	**15**	$N_{50} P_{92}K_0$	**27**	$N_{100}P_{92} K_0$	**39**	$N_{150}P_{92} K_0$
4	$N_0P_0K_{40}$	**16**	$N_{50}P_0K_{40}$	**28**	$N_{100}P_0 K_{40}$	**40**	$N_{150}P_0 K_{40}$
5	$N_0P_{46}K_{40}$	**17**	$N_{50}P_{46}K_{40}$	**29**	$N_{100}P_{46} K_{40}$	**41**	$N_{150}P_{46} K_{40}$
6	$N_0P_{92}K_{40}$	**18**	$N_{50}P_{92}K_{40}$	**30**	$N_{100}P_{92} K_{40}$	**42**	$N_{150}P_{92} K_{40}$
7	$N_0P_0K_{80}$	**19**	$N_{50}P_0K_{80}$	**31**	$N_{100}P_0 K_{80}$	**43**	$N_{150}P_0 K_{80}$
8	$N_0P_{46}K_{80}$	**20**	$N_{50}P_{46}K_{80}$	**32**	$N_{100}P_{46} K_{80}$	**44**	$N_{150}P_{46} K_{80}$
9	$N_0P_{92}K_{80}$	**21**	$N_{50}P_{92}K_{80}$	**33**	$N_{100}P_{92}K_{80}$	**45**	$N_{150}P_{92} K_{80}$
10	$N_0P_0K_{120}$	**22**	$N_{50}P_0K_{120}$	**34**	$N_{100}P_0 K_{120}$	**46**	$N_{150}P_0 K_{120}$
11	$N_0P_{46}K_{120}$	**23**	$N_{50}P_{46}K_{120}$	**35**	$N_{100}P_{46} K_{120}$	**47**	$N_{150}P_{46} K_{120}$
12	$N_0P_{92} K_{120}$	**24**	$N_{50}P_{92} K_{120}$	**36**	$N_{100}P_{92} K_{120}$	**48**	$N_{150}P_{92} K_{120}$

Onion seedlings were raised in the nursery on a well prepared seedbed whose dimension was 5mX1m. The seeds were sown in rows marked 15 cm interval across the length of the seed bed and the beds were covered with dry grass mulch until emergence. Complete germination of the seeds took place within 7 to 10 days of sowing and seedlings were thinned out after three weeks in order to maintain optimum plant population and to keep them vigorous. Watering of the seed bed was done always in the morning and afternoon using watering can.

The seed beds were watered before uprooting the seedlings in order to minimize the damage of the roots. Healthy, uniform and 51 days old seedlings were transplanted to the prepared field at spacing of 20 cm between rows and 10cm between plants according to the EARO, 2004 recommendation. Finally, the entire levels of P and K as Triple Super Phosphate (46% P_2O_5) and Potassium Sulphate (50 % K_2O), respectively and the half rate of the nitrogen fertilizer as Urea (46%) were applied at the time of transplanting. The remaining half of the nitrogen was applied as side dressing after 45 days of transplanting. Weeds were controlled mechanically (by hand weeding) (Appendix Plate 2).

The size of each plot was 1.2 m^2 (1 m x 1.2 m). All the 48 treatment combinations were randomly assigned to the unit plot of each block so as to allot one treatment combination only once in each block. There were 10 plants in each row and 60 plants per plot. A foot path of 0.5m and 1 m were left between plots and replications, respectively. During the course of the study Mancozeb was applied to prevent the damage of disease at rate of 4.0 kg per ha mixed in 600 liter of clean water. All other agronomic management practices were provided as per the recommendation equally for all the treatments (Getachew *et al.,* 2009).

Lastly, bulbs from the central four rows were harvested after 60% neck-break and used for analysis. Curing of bulbs was done for ten days under partial shade and ten sample bulbs were taken to storage room. Sample bulbs were taken from each plot for bulb characteristics measurement and stored in naturally ventilated house constructed from wire mesh wall and corrugated iron sheet roofing then kept in boxes made of wire mesh to evaluate shelf life (Appendix Plate 3). Daily storage room temperature and relative humidity was recorded using digital sling Psychrometer (AZ8706 model, China). The average daily maximum and minimum temperatures during the two month storage periods were used. The storage time was in the month of May to July 2003 E.C. in which the average monthly temperatures were 17.23^{o}c and 16.72^{o}c, respectively and relative humidity of 75.32% and 77.65%, respectively.

3.4. Data Collected

Data were collected from the central four rows excluding the border. Individual parameters were recorded from ten randomly selected plants in the middle rows on the net plot bases.

1. **Plant height (cm):** The mean height of ten sampled plants was measured and divided by number of sample plants. It was measured using ruler from the soil surface to the tip of the leaves at physiological maturity.

2. **Leaf length (cm):** The mean leaf length was measured from ten sampled plants using ruler from the sheath to tip of the leaf (from the 3rd youngest matured leaf) at physiological maturity and expressed in cm.

3. **Leaf diameter (mm):** The mean diameter of ten sampled plants was measured at the time of physiological maturity using ruler at the widest point of measured leaf (from the 3rd youngest matured leaf).

4. **Leaf sheath/shaft length (cm):** The mean sheath length of ten sampled plants was measured at physiological maturity using ruler from the bulb tip to start of the leaf and expressed in cm.

5. **Leaf number per plant:** The mean number of leaves was recorded from ten sampled plants at physiological maturity and expressed as number of leaves per plant.

6. **Bulb Diameter (cm):** The mean bulb diameter of ten sampled plants was measured at harvest using a Vemier caliper at the widest point in the middle portion of the matured bulb and expressed in cm.

7. **Bulb length (cm):** The mean bulb length of ten sampled plants was measured at harvest using a Vemier caliper from the bottom to the top of the matured bulb and expressed in cm.

8. **Bulb shape index:** The shape of ten randomly selected mature bulbs per plot was classified based on IPGRI descriptors for alliums species (IPGRI, ECP/GR, AVRDC, 2001). The bulb shape index (bulb length to bulb diameter ratio) was used for analysis.

9. **Number of bolters per plot (%):** The number of bolter per plot was counted at physiological maturity (harvest) expressed in percent.

10. **Days to maturity:** Number of days was computed from date of transplanting to the date at which more than 60% of the plant's showed neck break.

11. **Marketable yield (tone ha^{-1}):** The total bulb yield was further categorized by weight in to over size (>160g), large (100 to 160g), medium (50 to 100g) and small (21 to 50g) and expressed as kg/plot and converted into tone ha$^{-1.}$ Total weight of clean, disease and damage free bulbs with greater than 21g in weight was measured as marketable bulb yield.

12. **Unmarketable yield (tone ha^{-1}):** The unmarketable bulbs were determined by categorizing which were under sized (<20g), diseased, decayed, physiological disordered such as thick necked, splitted and boltered were weighed and expressed as tone ha^{-1}.

13. **Total bulb yield (tone ha^{-1}):** The sum total of marketable and unmarketable bulbs in kg/plot and expressed in tone per hectare.

14. **Marketable bulb percentage (%):** The marketable bulb percentage further categorized by weight in to over size (>160g), large (100 to 160g), medium (50 to 100g) and small (21 to 50g) and counted out of the total number of bulbs in net plot base and expressed as percent per plot. Total weight of clean, disease and damage free bulbs with greater than 21g in weight was measured and counted.

15. **Mean bulb weight per plant (g):** Average fresh weight of ten marketable bulbs was measured from central four rows of each plot and expressed in gram.

16. **Harvest index:** It is the proportion of the crop that is of economic importance. It's the ratio of mature dry bulb yield of plants from central four rows and total biological yield of plants of the same rows in gram. This was calculated by:

$$\mathbf{HI = \frac{EY}{BY}}$$

Where: **EY**: Weight of matured dry bulb (Economic Yield)
BY: Weight of biological yield

17. **Bulb dry matter content (%):** A homogenate was prepared from bulbs of each plot of the sampled plants. For determination of percent dry matter 25g of the homogenate was taken and oven dried at a temperature of 80^{o}C for 48 hrs. Then the weight was measured using digital balance and percent dry matter was calculated using a formula

$$\mathbf{DMC = \frac{(FW)}{(DW)} \times 100}$$

Where: **DMC**= dry matter content
FW= fresh weight
DW=dry weight

18. **Total soluble solid (^{o}Brix):** The TSS was determined using the procedures described by Waskar et al. (1999). Mortar was used to crush the bulb and prepare and extract Aliquot. The TSS was determined by hand refractometer (Bellingham and Stanley, UK) with a range of 0 to 32 ^{0}Brix and resolutions of 0.2 ^{0}Brix by placing 1 to 2 drops of clear juice on the prism, washed with distilled water and dried with tissue paper before use and

reuse. The refractometer was standardized against distilled water (0 ^{0}Brix TSS).This was done in the laboratory of post-harvest management department.

19. **Physiological bulb weight loss (%):** Determined using the methods described by Waskar et al. (1999). The measurement was based on the difference in weight of bulbs at the beginning and end of five bulbs was taken from each treatment randomly. The difference between the initial weight and successive weights gave the weight loss percentages.

$$\mathbf{WL\ (\%) = \frac{Wi - Wf}{Wi}\ X100}$$

Where: **WL**= bulb weight loss (%)
Wi = initial weight
Wf = final weight

20. **Number of bulbs sprouted (%):** Percentage of bulbs sprouted was cumulative, which was based on the number of bulbs sprouted in biweekly storage period. The incidence of sprouting was ascertained by counting the number of bulbs sprouted at the beginning and mid of each month. The sprouted bulbs were discarded after each biweekly count to avoid double counting. A bulb that sprouted and rotted at the same time was classified as sprouted.

21. **Weeks to 50% bulb sprout (week):** It’s the number of weeks it take to reach on the 50% of the sample onion bulb kept in the storage room to sprout and expressed in number of weeks.

22. **Number of rotten bulbs (%):** The measurement of percentage of bulbs rotted was cumulative and was based on the number of bulbs rotted in biweekly storage period. The incidence of rotting was determined by counting the number of bulbs rotted at the beginning and mid of each month. The rotted bulbs were discarded after each biweekly count to avoid double counting.

23. **Economic analysis:** To estimate the economic optimum levels of N, P and K fertilizer treatments, CIMMYT (1988) partial budget analysis procedures was employed.

3.5. Statistical Analysis

The parameters considered in this study were subjected to statistical analysis. Analysis of variance (ANOVA) was done using GenStat versions 12.1 (2009) with the REML variance component analysis. Mean differences were tested following least significant difference (LSD) at ($P \leq 0.05$). Interpretations and use of some biometrical equations were made according to Gomez and Gomez (1984).

4. RESULTS AND DISCUSSION

4.1. Growth Parameters

4.1.1. Plant height

Main application of N, P and K had shown a highly significant ($p<0.001$) difference on mean plants height at physiological maturity. However, the interaction effect among N, P and K on mean plants height was not significant (Figure 1 and Appendix Table 1). The maximum mean plant height (49.59 cm) was recorded from the plots that received N at 150 kg ha^{-1}. Increasing the level of applied N from 0 to 150 kg ha^{-1} increased the mean plants height by about 12% as compared to the control (43.84 cm). The observed increase in mean plants height at increased application of N could be attributed to its involvement as building blocks in the synthesis of amino acids which link together and form proteins and make up metabolic processes required for plant growth. Similar results have been reported by Amans *et al*. (1996), Kumar *et al*. (1998), Khan *et al*. (2002), El-Shaikh (2005), Shaheen *et al. (*2007) and Abdissa *et al.* (2011).

CV(%) 1.68 = LSD(0.05)= for N and K =0.37 and for P = 0.39

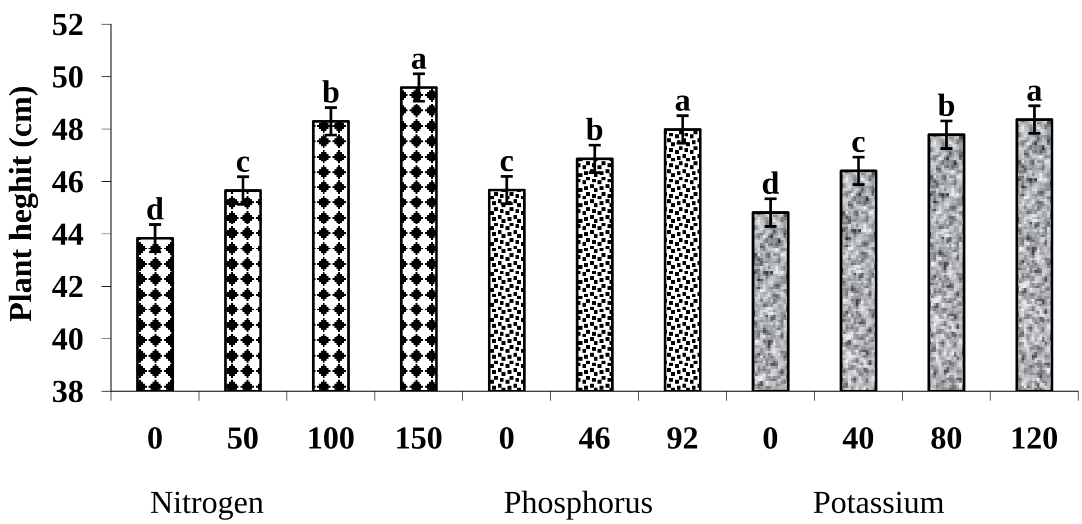

Figure 1. Main effect of N, P and K on mean plants height

Application of P imparted a highly significant ($P < 0.001$) influence on mean plants height at physiological maturity (Figure 1 and Appendix Table 1). Maximum application of P (92 kg ha^{-1}) increased the mean plants height by about 5% as compared to control (45.86). The positive response of onion to P fertilization was mainly due to the fact that onion plants have weak root system to effectively explore and utilize soil P and yet the nutrient plays a key role as part of the enzyme system having a vital role in the synthesis of other compounds from carbohydrates and is considered as a constituent of nuclear proteins. Similar results were also reported (El-Sheekh, 1997; El-Shaikh, 2005; Shaheen *et al.*, 2007) illustrating the responsiveness of onions to P application in respect of plant height.

The results of the present study (Figure 1 and Appendix Table 1) also revealed that, application of K had a highly significant ($p<0.001$) promoting effect on mean plant height at physiological maturity. The maximum mean plants height (48.37 cm) was recorded in the plots that received K at 120 kg ha^{-1}, while the minimum (44.82 cm) was observed in the unfertilized plots. Increasing the level of applied K from 0 to 120 kg ha^{-1} increased the mean plants height by about 7% as compared to the control. This might be associated with the role of K in protein synthesis and transport of water and essential nutrients throughout the plant. The result of this study is in line with the findings of Hariyappa (2003) who reported that application of K at 125 kg ha^{-1} showed significantly the highest plants height in onion. There are also many other investigators who reported an increase in vegetative growth with increased potassium fertilization levels on other crops; El- Masry (2000), Nassar *et al.* (2001) and Fawzy *et al.* (2005) on sweet pepper; Chen Zhen De *et al.* (1996) and Fawzy *et al.* (2007) on egg plant; Nanadal *et al.* (1998), Al-Karaki (2000) and Gupta and Sengar (2000) on tomato and Lester *et al.* (2006) on muskmelon. In the present, mean plants height was observed to have a strongly positive and significant correlation with leaf length (r = 0.70**), leaf sheath length (r = 0.88**), total bulb yield (r = 0.89**) and marketable bulb yield (r = 0.92**). Nevertheless, showed a significant and negative correlation with harvest index (r = -0.01**), unmarketable bulb weight (r = -0.27**), bulb sprouts percentage (r = -0.01**) and rotten bulbs percentage (r = -0.03**) (Appendix Table 9). In general, plant height was promoted as a result of the N, P and K application that increased available nutrients in root area and created less competition for resources and hence increased above ground and bulb biomasses.

4.1.2. Number of leaves per plant

The number of leaves is an important yield component. Leaves manufacture food with the help of chlorophyll and translocate it down for bulb development. Leaf number per plant at physiological maturity was highly and significantly ($p<0.001$) affected by combined application of N and P (Figure 2 and Appendix Table 1). The highest mean value (11.62) was obtained from the combined application of 150kg N and 92kg P ha^{-1} and the lowest mean value (8.02) was recorded in the control treatment. Combined application of N and P at 150:92 kg ha^{-1} increased the mean number of leaves by about 31% as compared with the unfertilized plots. This could probably be attributed to synergetic effect of the nutrients due to their complementary function in stimulating of lateral root production (Drew, 1995; Thaler and Pages, 1998; Zhang and Forde, 1998; Zhang *et al.*, 1999). The findings of this investigation are in close conformity with Patel *et al.* 1990, who reported significant effects of nitrogen and phosphorus application on mean leaf number of onion plants. Similarly, Halder *et al*. (1998) also observed that combined application of N and P at higher rates produced excellent performance on onion plants.

Similarly, the results of this study revealed that application of K at different levels showed a highly significant ($p<0.001$) effect on the mean number of leaves per plant (Appendix Table 1). The plots that were fertilized with the maximum rate of K (120 kg ha^{-1}) showed about 14.7% increase in mean number of leaves per plant which is statistically the same with value (14.2%) registered from plots that received only 80 kg of K ha^{-1}. Further application of K above 80 kg ha^{-1} did not bring change on onion mean number of leaves per plant. However, the minimum result (8.93) was recorded in the control treatment.

CV(%) = 4.64   LSD(0.05) = 0.213

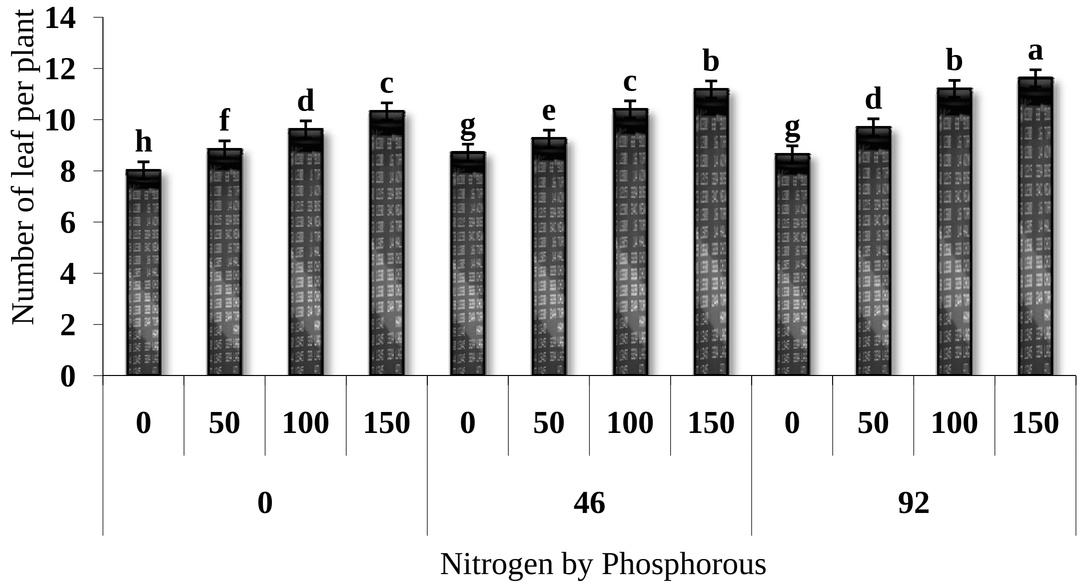

Figure 2. Number of leaves per plant as influenced by combined effect of N and P

Moreover, mean number of leaves was noted to have positive and highly significant correlation with leaf sheath length (r = 0.83**), total bulb yield (r = 0.88**), marketable bulb yield (r = 0.90**), bulb diameter (r = 0.76**), TSS (r = 0.78**) and dry matter content (r = 0.76**) however, a negative and highly significant correlation was revealed with unmarketable bulb (r = -0.34**) (Appendix Table 9). These results further indicated that leaf number was favored due to the application of N, P and K fertilizer owing to availability of more available nutrients in the root zone which up on uptake increases the vegetative growth and the area for photosynthesis to produce more assimilates. These all subsequently lead to increased total and marketable yield, while unmarketable bulb yield decreased due to application of N, P and K fertilizers.

4.1.3. Leaf length

A highly significant variation ($p<0.001$) was observed in terms of leaf length (cm) with the application of N, P and K. However, there was no significant interaction effect accountable to the combined application of N, P and K (Figure 3 and Appendix Table 1). The longest leaf (39.84 cm) was obtained from the plot that received 150 kg of N ha^{-1}. Increasing the level of N application from 0 to 150kg ha^{-1} highly and significantly increased the mean leaf length per plant by about 16% when compared with the control (33.51 cm). The positive effect of N on leaf length may be due to its key role in the synthesis of chlorophyll, enzymes and proteins. The result of this study is in agreement with the finding of Jilani (2004) who reported that, application of 200 kg N ha^{-1} significantly enhanced the length of onion leaves. Similarly, Kumar *et al.* (1998) and Singh and Chaure (1999) indicated that application of N at 150 kg ha^{-1} gave the best result with the regard to onion leaf length. Abdissa *et al.* (2011) also reported that N application showed a significant effect on onion leaf length.

CV(%)= 2.99   LSD(0.05)= for N and K=0.515; for P=0.596

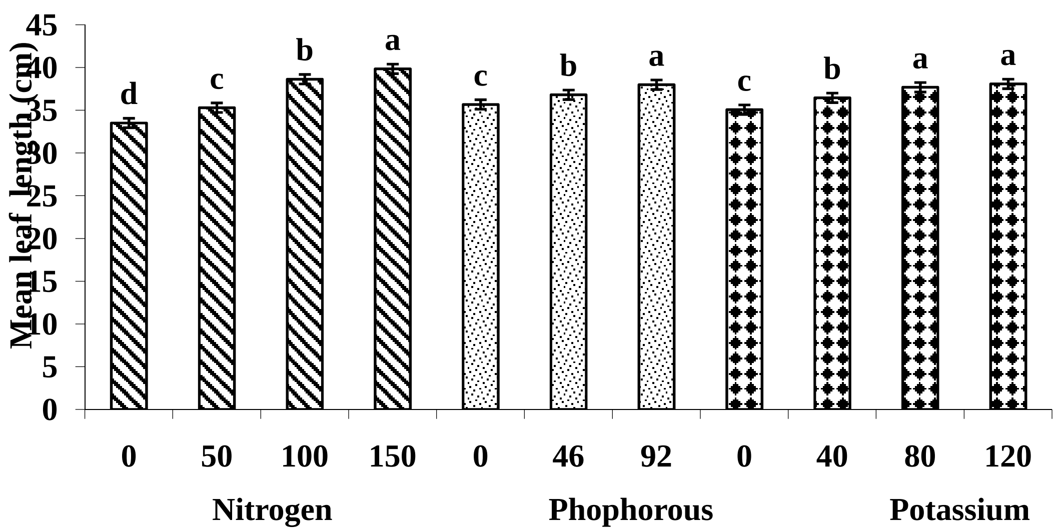

Figure 3. Main effect of N, P and K on mean leaf length

Results pertaining to leaf length are presented in Figure 3 and Appendix Table 1 indicated that, application of P resulted in a highly significant ($p<0.001$) difference on the mean leaf length of Bombay Red onion plants. Increasing the level of P application from 0 to 92 kg ha^{-1} highly and significantly increased the mean leaf length per plant by about 6.2% when compared with the control (35.67). This might be because of the presence of more available P around the plant root zone encourages plant growth. The results are correlated to the findings of Nikolay *et al.* 1996, Vacchain and Patel 1996, Warade *et al*. 1996, Hinsinger 2001, Pant and Reddy 2003 and Shafeek *et al*. 2004.

Similarly, the results of this study revealed that application of K at different levels showed a highly significant ($p<0.001$) effect on the mean leaf length per plant (Figure 3 and Appendix Table 1). The plots that were fertilized with the maximum rate of K (120 kg ha^{-1}) showed about 8% increase in mean leaf length per plant which is statistically the same with value (7.01%) registered from plots that received only 80 kg of K ha^{-1}. Further application of K above 80 kg ha^{-1} did not bring change on onion mean leaf length. However, the minimum mean leaf length (35.07cm) was recorded in the control treatment. Similar result was reported by El-Bassiouny (2006) that K significantly increased the mean leaf length of onion plants with increased K application.

A highly significant and positive correlation was observed between the leaf length with plant height (r = 0.70**), leaf shaft length (r = 0.57**), total bulb yield (r = 0.78**), marketable bulb yield (r = 0.70**), mean bulb weight (r = 0.80**), TSS (r = 0.87), dry matter content (r = 0.81**) and bulb diameter (r = 0.69**). It implies that the variation in mean leaf length might have been affected by plant height, leaf shaft length, dry matter content, TSS, total bulb yield, marketable bulb yield, mean bulb weight and bulb diameter or vice versa (Appendix Table 9). The production of higher leaf length with increasing levels of N, P and K fertilizers application could be because of more availability of mineral nutrients for plants in the root zone; since naturally onion plants have shallow and un-branched root system which is less efficient to absorb the mineral nutrients in the soil.

4.1.4. Leaf diameter

Application of N, P and K at different rates showed a highly significant ($p<0.001$) effect on leaf diameter. The results of this study revealed that regardless of the amount of P and K applied fertilizing plots with N resulted in a highly significant ($p<0.001$) differences among plots in respect of mean leaf diameter per plant, while the interaction among N, P and K did not show significant difference (Figure 4 and Appendix Table 2). Increasing the level of N application from 0 to 150 kg ha^{-1} highly and significantly increased mean leaf diameter per plant by about 29% as compared to control treatment (7.57 mm). This much discrepancy could occur probably due to an adequate supply of N which initiates vigorous vegetative growth and more efficient use of available inputs. Similarly, Kumar *et al*. (1998) reported that N application at 150 kg ha^{-1} gave the best result with regard to leaf diameter of the longest leaf.

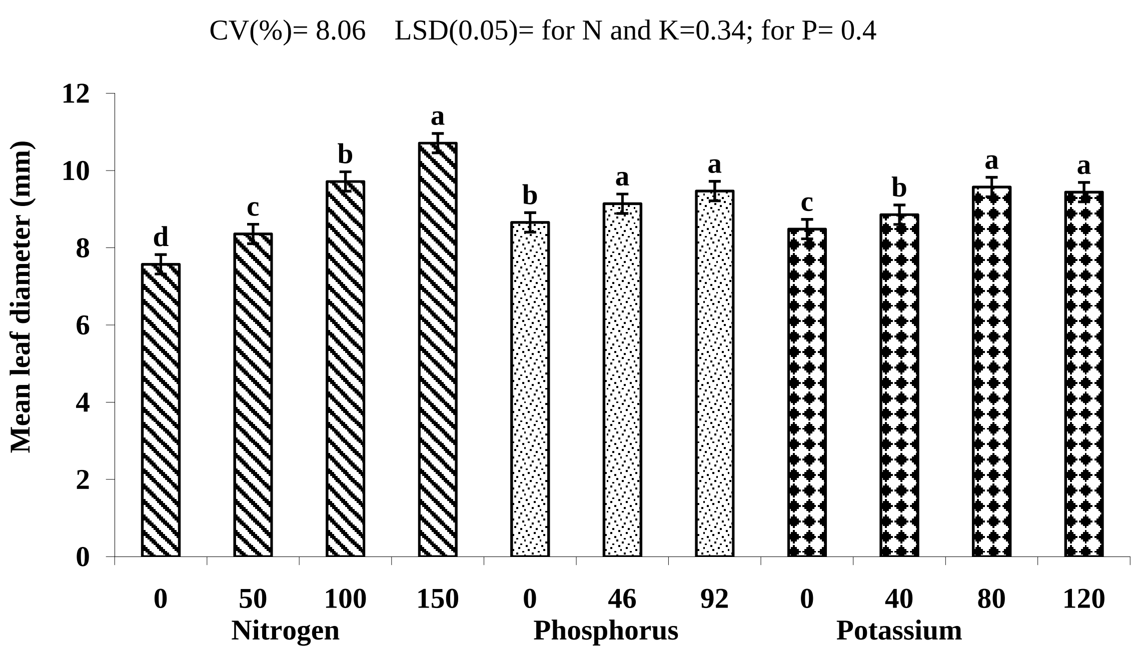

Figure 4. Main effect of N, P and K on mean leaf diameter

At the same time, application of P and K also independently showed a highly significant ($p<0.001$) effect on the mean leaf diameter per plant (Figure 4 and Appendix Table 2). However, the plants did not respond for further application of P and K above 46 kg ha^{-1} and

80 kg ha^{-1}, respectively. These rates could be technically the optimum level for P and K in the growth of onion leaf diameter. The results of this investigation are in line with the findings of Pettigrew (2008) who reported that potassium deficiency can lead to a reduction in both the number of leaves produced and the size of individual leaves.

4.1.5. Leaf sheath (shaft) length

The analysis of variance indicated that independently, fertilization of onion plants with N, P and K highly and significantly ($p<0.001$) influenced the mean leaf sheath length, while their interaction did not (Figure 5 and Appendix Table 2). Without considering the levels of P and K maximum application of N (150 kg ha^{-1}) increased the mean leaf sheath length by about 23% compared with the unfertilized plot (5.09 cm). This could show that nitrogen plays an important role in leaf sheath length via its role in vegetative growth. This result is in conformity with the findings of Khan *et al*. (2002) who reported that number of leaves per plant increased with increasing nitrogen level up to 150 kg ha^{-1} which also increases the leaf sheath length.

CV(%)= 5.37   LSD(0.05)=0.15

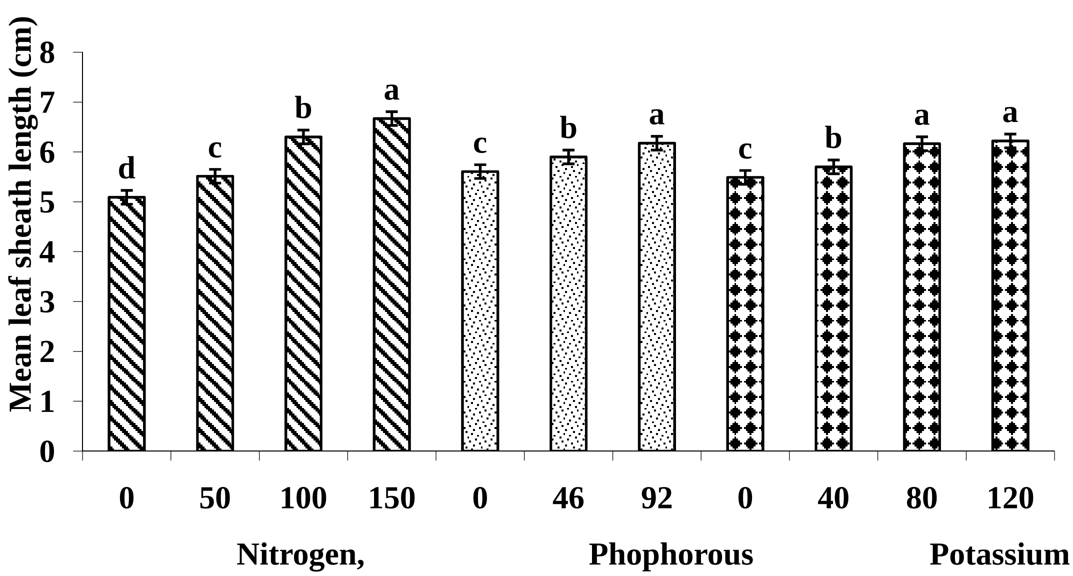

Figure 5. Main effect of N, P and K on leaf sheath (shaft) length

The results from figure 6 above revealed that the increasing levels of K had a highly significant ($P<0.001$) effect on the mean leaf sheath length. However, further application of K above 80 kg ha^{-1} did not bring change. Regardless of the levels of N and P, application of K up to 80 kg ha^{-1} increased the mean leaf sheath length by about 12% compared to the control treatment (5.49 cm). This result is in line with the finding of Pettigrew (2008) who reported that potassium deficiency can lead to a reduction in both the number and size of individual leaves produced, which is also the same for the mean leaf sheath length. A strongly and positively significant correlation was observed between leaf sheath length and plant height (r = 0.88**), leaf length (r = 0.57**), number of leaves (r = 0.83**), dry matter content (r = 0.67**), total bulb yield (r = 0.81**), marketable bulb yield (r = 0.85**), TSS (r = 0.64**) and bulb diameter (r = 0.71**). It is probable that plants having long sheath length will increase the area for photosynthesis and produce high total bulb yield, marketable bulb yield, dry matter content, TSS and bulb diameter in application of adequate amount of N, P and K fertilizer (Appendix Table 9).

4.1.6. Percentages of bolters

As depicted in Figure 6 and Appendix table 4, the percentage of bolted plants was highly significantly affected by N, P and K application. However, their interaction effects were not significant. All the levels of N showed a highly significant ($p<0.001$) difference on percentage bolting of onion plants. Increased levels of N fertilization significantly reduced the bolting percentage; in contrary K application had shown an increment in bolting percentage. The percentage of bolted plants decreased by about 15%, 36% and 59% in response to the application of 50, 100 and 150 kg of N ha^{-1}, respectively over the control treatment. This could be associated with the effect of N in extending the vegetative growth period of plants while delaying flowering. Nitrogen fertilizer increased the leaf area which increases the amount of solar radiation intercepted and consequently, delay flowering (Krshnappa, 1989). The findings of this investigation are in close conformity with those of Yamasaki and Tanaka, (2005) who reported that, in *Allium fistulosum* L. low nitrogen promoted bolting in onion plants. Abdissa *et al.* (2011) also reported similar results. In general, significantly higher bolting percentage was observed in the control than fertilized plants, which may be linked to limitation of N.

Similarly, P application had shown a significant (p<0.001) effect on percentage of bolted plants. Statistically high percentage of bolters (1.45%) was recorded in the control treatments followed by application of 46 kg P ha^{-1}. The result of this study also revealed that maximum application of P (92 kg ha^{-1}) reduced percentage of bolted plants (Figure 6 and Appendix Table 4). Similar findings were also reported by Amans (1982) and Umar (2000) who stated that P application can suppress bolting in onion.

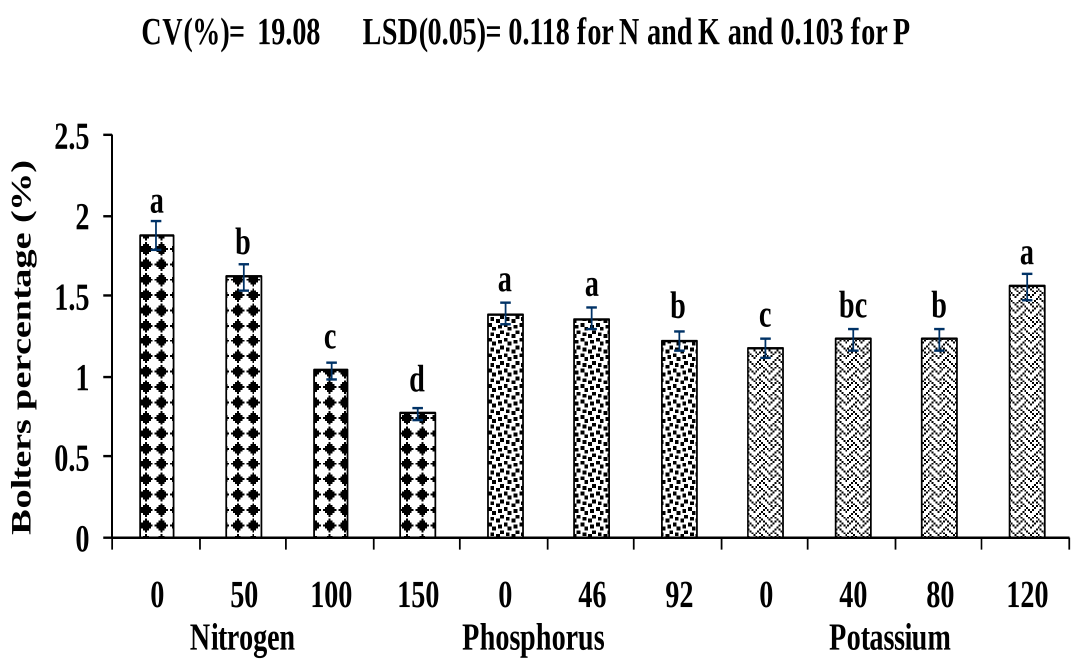

Figure 6. Main effect of N, P and K on percentage of bolters

The results presented in figure 6 above and Appendix Table 4 explain that K application also resulted in a significant (p<0.001) difference pertaining to the percentage of bolted plants. In the present study, the highest percentage of bolted plants (1.56%) was registered in the plots that received K at higher rate (120 kg ha^{-1}). Increasing the level of K application from 0 to 120 kg ha^{-1} highly and significantly increased the percentage of bolted plants by about 24.24% as compared with the control. Physiologically, K is important in enhancing the rate of carbohydrate assimilation and tissue maturation hence shortening harvesting time by switching vegetative growth phase and entering to the reproductive phase. Similarly, Singh and Singh (2000) reported maximum bolting (1.5%) with application of 50 kg K_2O ha^{-1}. Bolting could be affected by genetic factors, changes in temperature, poor seed quality, poor soil and cultural practices affecting the growth, relative length of day and night, spacing, and seedling size (Salunkhe, 1998).

4.1.7. Days to physiological maturity

Main effects of N, P and K had shown a highly significant ($p<0.001$) difference on the number of days to attain physiological maturity. However their interaction did not show significant difference (Figure 7 and Appendix Table 2). Increasing the level of applied N from 0 to 150 kg ha^{-1} prolonged the days to attain physiological maturity by about six days over the unfertilized plot (105 days). This could be due to the fact that N fertilization extended the vegetative growth period of plants; as a result it delayed maturity. Nitrogen fertilizer increased the leaf area which increases the amount of solar radiation intercepted and consequently, increases days to physiological maturity (Krshnappa, 1989). This result is in agreement with the findings of Brewester (1994), Sorensen and Grevsen (2001) and Abdissa *et al.* (2011) who reported that too much nitrogen promotes excessive vegetative growth and delayed maturity.

CV(%)=2.22 LSD (0.05)= for N and K = 1.25 and for P = 1.30

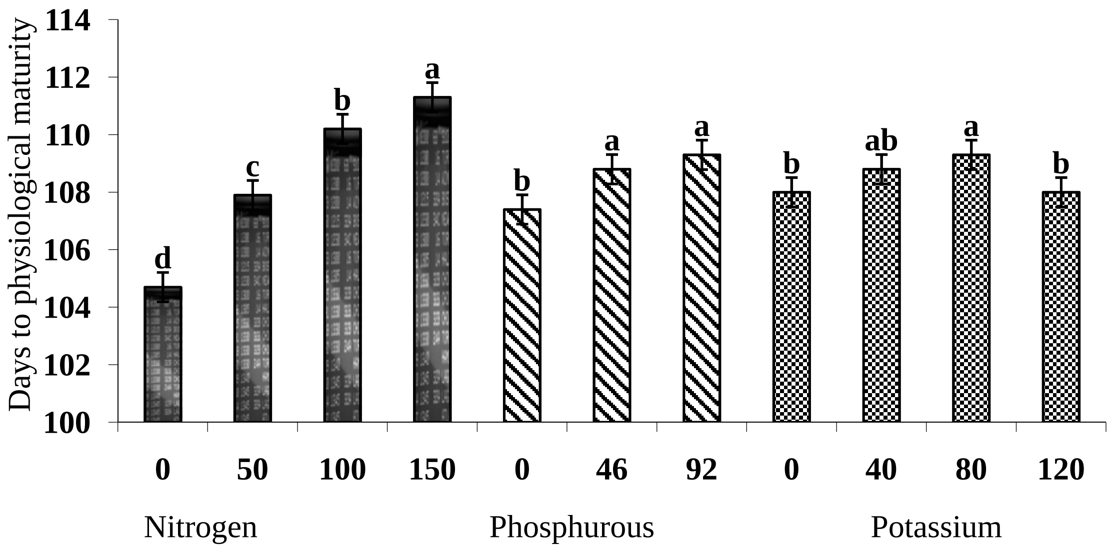

Figure 7. Main effect of N, P and K on days to attain physiological maturity

Similarly, P application produced a highly significant ($p<0.001$) difference on the days to attain physiological maturity. Application of P at the rate of 46 kg ha^{-1} prolonged days to attain physiological maturity by about three days as compared to the unfertilized plot (107 days). The result is statically the same with results recorded with the maximum P applied (92 kg ha^{-1}). Further application of P above 46 kg ha^{-1} had no significant effect on days to attain physiological maturity in onion plants (Figure 7 and Appendix Table 2). This result is in contrast with the finding of other workers (Ojala *et al.,* 1983; Brewster, 1994; and Greenwood *et al.,* 2001) who reported that P deficiencies can delay maturation. However, P application in the present study tended to delay the days to attain physiological maturity.

In the same manner, K nutrient application at the rates of 80 kg ha^{-1} delayed the days to attain physiological maturity by about three days; while further application of K above 80 kg ha^{-1} did not increase the days to attain physiological maturity and the graph started to decline (Figure 7 and Appendix Table 2). A significant delaying effect of K application at 80 kg ha^{-1} might be attributed to the additional sulfur mineral nutrients contained with K which often helps the crop to stay in vegetative growth period. This result is correlated with the reports of Anwar *et al. (*2001) who reported sulphur as essential for a good vegetative growth and bulb development in onion. A highly significant and positive correlation was observed between days to attain physiological maturity with plant height (r = 0.26**), leaf length (r = 0.80**), number of leaves per plant (r = 0.32**), leaf sheath length (r = 0.17**) and total bulb yield (r = 0.43**) which could be because of that long vegetative growth phase that extended the number of days required to attain physiological maturity. A highly significant and negative correlation between days to attain physiological maturity with percent weight loss (r = -0.66**), bulb sprouts percentage (r = -0.88**) and bulb length (r = -0.84**) in the present study revealed that as harvesting time was delayed, percent weight loss, percentage of sprouting bubs and bulb length were found to be negatively affected (Appendix Table 9).

4.2. Yield Parameters

4.2.1. Bulb diameter and bulb length

Separate application of N at different levels illustrated a highly significant ($P<0.001$) effect on both mean bulb diameter and bulb length, while the interaction between and among N, P and K did not show significant effect (Table 5 and Appendix Table 3). Of all the levels tested, the maximum rate fertilization for N (150kg ha^{-1}) increased the mean bulb diameter by about 13% in reference to the control treatments (5.22cm). Larger bulb diameter in onion with N application could be associated with promoting nature of nitrogen in cell elongation, above ground vegetative growth and synthesis of more chlorophyll to impart dark green color of leaves which may be linked to the increase in dry matter production and translocation to the bulb (Brady, 1985). This result is in coherence with that of Nasreen *et al*. (2007) who reported a significant increase in the mean diameter of bulbs due to the application of N up to 120 kg ha^{-1}. Similar results were also reported by Yadav *et al*. (2003) who found that N at 150 kg ha^{-1}, enhanced the formation of bulbs with larger diameters. Kumar *et al*. (1998), Khan *et al*. (2002) and Abdissa *et al.* (2011) also reported that bulb diameter is significantly affected by the application of N.

In the same manner, P application regardless of N and K applied resulted in a highly significant ($P<0.001$) difference in the mean bulb diameter and bulb length of onions (Table 5 and Appendix Table 3). The highest mean bulb diameter (5.76cm) and bulb length (4.94cm) were recorded in the plots that received the maximum rate of P (92 kg ha^{-1}) which are statically similar with the results obtained in application of 46 kg ha^{-1} in both cases. Statically the lowest mean bulb diameter and mean bulb length were recorded in the control treatments. These effects of P on the mean bulb diameter and length of onions may be through its influence on bulb development of onion plants. similarly, Mangrio *et al*. (1987) suggested that application of P at 100 kg ha^{-1} gave wider bulb diameter. El-Rehim (2000) also reported similar results.

Table 6. Main effect of N, P and K on onion bulb diameter, length and mean bulb weight

Treatments	Bulb length (cm)	Bulb diameter (cm)	Mean bulb weight (g)
Nitrogen (kg ha^{-1})			
0	5.21^{c}	4.42^{c}	41.35^{d}
50	5.35^{c}	4.53^{c}	43.37^{c}
100	5.75^{b}	4.96^{b}	46.82^{b}
150	6.02^{a}	5.23^{a}	49.78^{a}
$LSD_{(0.05)}$	0.232	0.202	1.791
CV (%)	8.89	9.01	8.45
Phosphorus (kg ha^{-1})			
0	5.43^{b}	4.59^{b}	42.86^{b}
46	5.55^{ab}	4.81^{ab}	45.61^{a}
92	5.76^{a}	4.94^{a}	47.52^{a}
$LSD_{(0.05)}$	0.268	0.233	2.069
CV (%)	8.89	9.01	8.45
Potassium (kg ha^{-1})			
0	5.32^{b}	4.53^{b}	40.94^{c}
40	5.45^{b}	4.63^{b}	44.72^{b}
80	5.74^{a}	4.90^{ab}	47.25^{a}
120	5.82^{a}	5.07^{a}	48.41^{a}
$LSD_{(0.05)}$	0.232	0.202	1.791
CV (%)	8.89	9.01	8.45

** Means in a column followed by the same letter(s) are not significantly different at 5%*

Results from Table 5 and Appendix Table 3 above indicate that, K application irrespective of the N and P applied showed a highly significant ($p<0.001$) difference on both the mean bulb diameter and bulb length of onions. Statistically the highest mean bulb diameter and length were recorded in the plots that received K at rate of 80 kg ha^{-1} and at 120 kg ha^{-1}. The results again showed that further application of K above 80 kg ha^{-1} did not bring any additional increase in both mean bulb length and diameter. On the other hand for both parameters the lowest records were observed in the unfertilized plot. Lower records in the control treatments clearly attesting that K requirement of onion plants increases with yield and its functions are linked to photosynthesis (Greenwood and Stone, 1998). This result is in line with the findings of Hariyappa (2003) who reported that, application of potassium at 125 kg ha^{-1} showed higher bulb length and bulb diameter as compared to control.

4.2.2. Mean bulb weight

There was statistically highly significant ($p<0.001$) difference encountered in mean bulb weight due to application of N, P and K at different levels. Nonetheless, their interactions were not significantly different (Table 5 and Appendix Table 3). Regardless of P and K applied, increasing the level of N from 0 to 150 kg ha^{-1} highly and significantly increased the mean bulb weight by about 17% when compared with the control treatment (41.35g). The mean bulb weight improvement in response to N application could be attributed to the increased assimilate production and allocation to the bulbs as manifested in terms of increase in plant height, number of leaves produced, leaf diameter, leaf length, and extended physiological maturity in response to the N fertilization. Similarly Kashi and Frodi (1998), Greenwood *et al*. (2001), Khan *et al*. (2002) and Abdissa *et al.* (2011) also reported significant increase in bulb weight due to increased N application.

Likewise, mean bulb weight of onion was highly and significantly affected by P, wherein application of 92kg ha^{-1} registered the maximum mean value (47.52g) which was statistically the same with the result (45.61g) obtained from the application of P at 46 kg ha^{-1} (Table 5 and Appendix Table 3). This result indicates that, further application P above 46 kg ha^{-1} had no significant effects on mean bulb weight. Marschner (1995) and Greenwood *et al.* (2001) similarly opined that P application has vital role in mean bulb weight of onion plant.

Though P had a positive effect on mean bulb weight, the percentage of mean weight increment due to P was smaller than the mean weight increment due to N and K. This could probably be explained by the fact that P leads to faster closure of canopy and shorten the growing period (Sommerfeld and Knutson, 1965). The other possible reason is that applied P may not be available to the plants at a rate similar to N and K fertilizer because of problem of soil fixation to satisfy first the soil demand of P.

As illustrated in Table 5 above and Appendix Table 3, application of K had shown a highly significant ($P<0.001$) difference on the mean bulb weight of onions. Of all levels considered in the study, application of K at a rate of 120kg ha^{-1} increased the mean bulb weight values by about 16% over control treatments (40.94g). The increase in mean bulb weight with the supply of K fertilizer nutrients could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthates which helped in producing bigger bulb, hence resulting in higher yields. This finding is supported by Yadav *et al*. (2002) who obtained a significantly higher yield of bulb (247.79 q ha^{-1}) and fresh weight of bulbs (49.53g) with application of 150 kg of K_2O ha^{-1} over other potassium levels. Marschner, (1995) and Greenwood and Stone, (1998) also pointed out that K requirement of onion plants increases with yield and its functions are linked with photosynthesis. Mean bulb weight was strongly and positively correlated with plant height ($r = 0.67^{**}$), leaf number ($r = 0.64^{**}$), leaf length ($r = 0.80^{**}$) and leaf sheath length ($r = 0.58^{**}$). Onion bulb dry matter content, total bulb yield and marketable bulb yield can be increased by the application of N, P and K during the growing period. In the present study, mean bulb weight was positively and strongly correlated with dry matter content ($r = 0.80^{**}$), total bulb yield ($r = 0.77^{**}$) and marketable bulb yield ($r = 0.71^{**}$) signifying that N, P and K fertilization increased mean bulb weight by improving these parameters (Appendix Table 9).

4.2.3. Marketable bulb yield and marketable bulb percentage

The interaction effect among N, P and K resulted in a highly significant ($p<0.001$) difference in respect of the marketable bulb yield, while the main effect of N, P and K highly and significantly affected the marketable bulb percentage (Table 6 and Appendix Table 5). Among all treatment combinations the combined application of N-P-K at 150:46:120 kg ha^{-1} increased the marketable bulb yield by about 47% as compared with the control treatment (9.83 ton ha^{-1}). This result is on par with the value achieved with fertilizers applied at the rate of 150:92:120; 150:46:80; 150:92:80 and 100:92:120 kg of N-P-K ha^{-1}. This finding is in accordance with the result of Girigowda *et al*., (2005) who reported that the higher marketable bulbs yield was recorded with application of N-P-K fertilizer at the rate of 188:75:188 kg of N-P-K ha^{-1}. Similarly, Singh *et al*. (1997) also reported that application of N-P-K at rate of 100:50: 50 kg ha^{-1} increased the marketable yield in onion.

Table 6. Marketable yield (t/ha) as influenced by interaction effects of N-P-K fertilizers

Nitrogen (kg ha^{-1})	Potassium (kg ha^{-1})	Phosphorus (kg ha^{-1})		
		P_0	P_{46}	P_{92}
N_0	K_0	9.83^{z}	10.73^{yz}	11.36^{xyz}
	K_{40}	10.67^{za}	10.67^{za}	12.69^{t-w}
	K_{80}	11.42^{xyz}	12.79^{s-v}	14.05^{opq}
	K_{120}	12.02^{u-x}	14.89^{k-o}	15.30^{jkl}
N_{50}	K_0	10.81^{yz}	11.57^{xy}	13.63^{q-s}
	K_{40}	11.91^{wx}	12.89^{r-u}	13.76^{pqr}
	K_{80}	12.63^{t-w}	14.59^{l-p}	15.22^{j-m}
	K_{120}	14.37^{m-q}	15.19^{j-n}	16.67^{fgh}
N_{100}	K_0	11.98^{vwx}	14.35^{m-q}	15.43^{jkl}
	K_{40}	14.32^{n-q}	16.00^{h-j}	16.41^{g-i}
	K_{80}	15.17^{j-n}	17.09^{d-g}	17.68^{b-e}
	K_{120}	17.05^{d-g}	17.30^{c-f}	17.91^{a-d}
N_{150}	K_0	13.13^{rst}	15.56^{ijk}	17.20^{d-g}
	K_{40}	15.00^{k-n}	17.20^{d-g}	16.98^{efg}
	K_{80}	17.05^{d-g}	18.49^{ab}	18.14^{abc}
	K_{120}	17.40^{c-f}	18.57^{a}	18.50^{ab}

$LSD_{(0.05)} = 0.0187$
CV(%) = 3.67

** Means in a column followed by the same letter(s) are not significantly different at 5%*

Furthermore, the highly significant and strong positive correlation of marketable bulb yield per hectare with plant height (r = 0.92**), leaf number (r = 0.90**), leaf length (r = 0.71**), leaf sheath length (r = 0.85**), dry matter content (r = 0.79**) and total bulb yield (r = 0.98**) in the present study revealed that the presence of high marketable bulb weight is associated with the positive influences of N, P and K applications on the photosynthetic area and the resulted sink (Appendix Table 9).

4.2.4. Total bulb yield

With regard to total bulb yield of onion per hectare, there was a highly significant ($P<0.001$) variation attributable to the interaction effect of N-P-K. The results depicted in Table 7 and Appendix Table 5 indicate that of all the treatment combinations the maximum combined application of N-P-K at the rate of 150:92:120 kg ha^{-1} significantly increased the total bulb yield by about 40% as compared with the unfertilized plot (11.11 t/ha). Which, however, happened to be at par with the results of fertilizer at levels 150:46:120; 150:46:80; 150:92:80; 100:92:120 and 100:92:80 kg ha^{-1}.

The results of this finding is in conformity with the results of Singh *et al*. (2000) who pointed out that onion productivity could be enhanced considerably by application of 100:30.8:83 N-P-K kg ha^{-1}. Koondhar (2001) also showed that the highest bulb yield (48.67 tone) was obtained when the plots received 100:80:75 kg of N-P-K per hectare. Similarly, Girigowda *et al*. (2005) also reported that higher bulb yield (41.69 t/ha) was recorded with fertilizer level of 188:75:188 kg of N-P-K ha^{-1} and it was on par with fertilizer level of 156:63:156 kg of N-P-K ha^{-1}. Moreover, total bulb yield was highly significant and positively correlated to plants height (r = 0.89**), leaf length (r = 0.78**), leaf sheath length (r = 0.82**) and leaf numbers (r = 0.88**) (Appendix Table 9).

Table 7. Total bulb yield per hectare as affected by interaction effects of N-P-K fertilizers

Nitrogen (kg ha^{-1})	Potassium (kg ha^{-1})	Phosphorus (kg ha^{-1})		
		P_0	P_{46}	P_{92}
N_0	K_0	11.11^{u}	11.86^{tu}	12.38st
	K_{40}	11.75^{tu}	12.92^{rs}	13.64^{o-r}
	K_{80}	12.42st	13.69^{o-r}	14.87^{k-n}
	K_{120}	13.01^{qrs}	15.70^{h-k}	16.07^{g-j}
N_{50}	K_0	11.80^{tu}	12.46st	14.47^{l-o}
	K_{40}	12.86^{rs}	13.83^{opq}	14.40^{m-p}
	K_{80}	13.59^{pqr}	15.34^{i-l}	15.97^{g-j}
	K_{120}	14.82^{lmn}	15.83^{g-j}	17.25^{cde}
N_{100}	K_0	12.87^{rs}	15.28^{jkl}	16.16^{ghi}
	K_{40}	15.21^{j-m}	16.64^{efg}	17.08^{def}
	K_{80}	15.89^{g-j}	17.60^{bcd}	18.16^{ab}
	K_{120}	17.55^{bcd}	17.80^{bcd}	18.02^{abc}
N_{150}	K_0	14.03^{nop}	16.28^{fgh}	17.80^{bcd}
	K_{40}	15.78^{g-j}	17.74^{bcd}	17.52^{bcd}
	K_{80}	17.55^{bcd}	18.72^{a}	18.25^{ab}
	K_{120}	17.70^{bcd}	18.78^{a}	18.78^{a}
LSD $_{(0.05)}$ = 0.877				
CV (%) = 3.52				

** Means in a column followed by the same letter(s) are not significantly different at 5%*

Furthermore, mean bulb weight (r = 0.76**), TSS (r = 0.82**), dry matter content (r = 0.83**), days to maturity (r = 0.43**) and bulb diameter (r = 0.80**) also showed a strong and positive correlation with the total onion bulb yield. This result demonstrated that as individual bulb size, dry matter content and days to harvest increases, it is fundamental to maximize onion productivity per unit area (Appendix Table 9).

4.2.5. Unmarketable bulb yield

The main effect of N, P and K had shown a highly significant (P<0.001) difference in terms of unmarketable bulb yield (t/ha), while their interaction did not show significant effect (Table 8 and Appendix Table 5). Accordingly the results indicate that higher rate application of N, P and K decreased the unmarketable bulb yield per hectare. Among all treatments combinations the highest unmarketable bulb yield was recorded in the unfertilized plots.

Without considering the P and K levels, maximum application of N at rate of 150 kg ha^{-1} decreased the unmarketable bulb yield per hectare by about 52.1 % as compared to the unfertilized plot. Sub-optimal supply and low nitrogen levels have been associated with early bulb formation, plants can be severely stunted, with bulbs size and marketable yields reduced in onion.

Table 8. Influences of N, P and K on unmarketable bulb yield and harvest index per hactare

Treatments	Unmarketable bulb yield (ton ha^{-1})	Harvest index
Nitrogen (kg ha^{-1})		
0	0.98^{a}	0.66^{d}
50	0.78^{b}	0.73^{c}
100	0.63^{c}	0.77^{b}
150	0.47^{d}	0.80^{a}
$LSD_{(0.05)}$	0.072	0.020
CV (%)	21.38	5.88
Phosphorus (kg ha^{-1})		
0	0.82^{a}	0.70^{b}
46	0.71^{b}	0.75^{a}
92	0.62^{c}	0.77^{a}
$LSD_{(0.05)}$	0.083	0.024
CV (%)	21.33	5.88
Potassium (kg ha^{-1})		
0	0.91^{a}	0.69^{c}
40	0.79^{b}	0.74^{b}
80	0.64^{c}	0.74^{b}
120	0.51^{d}	0.78^{a}
$LSD_{(0.05)}$	0.072	0.020
CV (%)	21.46	5.88

** Means in a column followed by the same letter(s) are not significantly different at 5%*

In similar manner, the result of this study revealed that, application of P and K imparted a highly significant ($P<0.001$) effect on the unmarketable bulb yield of onions (Table 8 and Appendix Table 5). The plots that received P and K at 92 and 120 kg ha^{-1}, respectively regardless of the amount of N applied decreased level of unmarketable bulb by about 43% and 24.4%, respectively as compared to the control wherein the maximum was registered. The lowest unmarketable bulb yield and its best physical properties achieved with increasing rate of potassium application might be attributed to many vital roles of potassium in plant nutrition vis-à-vis it increases root growth, improves drought resistance, enhances several enzyme functions, bulbs cellulose, reduces lodging, controls plant turgidity, maintains the selectivity and integrity of the cell membranes, helps translocation of sugars and starch, reduces water loss, reduces respiration, prevents energy loses, helps in protein synthesis and uplifts the protein content of plants and controls plants diseases Shaheen, (2007). This result is in agreement with the reports of Abo-zeid and Farghali (1996) who based on field trials reported the highest marketable yield obtained with 120 kg K_2SO_4 ha^{-1} on sandy calcareous soils.

A strongly positive correlation was apparent between unmarketable bulb weight and weight loss percentage (r = 72**), bulb sprouts percentage (r = 92**) and rotten bulbs percentage (r = 18**). A strongly negative and yet significant correlation was noted between unmarketable bulb yield per hectare with plant height (r = -0.27**), leaf number (r = -0.35**), leaf length (r = -0.81**), leaf sheath length (r = -0.16**), dry matter content (r = -0.61**), marketable bulb yield(r = -0.33**) and total bulb yield (r = -0.46**) (Appendix Table 9).

4.2.6. Harvest index

The results given in Table 8 and Appendix Table 4 explain that independent application of N, P and K had produced a highly significant ($P<0.001$) variation in respect of the harvest index of onion plants. A close analysis of the data further indicates that increasing the level of N application from 0 to 150kg ha^{-1} highly and significantly increased the harvest index by about 17.6% over the respective check. The observed harvest index improvement could be attributed to an increased photosynthetic area in response to N fertilization that enhanced assimilate production and greater partitioning of the same to the bulbs. The findings from the investigation of Anwar *et al.* (2001) and Abdissa *et al.* (2011) on onion also implied similar effects. However, contrary to the present results, Millard and Marshall (1986) reported that nitrogen application increased aboveground biomass yield in the case of potato.

In the same manner, application of P, without considering the amount of N and K applied, also resulted in an increment of onion plants harvest index. Maximum application of P (92 kg ha^{-1}) increased the harvest index by about 9% as compared with the control. Harvest index showed a tendency to increase with additional P up to 46 kg ha^{-1} after which it remained statistically the same. The presence of high harvest index is associated with the production of high bulb weight relative to the above ground biomass. In line with result of the present study, a finding indicated that in soils with moderately low in P, onion growth and yield can be enhanced in response to P fertilization (Alt *et al*., 1999).

Application of K at different rates demonstrated a highly significant ($p<0.001$) difference on the harvest index of onion plants (Table 8 and Appendix Table 4). The highest mean values (0.78) was recorded in the plot that received K at rate of 120 kg ha^{-1} and the lowest mean values (0.69) was recorded from the unfertilized plot. This might be because of the fact that K requirement of onion plants increases with yield and its functions are linked to photosynthesis. In addition, it could be associated with presence of sulphur in the potassium sulphate fertilizer applied; which might have exerted a significant influence on number of leaves/plant, plant height, bulb size, and weight of onion plant. The results from this study showed that increasing the level of K application increases the harvest index of the onion plants.

The highly significant positive correlation between harvest index and unmarketable bulb weight (r = 0.94**), bulb weight loss (r = 0.87**) and bulb sprouts percentage (r = 0.97**) 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 but negative association was observed between harvest index and leaf length (r = -0.65**), dry matter content (r = -0.42**), total bulb yield (r = -0.21**), average bulb weight (r = -0.52**), total soluble solid (r = -0.50**), days to physiological maturity (r = -0.91**) and marketable bulb percentage (r = -0.60**) (Appendix Table 9).

4.3. Quality Parameters

4.3.1. Total soluble solid (TSS)

Regarding the total soluble solid (TSS), the interaction of N-P had shown a highly significant (Table 9 and Appendix Table 6) difference. The highest TSS value (11.67 ^{o}Brix) was recorded as a result of the combined application of N-P at the rate of 150:92 kg ha^{-1}; while the minimum TSS value (8.08 ^{o}Brix) was recorded in control. More explicitly, the maximum TSS which was registered from the combined application of N-P (150:92 kg ha^{-1}) was higherthe control by about 30%.

Table 7. TSS of onion bulbs as influenced by combined application of NXP and NXK

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})		
	0	46	92
0	8.08^{h}	8.83^{g}	8.84^{g}
50	8.75^{g}	9.58^{f}	9.71^{f}
100	9.63^{f}	10.38^{d}	11.34^{b}
150	10.00^{e}	10.83^{c}	11.67^{a}
LSD $_{(0.05)}$ = 0.222			
CV (%) = 4.85			

Nitrogen (kg ha^{-1})	Potassium (kg ha^{-1})			
	0	40	80	120
0	7.99^{j}	8.28^{i}	8.99^{h}	8.99^{h}
50	8.83^{h}	9.66^{ef}	9.56^{ef}	9.33^{g}
100	9.49^{fg}	10.28^{d}	10.78^{c}	11.23^{b}
150	9.78^{e}	10.73^{c}	11.56^{a}	11.28^{b}
LSD $_{(0.05)}$ = 0.222				
CV (%) = 4.85				

** Means in a column followed by the same letter(s) are not significantly different at 5%*

The results in Table 9 and Appendix Table 6 revealed that combined application of N and K had shown a highly significant effect on the TSS of onion bulbs. The highest TSS value (11.56 ^{o}Brix) was obtained with the combined application of N and K at the rate of 150:80 kg ha^{-1}; while the minimum TSS value (7.99 ^{o}Brix) was recorded in the control. Regardless of the levels of P applied, combined application of N and K at 150:80 kg ha^{-1} increased the TSS by about 31% as compared to control (7.99 ^{o}Brix).

In the present study total soluble solid showed a strong and positive correlation with plant height (r = 0.74**), leaf length (r = 0.87**), leaf sheath length (r = 0.64**), number of leaves per plant (r = 0.78**), dry matter content (r = 0.83**), total bulb yield (r = 0.83**), marketable bulb yield (r = 0.77**) and days to physiological maturity (r = 0.69**) which have direct relationship in the synthesis and increment of total soluble solid of onion bulbs. On the other hand, total soluble solid was negatively correlated with bulb length (r = -0.33**) indicating that high total soluble solid is associated with smaller bulbs (Appendix Table 9).

4.3.2. Bulb shape index

Onion bulb shape index is a function of variety and growth environment. It is vary from flat to globe to torpedo which has different requirements in different markets. The onion bulb shape was assessed by the bulb shape index; this was determined by the ratio of bulb length to diameter. The result of this study revealed that application of N, P and K at different levels independently resulted in a highly significant (P<0.001) difference on the bulb shape index, while their interaction did not (Table 10 and Appendix Table 4). This result also showed that the null and lower application of N, P and K fertilizers increased the percentage of shape rejects as compared to the plots that received higher levels of N, P and K (150 kg N ha^{-1}, 92 kg P ha^{-1} and 120 kg K ha^{-1}), respectively. Similarly, Geremew, (2009) reported as bulb shape of onion as affected by mineral nutrients.

Table 10. Bulb shape index and dry matter contents as affected by N, P and K fertilizers

Treatments	Bulb shape index	Dry matter contents (%)
Nitrogen (kg ha^{-1})		
0	0.84^{c}	9.26^{d}
50	0.84^{bc}	9.65^{c}
100	0.86^{ab}	10.19^{b}
150	0.87^{a}	10.54^{a}
$LSD_{(0.05)}$	0.021	0.18
CV (%)	5.15	3.82
Phosphorus (kg ha^{-1})		
0	0.84^{b}	9.54^{c}
46	0.86^{ab}	9.89^{b}
92	0.87^{a}	10.30^{a}
$LSD_{(0.05)}$	0.024	0.205
CV (%)	5.15	3.82
Potassium (kg ha^{-1})		
0	0.84^{b}	9.20^{d}
40	0.85^{ab}	9.78 ^{c}
80	0.85^{ab}	10.23^{b}
120	0.87^{a}	10.42^{a}
$LSD_{(0.05)}$	0.021	0.18
CV (%)	5.15	3.82

** Means in a column followed by the same letter(s) are not significantly different at 5%*

Among the levels, higher application of N (150 kg ha^{1}), P (92 kg ha^{-1}) and K (120 kg ha^{-1}) increased the bulb shape index by about 3%, 3% and 2.5% over the control, respectively (Table 10 and Appendix Table 4). The reason such an increase in the value of bulb shape index following the application of high dose N, P and K was associated with the vital role these nutrients can play in plant growth and development. Kimani *et al.* (1993) reported that bulb shape to be different among onion cultivars and was affected by growing environment and that globe shaped bulbs (shape index = 1) are preferred by the consumers.

4.3.3. Dry matter contents

Regarding the dry matter contents, application of N, P and K unilaterally resulted in a highly significant effect, while their interaction did not (Table 10 and Appendix Table 6). The increasing levels of N, P and K encouraged bulbs with a significantly higher dry matter contents as compared to the unfertilized plot.

The maximum dry matter contents of onion bulbs (10.54%), (10.30%) and (10.42%) were recorded with application of N, P and K at higher rates of 150, 92 and 120 kg ha^{-1}, respectively. On the other hand, the minimum dry matter contents (9.26%), (9.54%) and (9.20%) were detected in controls for N, P and K, respectively (Table 10 and Appendix Table 6). This finding is in coherence with the result of Mojsevich (2008) who reported that an increase in the doses of N, P and K from 70, 45, 70 kg ha^{-1} to N, P and K 110, 75, 110 kg ha^{-1} increased the dry matter content of bulbs from 14.6% to 15.5%.

Dry matter content showed a strongly positive correlation with plants height (r = 0.80**), leaf length (r = 0.82**), leaf sheath length (r = 0.68**) and leaf number (r = 0.77**) which have direct relationship with the synthesis and increment of dry matter content in onion bulb. Similarly, total bulb yield (r = 0.83**), marketable bulb yield (r = 0.79**) and mean bulb weight (r = 0.80**) also showed positive relationships with the onion bulb dry matter content (Appendix Table 9).

Furthermore, On the contrary, dry matter content was negatively correlated with harvest index (r = -0.41**), weight loss percentage (r = -0.12**), bulb sprouts percentage (r = -0.43**) and bulb rots percentage (r = -0.14**) that indicating lower dry matter content was associated with unmarketable bulbs (Appendix Table 9).

4.4. Storage Life Parameters of Onion Bulb

4.4.1. Bulbs storage rots percentage

Although no apparent significant interaction effects were observed, N and K application had a highly significant ($p \leq 0.05$) effect on bulb rotting percentage during the storage time (Table 11 and Appendix Table 7). The highest percent of bulb rot percentage (3.69%) was recorded in the plots which received 150 kg N ha^{-1} whereas the least was from unfertilized plots. (Jones and Mann, 1963) also reported that onion bulbs produced without nitrogen application resulted in the lowest rotting (22%), while the highest rotting (36 to 54%) was recorded in bulbs produced under higher dose of nitrogen. Similarly in India, Singh and Dhankar (1991) and Pandey and Pandey (1994) reported that increasing the rate of applied nitrogen (N) from 50 to 150 kg ha^{-1} led to significant increases in storage rots of onion during 4 to 5 months under ambient conditions.

Similarly, application of K also created a highly significant ($p<0.001$) difference in the bulb rots percentage of onion plants (Table 11 and Appendix Table 7). The findings indicated that the application of K at the maximum rate (120 kg ha^{-1}) significantly decreased bulb rot percentage which is about 53.5% when compared with the unfertilized plots. These findings are in harmony with the reports of Singh and Dhankar (1991) who recorded that rotting percentage was reduced considerably during storage in the bulbs produced by the application of 100 kg K_2O ha^{-1}. Similarly, Nandi *et al*. (2002) also recorded that the lowest rotting (7.60 %) with application of K at 180 kg ha^{-1} as compared to the control.

Table 11. Storage rots(%), PWL and bulb sprout (%) as affected by N, P and K fertilizers

Treatments	Storage rots of bulbs (%)	PWL (%)	Bulb sprouts percentage (%)
Nitrogen (kg ha^{-1})			
0	7.78 (2.38^{c})	32.05^{d}	60.28 (7.75^{b})
50	9.72 (2.88^{b})	34.48^{c}	56.39 (7.49^{c})
100	10.83 (3.07^{b})	37.14^{b}	59.72 (7.72^{b})
150	13.89 (3.69^{a})	39.53^{a}	66.11 (8.12^{a})
$LSD_{(0.05)}$	0.42	0.92	0.202
CV (%)	30.08	5.5	5.55
Phosphorus (kg ha^{-1})			
0	10.83 (2.99)	35.93	59.38 (7.68)
46	9.58 (2.87)	35.80	61.04 (7.79)
92	11.25 (3.16)	35.66	61.46 (7.89)
$LSD_{(0.05)}$	Ns	Ns	Ns
CV (%)	30.08	5.5	5.55
Potassium (kg ha^{-1})			
0	19.44 (4.41^{a})	36.39 ^{a}	66.11 (8.11^{a})
40	10.00 (3.07^{b})	36.27 ^{a}	59.72 (7.72^{b})
80	7.22 (2.50^{c})	35.54^{ab}	58.89 (7.59^{b})
120	5.56 (2.05^{d})	34.99^{b}	57.72 (7.66^{b})
$LSD_{(0.05)}$	0.42	0.92	0.202
CV (%)	30.08	5.5	5.55

** Ns = not significant; Means in a column followed by the same letter(s) are not significantly different at 5%. Numbers in parenthesis are square root transformations.*

Furthermore, the positive but weak correlation between bulb storage rot percentage with unmarketable bulb weight (r = 0.18**), bulb weight loss percentage (r = 0.23**) and bulb sprout percentage (r = 0.21**) in the present study revealed that the presence of high unmarketable bulb percentage is associated with the production of more storage rot percentage, sprout percentage and onion bulb weight loss with the applications of N, P and K at different levels (Appendix Table 9).

4.4.2. Physiological bulb weight loss percentage

Among the fertilizers applied, N had a highly significant ($P<0.05$) contributing effect on the weight loss percentage of stored onion bulb during the two month storage time (Table 11 and Appendix Table 7). Greater weight loss percentage (39.53%) was seen in bulbs harvested from plots which had received the maximum N (150 kg ha^{-1}). This vivid effect of N may be associated with the resumption of higher incidence of sprouting and rotting presumably through increase in the rate of respiration. Comparatively speaking, the high weight loss percentage (39.53) incurred as a result of N application at the maximum rate (150 kg ha^{-1}) was about 19% greater than the control. Dankhar and Singh (1991) also reported a similar result that weight loss of bulbs increased with an increase in the nitrogen level.

At the same time, K also had a highly significant ($P<0.001$) effect on the weight loss percentage of onion bulb during the storage. Unlike N and K application decreased the weight loss of the bulb. The results presented in table 11 and Appendix Table 7 indicates that K application at the rate of 80 kg ha^{-1} showed a significantly lower weight loss as compared to the unfertilized plots. However, further application of K above 80 kg ha^{-1} had no significant effect on bulb weight loss percentage. The results of the present study are in alignment with the reports of Singh and Dhankar (1991) in which loss in total weight was reduced considerably during storage in the bulbs produced by the application of 100 kg K_2O ha^{-1}. Similarly, Nandi *et al*. (2002) also recorded the lowest weight loss (9.21%) with application of K at the rate of 180 kg ha^{-1} compared to control.

4.4.3. Bulb sprouts percentage and weeks to 50% bulb sprouts

Sprouting is a physiological change that occurs in onion bulbs during storage. N and K application had shown a significant ($P<0.001$) difference on percentage bulb sprouts; K application also had a significant effect on weeks to 50% bulb sprouts**,** while their interaction did not (Table 11 and Appendix Tables 5 and 7). The highest incidence of sprouting was seen in bulbs harvested from the plots that received the maximum rates of N (150 kg ha^{-1}); while the least record was observed from unfertilized plots at the end of the two months storage period. There is similar report by Bhalekar *et al.* (1987) who observed that sprouting was increased with increasing nitrogen levels from 0 to 150 kg N ha^{-1}. Dankhar and Singh (1991) also reported that higher doses of nitrogen produced thick-necked bulbs that increased sprouting in storage due to greater access of oxygen and moisture to the central growing point.

K application significantly decreased the sprouts percentage (Table 11 and Appendix Table 5 and 7). In this regard the maximum sprout of bulb was recorded with control treatment, while the minimum sprouts occurred in bulbs which were collected from plots fertilized with the K at the rate of 40 kg ha^{-1}. However, further application of K had no significant effect on the bulb sprouts percentage. Similarly, Nandi *et al*. (2002) also recorded that the lowest sprouting (20.00%) with application of K at 180 kg ha^{-1} compared to control. Masalkar *et al*., (2005 a) also reported that sprouting of bulbs in storage had declined with successive increase of K.

Keeping onions for longer duration without sprouting and decay is a big challenge along the commodity chain. In the present study, the results of storage study pertaining to weeks to 50% bulb sprout (Appendix Table 5 and 7) revealed that as the amount of K applied in the field increased, the weeks to attain 50% bulb sprouts was also extended. Among the levels studied, irrespective of N and P applied, k application at maximum rate (120 kg ha^{-1}) increased the weeks to attain 50% bulb sprouts by about 1.3 weeks (Appendix Table 5) as compared to the unfertilized plots. This result is in line with the finding of Masalkar *et al*., (2005) who reported that sprouting of bulbs in storage had declined with successive increase of K.

4.5. Economic Analysis

To estimate the economic significance of N, P and K fertilizer treatments, partial budget analysis (CIMMYT, 1988) was employed to calculate the marginal rate of return (MRR) in onion bulb production. Economic analysis was done on N by P by K factorial treatments. Before economic analysis, the total marketable bulb yield was adjusted down by 10% to minimize the effect of researcher managed small plots that may differ from the yield level on farmers' field. The farm gate price of 700 ETB per 100 kg of onion bulb was used and this was the actual average price of onion bulb during the year 2003 E.C. harvesting season at Jimma town market.

The price of 100kg fertilizer during the current season was 890.00 ETB for Urea, 1000.00 ETB for DAP and 928.00 ETB for potassium sulphate and hence for this particular study, the above listed prices of fertilizers were used for the economic analysis. Urea, TSP (Triple Super Phosphate) and K_2SO_4 (Potassium Sulphate) were used as source of N, P and K, respectively. Since TSP fertilizer is not available in local markets, the price of DAP was considered as a base for the price of TSP for economic analysis in this particular study and the price information about K_2SO_4 fertilizer was obtained from National Fertilizers Industry Agency. Costs of harvesting, and bagging were assumed to be 20.00 and 20.00 ETB per 100kg of onion bulb, respectively. These prices were directly used in the partial budget analysis. The average market price (7 birr/kg) as per local market price survey in the 2003 E.C. production season was used for the analysis. The marginal rate of return (MRR %) is used as basis for fertilizer recommendation. Treatments with lower net benefit than treatments of lower cost are dominated, and are not included in the partial budget analysis.

Table 12. Partial budget analysis of N-P-K fertilizer trial of onion using the price at Jimma town by the year of 2010/11

N	P	K	TY (t/ha)	ATY (t/ha)	GFB	HBC	FC	TCTV	NB	MRR (%)
0	0	0	9.83	8.847	61929	3538.8	0	3538.8	58390.2	
0	46	0	10.73	9.657	67599	3862.8	720	4582.8	63016.2	443.1034
0	0	40	10.67	9.603	67221	3841.2	742.4	4583.6	62637.4	D
50	0	0	10.81	9.729	68103	3891.6	967.43	4859.03	63243.97	220.2266
0	92	0	11.36	10.224	71568	4089.6	1440	5529.6	66038.4	416.7246
0	46	40	11.96	10.764	75348	4305.6	1462.4	5768	69580	1485.57
0	0	80	11.42	10.278	71946	4111.2	1484.8	5596	66350	D
50	46	0	11.57	10.413	72891	4165.2	1687.43	5852.63	67038.37	268.2344
50	0	40	11.91	10.719	75033	4287.6	1709.83	5997.43	69035.57	1379.282
100	0	0	11.98	10.782	75474	4312.8	1934.86	6247.66	69226.34	76.23786
0	92	40	12.69	11.421	79947	4568.4	2182.4	6750.8	73196.2	789.017
0	46	80	12.79	11.511	80577	4604.4	2204.8	6809.2	73767.8	978.7671
0	0	120	12.02	10.818	75726	4327.2	2227.2	6554.4	69171.6	D
50	92	0	13.63	12.267	85869	4906.8	2407.43	7314.23	78554.77	1234.904
50	46	40	12.89	11.601	81207	4640.4	2429.83	7070.23	74136.77	D
50	0	80	12.63	11.367	79569	4546.8	2452.23	6999.03	72569.97	D
100	46	0	14.35	12.915	90405	5166	2654.86	7820.86	82584.14	1218.521
100	0	40	14.32	12.888	90216	5155.2	2677.26	7832.46	82383.54	D
150	0	0	13.13	11.817	82719	4726.8	2902.29	7629.09	75089.91	D
0	92	80	14.05	12.645	88515	5058	2924.8	7982.8	80532.2	1538.631
0	46	120	14.89	13.401	93807	5360.4	2947.2	8307.6	85499.4	1529.31
50	92	40	13.76	12.384	86688	4953.6	3149.83	8103.43	78584.57	D
50	46	80	14.59	13.131	91917	5252.4	3172.23	8424.63	83492.37	1527.958
50	0	120	14.37	12.933	90531	5173.2	3194.63	8367.83	82163.17	D
100	92	0	15.43	13.887	97209	5554.8	3374.86	8929.66	88279.34	1088.616
100	46	40	16	14.4	100800	5760	3397.26	9157.26	91642.74	1477.768
100	0	80	15.17	13.653	95571	5461.2	3419.66	8880.86	86690.14	D
150	46	0	15.56	14.004	98028	5601.6	3622.29	9223.89	88804.11	616.2639
150	0	40	15	13.5	94500	5400	3644.69	9044.69	85455.31	D
0	92	120	15.3	13.77	96390	5508	3667.2	9175.2	87214.8	1348.165
50	92	80	15.22	13.698	95886	5479.2	3892.23	9371.43	86514.57	D
50	46	120	15.19	13.671	95697	5468.4	3914.63	9383.03	86313.97	D
100	92	40	16.41	14.769	103383	5907.6	4117.26	10024.86	93358.14	1097.513
100	46	80	17.09	15.381	107667	6152.4	4139.66	10292.06	97374.94	1503.293
100	0	120	17.05	15.345	107415	6138	4162.06	10300.06	97114.94	D
150	92	0	17.2	15.48	108360	6192	4342.29	10534.29	97825.71	303.4496
150	46	40	17.2	15.48	108360	6192	4364.69	10556.69	97803.31	D
150	0	80	17.05	15.345	107415	6138	4387.09	10525.09	96889.91	D
50	92	120	16.67	15.003	105021	6001.2	4634.63	10635.83	94385.17	D
100	92	80	17.68	15.912	111384	6364.8	4859.66	11224.46	100159.5	980.9847
100	46	120	17.3	15.57	108990	6228	4882.06	11110.06	97879.94	D
150	92	40	16.98	15.282	106974	6112.8	5084.69	11197.49	95776.51	D
150	**46**	**80**	**18.49**	**16.641**	**116487**	**6656.4**	**5107.09**	**11763.49**	**104723.5**	**1580.742**
150	0	120	17.4	15.66	109620	6264	5129.49	11393.49	98226.51	D
100	92	120	17.91	16.119	112833	6447.6	5602.06	12049.66	100783.3	389.6597
150	92	80	18.14	16.326	114282	6530.4	5827.09	12357.49	101924.5	370.7144
150	46	120	18.57	16.713	116991	6685.2	5849.49	12534.69	104456.3	1428.781
150	92	120	18.5	16.65	116550	6660	6569.49	13229.49	103320.5	D

ABY (10%) = Adjusted Bulb Yield (t/ha), D = Dominated Treatment, TCTV = Total Costs That Vary (ETB/ha), GFB = Gross Field Benefit in Birr/ha, NB=Net Benefit (ETB/ha), ETB = Ethiopian Birr, HBC = Harvesting, Bagging, FC = Fertilizer Cost in Birr.

The economic analysis of this study revealed that the economic optimum level of onion bulb yield was obtained with application of 150:46:80 kg of N-P-K ha^{-1} with the highest net benefit of 104723.5 ETB per hectare (Table 12). High net return from the foregoing treatments could be attributed to high yield and the low net return was attributed to low yield. From the economic point of view, it was apparent that 150:46:80 kg of N-P-K ha^{-1} are more profitable than the rest of treatment combinations; whereas, it was lowest with no application of N-P-K (58390.2 ETB). These results are further supported by Singh *et al*. (1997) who reported that the highest net return was obtained with applications of N-P-K at 100:25:25 Kg ha^{-1}.

5. SUMMARY AND CONCLUSIONS

Onion *(Allium cepa* L.) is by far the most important of the bulb crops cultivated commercially in most parts of the world**.** The crop is grown for consumption both in the green state as well as mature bulb. Onion was introduced to the agricultural community of Ethiopia in the early 1970's when foreigners brought it in. Though shallots are traditional crop in Ethiopia, onion is being more widely grown in recent years. Currently, the crop is in production in different parts of the country for local consumption. Ethiopia has high potential to benefit from onion production and the demand for onion increased for its high bulb yield and seed production potential in recent years.

Optimum levels of any agronomic practices such as plant population, planting date, harvesting date, and fertilizer of the crop varies with environment, purpose of the production and variety. Although some technologies are developed in the country, it is very difficult to give general recommendation that can be applicable to different agro-ecological zones. Hence, there is no specific recommended agronomic practice including fertilizer rate and type to the study area.

In line with the above idea, field, storage and laboratory experiments were carried out at Jimma University College of Agriculture and Veterinary Medicine with the objectives of to determine the optimum doses of N, P and K fertilizer for onion (*Allium cepa* L.) optimum growth, yield, quality and storage life under Jimma conditions, South Western Ethiopia. Four levels of each of Nitrogen (N) and Potassium (K) with three levels of Phosphorus (P) fertilizers were applied and unfertilized plot was considered as control during the year of 2003 E.C. under irrigation condition. The experiment was conducted using factorial randomized incomplete block design (RIBD). The cured bulbs were stored in the constructed ambient storage room. Partial budget analysis of the farm was done using the market price at Jimma town by the year of 2003 E.C.

The results of the study showed that main effects of N, P and K as well as their interactions had considerable influence on different parameters. All growth and yield properties as well as storage life of the bulbs showed significant differences due to the treatments applied. The result of the experiment indicated that growth, yield, quality and storage life of Bombay Red onion plants was significantly affected by various main and combined applications of N, P and K. The interaction effect of showed significant difference on mean number of leaves per plant, TSS (^{o}Brix), marketable bulb yield (ton/ha) and total bulb yield (ton/ha). Regardless of the levels, maximum combined application of N-P-K at 150:46:120 kg ha^{-1} increased the marketable bulb yield by about 47% as compared with the control treatments (9.83 ton) and the result is on par with the results of fertilizer level at 150:92:120; 150:46:80; 150:92:80 and 100:92:120 kg of N-P-K ha^{-1}. At the same time, maximum combined application of N-P-K at 150:92:120 kg ha^{-1} increased the total bulb yield by about 40% as compared with the unfertilized plots (11.11 ton/ha) and this result is on par with the results of fertilizer levels at 150:46:120; 150:46:80; 150:92:80; 100:92:120 and 100:92:80 kg of N-P-K ha^{-1}.

Combined application of N and P at 150:92 kg ha^{-1} showed a higher mean number of leaves per plant (11.62); maximum total soluble solid contents (11.67 ^{o}Brix). Similarly, a combined application of N and K at 150:80kg ha^{-1} again gave statistically higher total soluble solid contents (11.56 ^{o}Brix).

Growth parameters of onion plants were affected by application of N, P and K fertilizer. The higher mean plants height (49.59cm, 47.99cm and 48.37cm) was obtained with fertilization of N at150 kg ha^{-1}, P at 92 kg ha^{-1} and K at 120 kg ha^{-1}, respectively; higher mean leaf length (39.84cm, 37.99cm and 38.08cm) was registered with application of N at 150 kg ha^{-1}, P at 92 kg ha^{-1} and K at 80 kg ha^{-1}, respectively; higher mean leaf diameter (10.71mm, 9.47mm and 9.57mm) was recorded from treatments of N at 150 kg ha^{-1}, P at 46 kg ha^{-1} and K at 80 kg ha^{-1}, respectively; higher mean leaf sheath length (6.67cm, 6.17cm and 6.22cm) recorded from the fertilization of N at 150 kg ha^{-1}, P at 92 kg ha^{-1} and K at 80 kg ha^{-1}, respectively; while, minimum percentage bolted (0.77%) recorded in the plot that received N at 150 kg ha^{-1}; maximum percentage bolted (1.56%) encountered with fertilization of K at 120 kg ha^{-1};

maximum days to attain physiological maturity (111.3) recorded with treatment of N at 150 kg ha^{-1} and minimum days to attain physiological maturity (108) registered as a result of application of K at (120 kg ha^{-1}).

Yield and quality of onion plants were affected with application of N, P and K at different levels. Higher mean bulb diameter (6.02cm, 5.76cm and 5.82cm) recorded in the application of N at 150 kg ha^{-1}, P at 92 kg ha^{-1} and K at 80 kg ha^{-1}, respectively; higher mean bulb length (5.23cm, 4.94cm and 5.07cm) encountered in the fertlization of N at 150 kg ha^{-1}, P at 92 kg ha^{-1} and K at 120 kg ha^{-1}, respectively; higher mean bulb weight (49.78g, 47.52g and 48.41g) recorded in the treatment of N at 150 kg ha^{-1}, P at 46 kg ha^{-1} and K at 80 kg ha^{-1}, respectively; lower unmarketable bulb yield (0.47t/ha, 0.62t/ha and 0.51t/ha) registered in the application of N at 150 kg ha^{-1}, P at 92 kg ha^{-1} and K at 120 kg ha^{-1}, respectively; higher harvest index (0.80, 0.77 and 0.78) encountered in main application of N at 150 kg ha^{-1}, P at 46 kg ha^{-1} and K at 120 kg ha^{-1}, respectively; higher dry matter content (10.54%, 10.30% and 10.42%) encountered in the main application of N at 150 kg ha^{-1}, P at 92 kg ha^{-1} and K at 120 kg ha^{-1}, respectively; maximum storage rot percentage (3.69%) recorded in the main application of N at 150 kg ha^{-1}; minimum storage rot percentage (2.05%) obtained in the fertlization of K at 120 kg ha^{-1}; higher bulb weight loss (39.53%) registered in the treatment of N at 150 kg ha^{-1}; lower bulb weight loss (34.99%) recorded in the main application of K at 120 kg ha^{-1}; higher bulb sprouts percentage (8.12%) recorded in the fertlization of N at 150 kg ha^{-1}, lower bulb sprouts percentage (7.59%) recorded in the treatment of K at 80 kg ha^{-1}.

The economic analysis of the study revealed that the economic optimum bulb yield of onion was obtained with application of 150:46:80 kg of N-P-K ha^{-1} with the highest net benefit of 104723.5 ETB per hectare. High net return from the foregoing treatments could be attributed to high yield and the low net return was attributed to low yield. From the economic point of view, it was apparent from the results of this study that 150:46:80 kg of N-P-K ha^{-1} is more profitable than the rest of treatment combinations; whereas, it was the lowest with the unfertilized treatment (58390.2 ETB).

In general, from marketable bulb yield, post-harvest quality and storability point of view, N, P and K fertilization was very sound; especially for our country farmers where their production is once in a year. If these methods are integrated and well applied, year round production of this crop may not be required. In addition, problem of market glut could be stabilized with balanced costs from stored bulbs dispatch. Therefore, the result of this study has shown that N, P and K fertilization has a sound and promising impact for total bulb yield, quality and post-harvest quality that could be applied for onion production.

Future Prospectives

- Multi-location experiments are required to recommend and use the output sustainably.
- Similar field and economic feasibility studies need to be carried out for a number of seasons in different soils.
- Combined experiments with other organic fertilizers in the same field may reflect the sustainability of this practice.
- Optimization of fertilizers with planting density and water requirement for the different varieties under different agro-ecological condition to understand their yield performance.
- Increasing level of nitrogen to reach peak point.
- Nutritional quality analysis of onion bulbs also need due consideration in further studies.

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7. APPENDICES

Appendix Table 1. Mean square values for plant height, leaf number and leaf length per plant as affected by N, P and K application rates at Jimma, SouthWestern Ethiopia, 2010/11

Sources	Degree of freedom	Mean square values		
		Plant height(cm)	Leaf number	Leaf length(cm)
Nitrogen (A)	3	1644.26**	879.09**	922.74**
Phosphorus (B)	3	287.87**	179.45**	127.39**
Potassium (C)	2	575.50**	308.30**	188.37**
A X B	6	4.99^{Ns}	26.17**	10.30^{Ns}
AX C	9	19.38^{Ns}	11.75^{Ns}	22.57^{Ns}
B X C	6	1.45^{Ns}	5.27^{Ns}	4.71^{Ns}
A X BX C	18	20.36^{Ns}	16.42^{Ns}	31.12^{Ns}

*Ns =Non significant at 5% probability level. * and ** indicates significant and highly significant at 5% and 1% probability level, respectively*

Appendix Table 2. Mean square values for leaf diameter, leaf sheath length and days to maturity as affected by N, P and K application rates at Jimma, SouthWestern Ethiopia, 2010/11

Sources	Degree of freedom	Mean square values		
		Leaf diameter (mm)	Leaf sheath Length (cm)	Days to maturity
Nitrogen (A)	3	272.75**	566.75**	188.89**
Phosphorus (B)	3	20.95**	78.67**	17.57**
Potassium (C)	2	37.22**	138.12**	7.31 **
A X B	6	5.61^{Ns}	10.43^{Ns}	11.66^{Ns}
AX C	9	7.31^{Ns}	4.63^{Ns}	12.88^{Ns}
B X C	6	4.43^{Ns}	4.73^{Ns}	1.65^{Ns}
A X BX C	18	16.92^{Ns}	25.37^{Ns}	13.58^{Ns}

*Ns =Non significant at 5% probability level. * and ** indicates significant and highly significant at 5% and 1% probability level, respectively*

Appendix Table 3. Mean square values for bulb diameter, bulb length and mean bulb weight as affected by N, P and K application rates at Jimma, SouthWestern Ethiopia, 2010/11

Sources	Degree of freedom	Mean square values		
		Bulb diameter (cm)	Bulb length (cm)	Mean bulb weight (g)
Nitrogen (A)	3	245.43**	566.17**	121.13**
Phosphorus (B)	3	54.47**	154.05*	42.39**
Potassium (C)	2	105.59**	193.05**	100.97**
A X B	6	6.95[Ns]	5.30[Ns]	6.76 [Ns]
AX C	9	7.79[Ns]	16.18[Ns]	10.63[Ns]
B X C	6	5.79[Ns]	2.91[Ns]	3.01[Ns]
A X BX C	18	23.70[Ns]	27.63[Ns]	15.42[Ns]

*Ns =Non significant at 5% probability level. * and ** indicates significant and highly significant at 5% and 1% probability level, respectively*

Appendix Table 4. Mean square values for harvest index, bulb shape index and bolters percentage as affected by N, P and K application rates at Jimma, SouthWestern Ethiopia, 2010/11

Sources	Degree of Freedom	Mean square values		
		Harvest index	Bulb shape index	Bolters (%)
Nitrogen (A)	3	236.90**	21.57**	27.19**
Phosphorus (B)	3	89.81**	15.13**	0.46*
Potassium (C)	2	147.78**	12.68[Ns]	1.02*
A X B	6	4.94[Ns]	3.47[Ns]	0.41[Ns]
AX C	9	4.01[Ns]	15.48[Ns]	0.77[Ns]
B X C	6	9.08[Ns]	5.73[Ns]	0.29[Ns]
A X BX C	18	16.06[Ns]	25.37[Ns]	1.94[Ns]

*Ns =Non significant at 5% probability level. * and ** indicates significant and highly significant at 5% and 1% probability level, respectively*

Appendix Table 5. Mean square values for marketable bulb yield, unmarketable bulb yield and total bulb yield as affected by N, P and K application rates at Jimma, SouthWestern Ethiopia, 2010/11

Sources	Degree of freedom	Mean square values		
		Marketable yield (t/ha)	Unmarketable yield (t/ha)	Total yield (t/ha)
Nitrogen (A)	3	2224.37**	222.63**	1708.94**
Phosphorus (B)	3	572.15**	41.65**	451.91**
Potassium (C)	2	1008.64**	144.06**	739.49**
A X B	6	16.29^{Ns}	4.75^{Ns}	13.55^{Ns}
AX C	9	22.45^{Ns}	24.44^{Ns}	21.36^{Ns}
B X C	6	25.02**	5.04^{Ns}	20.65^{Ns}
A X BX C	18	84.19**	20.09^{Ns}	82.74**

*Ns =Non significant at 5% probability level. * and ** indicates significant and highly significant at 5% and 1% probability level, respectively*

Appendix Table 6. Mean square values for marketable bulb (%), dry matter content and total soluble solid as affected by N, P and K application rates at Jimma, South Western Ethiopia, 2010/11

Sources	Degree of freedom	Mean square values		
		Marketable bulb percentage	Dry matter content (%)	Total soluble Solid (^{o}brix)
Nitrogen (A)	3	3010.87**	254.15**	500.31**
Phosphorus (B)	3	1697.78**	102.74**	172.67**
Potassium (C)	2	3585**	227.98**	149.65**
A X B	6	379.26^{Ns}	7.98^{Ns}	24.96**
AX C	9	890.66^{Ns}	12.27^{Ns}	35.50**
B X C	6	749.75^{Ns}	1.53^{Ns}	10.69^{Ns}
A X BX C	18	750.71^{Ns}	16.14^{Ns}	31.22^{Ns}

*Ns =Non significant at 5% probability level. * and ** indicates significant and highly significant at 5% and 1% probability level, respectively*

Appendix Table 7. Mean square values for PWL percentage, storage sprouts percentage & storage rots percentage as affected by N, P and K application rates at Jimma, SouthWestern Ethiopia, 2010/11

Sources	Degree of freedom	Mean square values		
		PWL Percentage	Storage sprouts percentage	Storage rots percentage
Nitrogen (A)	3	297.42**	39.62**	31.43**
Phosphorus (B)	3	0.48[Ns]	3.18 [Ns]	2.07 [Ns]
Potassium (C)	2	12.35[Ns]	32.36**	114.02**
A X B	6	6.07 [Ns]	1.02[Ns]	16.15[Ns]
AX C	9	16.78[Ns]	8.03[Ns]	10.77[Ns]
B X C	6	6.45[Ns]	3.25[Ns]	11.25[Ns]
A X BX C	18	9.04[Ns]	18.91[Ns]	24.29[Ns]

*Ns =Non significant at 5% probability level. * and ** indicates significant and highly significant at 5% and 1% probability level, respectively*

Appendix Table 8 Effect of N, P and K on marketable bulb (%) & weeks to 50% bulb sprout

Treatments	Parameters considered	
Nitrogen (kg ha^{-1})	Marketable bulb (%)	Weeks to 50% bulb sprouts
0	78.22c	5.67
50	80.92c	5.89
100	85.37b	6.06
150	90.27a	6.11
$LSD_{(0.05)}$	2.52	Ns
CV (%)	6.44	18.42
Phosphorus (kg ha^{-1})		
0	79.11b	5.83
46	84.62a	5.96
92	87.36a	6.0
$LSD_{(0.05)}$	2.52	Ns
CV (%)	6.44	18.42
Potassium (kg ha^{-1})		
0	76.69c	5.28c
40	82.31b	5.67bc
80	85.31b	6.22ab
120	90.47a	6.56a
$LSD_{(0.05)}$	2.52	0.58
CV (%)	6.44	18.42

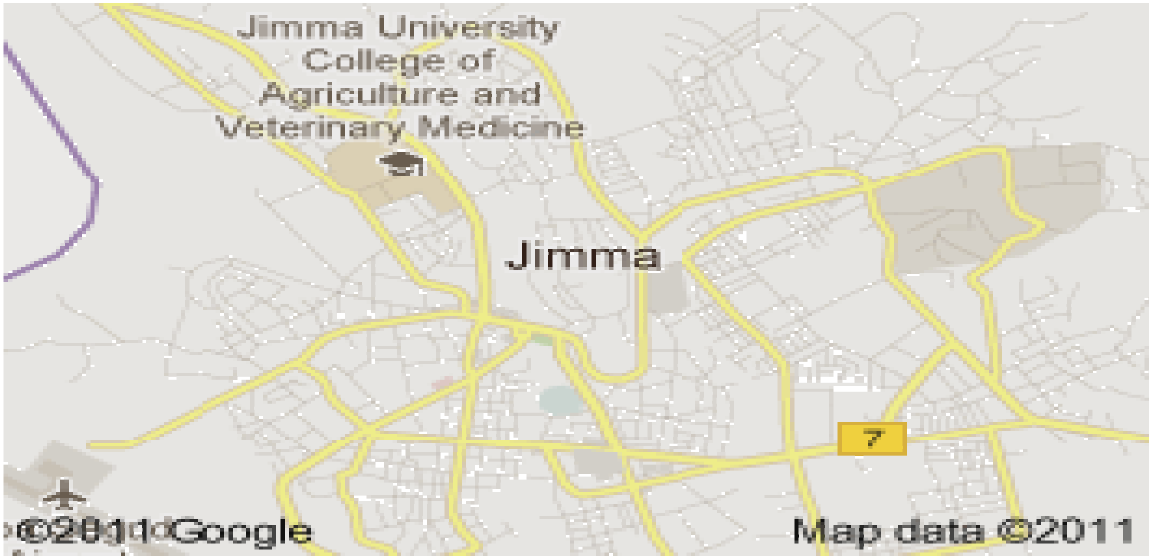
Ns =Non significant. Means in a column followed by the same letter(s) are not significantly different at 5%

Appendix Table 9. Simple-correlation on growth, yield, quality and storage life of onion plants

Variables	PH	LN	LL	LSL	DMC	TBY	MB	UMB	MBW	HI	TSS	DM	WLP	BSP	RBP	MBP	BL	BD
PH	**1**	**0.89****	**0.70****	**0.88****	**0.80****	**0.89****	**0.92****	**-0.27**	**0.66 ****	**-0.01**	**0.73 ****	**0.26****	**0.32****	**-0.01**	**-0.03**	**0.60****	**0.18**	**0.78****
LN		**1**	**0.70****	**0.83****	**0.76****	**0.88****	**0.90****	**-0.34****	**0.63 ****	**-0.07**	**0.78 ****	**0.32 ****	**0.26**	**-0.07**	**-0.01**	**0.63****	**0.11**	**0.76****
LL			**1**	**0.57****	**0.81****	**0.78****	**0.70****	**-0.81****	**0.80 ****	**-0.65****	**0.87 ****	**0.80 ****	**-0.31****	**-0.63****	**-0.08**	**0.82****	**-0.49****	**0.69****
LSL				**1**	**0.67****	**0.81****	**0.85 ****	**-0.16**	**-0.58****	**0.08**	**0.64 ****	**0.17**	**0.41 ****	**0.09**	**0.01**	**0.50****	**0.264**	**0.71****
DMC					**1**	**0.83 ****	**0.79****	**-0.61****	**0.80 ****	**-0.41****	**0.83 ****	**0.57 ****	**-0.11**	**-0.42****	**-0.14**	**0.77****	**-0.23**	**0.76****
TBY						**1**	**0.98 ****	**-0.45****	**0.76 ****	**-0.21 ***	**0.82 ****	**0.43 ****	**0.10**	**-0.20**	**-0.10**	**0.74****	**-0.01**	**0.80****
MB							**1**	**-0.33****	**0.70 ****	**-0.06**	**0.77 ****	**0.30**	**0.25****	**-0.05**	**-0.08**	**0.68****	**0.13**	**0.80****
UMB								**1**	**-0.67****	**0.94 ****	**-0.69****	**-0.93****	**0.72****	**0.92****	**0.17***	**-0.76****	**0.85****	**-0.42****
MBW									**1**	**-0.51****	**0.76****	**0.62 ****	**-0.26****	**-0.50****	**-0.23****	**0.77 ****	**-0.35****	**0.75****
HI										**1**	**-0.50****	**-0.91****	**0.87****	**0.97 ****	**0.17**	**-0.59****	**0.97****	**-0.19**
TSS											**1**	**0.69****	**-0.17**	**-0.49****	**-0.08**	**0.77 ****	**-0.33****	**0.72 ****
DM												**1**	**-0.66****	**-0.88****	**-0.09**	**0.69****	**-0.84****	**0.37 ****
WLP													**1**	**0.86****	**0.22**	**-0.32****	**0.91 ****	**0.100**
BSP														**1**	**0.21**	**-0.59****	**0.95 ****	**-0.18**
RBP															**1**	**-0.16**	**0.15**	**-0.07**
MBP																**1**	**-0.44****	**0.69****
BL																	**1**	**0.01**
BD																		**1**

*Ns, *, and ** = Ns =Non significant. Correlation are significant and highly significant at the 5% and 1% probability levels.*

PH= Plant height, LN= Leaf number, LL= Leaf length, LSL= Leaf sheath length, DMC= Dry matter content, TBY= Total bulb yield, WMB= Weight of marketable bulb yield, WUMB= Weight of unmarketable bulb yield, MBW= Mean bulb weight, HI= Harvest index, TSS= Total soluble solid, DM= Days to physiological maturity, WLP= Weight loss (%), BSP= Bulb sprout (%), RBP= Rotten bulb (%), MBP= Marketable bulb (%), BL= Bulb length and BD= Bulb diameter



Appendix Plate 1. Map of the study area located in Jimma Zone, Oromia regional state, Ethiopia

General over view of the experimental field

Appendix Plate 2. General over view of the experimental field

Crop apperance and different activities under taken during running the experiment

Different growth parameters were taken at different time during the study time

Watering of the experimental field was done daily by using watering can

Onion crops at physiological maturity and after harvested from the central four rows

Appendix Plate 3. Different field activities and management practices under taken in the experimenatl field

Constructed ambient onion storage room and the arranged onion bulb in the prepared boxes

Sproutted onion bulb in the storage room during the first month of the storage time

Some laboratory works in Post-harvest laboratory (JUCAVM)

Analysis of bulb TSS and TA in the Post-harvest laboratory (JUCAVM)

Appendix Plate 4. Post-harvest onion bulb in storage room and some laboratory work