EFFECTS OF SEEDLING AGE AND VARYING RATES OF PHOSPHORUS ON GROWTH AND YIELD PERFORMANCE OF ONION (*Allium cepa* L.) UNDER IRRIGATION AT ALAGE, CENTRAL RIFT VALLEY OF ETHIOPIA

M.Sc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

NOVEMBER, 2017

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SCHOOL OF GRADUATE STUDIES

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DEDICATION

I dedicate this Thesis to my mother Ayale Asefaw for her true love and innocent sympathy to see all my dimensional success and happiness.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an advanced M. Sc. Degree at the Hawassa University and is deposited at the university library to be made available to borrowers under rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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Place: College of Agriculture, Hawassa University, Hawassa

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LIST OF ACRONYMS AND ABBREVIATIONS

ADP	Adenosine Diphosphate
ANOVA	Analysis of Variance
ATP	Adenosine triphosphate
CEC	Cation Exchange Capacity
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Statistical Agency
DNA	Deoxyribonucleic Acid
EARO	Ethiopia Agricultural Research Organization
ETFRUIT	Ethiopia Fruit and Vegetable Marketing Enterprise
FAO	Food and Agricultural Organization
GLM	General Linear Model
IHD	Indian Horticulture Database
LSD	Least Significant Difference
MARC	Melkassa Agricultural Research Center
MOARD	Ministry of Agriculture and Rural Development
MRR	Marginal rate of return
RCBD	Randomized Complete Block Design
RNA	Ribonucleic Acid
SAS	Statistical Analysis System
TSP	Triple Super Phosphate

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By - Tilaye Anbes

Major Advisor - Walelign Worku (Ph.D)

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ABSTRACT

Onion is an important cultivated crop used as a condiment as well as a source of income for many farmers in Ethiopia. However, the yield of the crop is constrained by a number of factors among which inappropriate transplanting age and poor fertilizer management practices are important factors. Therefore, a field experiment was conducted at Alage Agricultural Technical and Vocational Education and Training College (Alage) campus, Central Rift Valley of Ethiopia, during 2016/17 season to determine the effect of seedling age and phosphorus rate on growth and yield performance of onion. The treatments comprised of three seedling ages (6, 7 and 8 weeks of seedling age) and four phosphorus rates (0, 46, 92 and 138 kg ha^{-1}*). The experiment was laid out in randomized complete block design (RCBD) with four replications. The result showed that seedling age and phosphorus rate significantly affected plant height, leaf length, days to maturity, fresh bulb weight, bulb dry matter fraction, bulb length, marketable bulb yield, total bulb yield, harvest index, medium and large sized bulb yield. Among these parameters, marketable bulb yield, total bulb yield and harvest index were also significantly affected by the interaction of seedling age and phosphorus rate. On the other hand, leaf number per plant, bulb diameter, bulb dry weight, total biomass yield, small bulb sized yield, under sized bulb yield and unmarketable bulb yield were only influenced by the main effect of phosphorus rate. In this study result, transplanting at 8 weeks of seedling age fertilized with 138 kg* P_2O_5 *ha*$^{-1}$ *recorded the highest total bulb yield (50.6 t ha*$^{-1}$*) and marketable bulb yield (48.33 t ha*$^{-1}$*), but no significant difference was showed with that obtained at 92 kg* P_2O_5 *ha*$^{-1}$ *with the same seedling age. Treatment combinations of seedling age at 6 weeks and no P (control) produced the lowest amounts of total bulb yield (24.27 t ha*$^{-1}$*) and marketable bulb yield (21.63 t ha*$^{-1}$*). The partial budget analysis revealed that the highest net benefit with low cost of production was obtained in response to the application of 92 kg* P_2O_5 *ha*$^{-1}$ *and the transplanting age of 8 weeks. The marginal rate of return for this treatment was 5657% which is* found to be economically feasible for producing *onion in the study area.*

Key words: *Onion, seedling age, phosphorus, bulb yield and partial budget.*

1. INTRODUCTION

Onion (*Allium cepa* L.) is one of the most important monocotyledonous, herbaceous, cross-pollinated and cool season vegetable crops, which belongs to the genus *Allium* and the family Alliaceae (Griffiths *et al*., 2002). The primary center of origin of onions lies in central Asia, while the Near East and the Mediterranean are the secondary centers of origin. The history of onion can be traced back to at least 5000 years. Onions as food, medicine and religious object were known during the first Egyptian dynasty (3200 B.C.) (Ray and Yadav, 2005). It is important in the daily diets of human's worldwide and in Ethiopia as well (MoARD, 2006).

The common onion (*Allium cepa* L.) is grown from either seed, transplants or sets for use as both green onions and dry onion (Decoteau, 2000). It is bulbous, biennial herb which gives off a distinctive and pungent odor when the tissues are crushed (Ray and Yadav, 2005). The crop onion is a popular vegetable and its bulb is used raw, sliced for seasoning salads, and cooked with other vegetables and meat. Onion bulbs are essential ingredients in many African sauces and relishes. The leaves, whole immature plants called 'salad onion' or leafy sprouts from germinating bulbs are used in the same way. In some parts of West Africa, leaves still green at bulb harvest are propounded, and then used to make sun-dried and fermented balls, which are used later for seasoning dishes. Sliced raw onions have antibiotic properties, which can reduce contamination by bacteria, protozoa or helminths in salads (Grubben and Denton, 2004). The popularity of a health conscious world for salad bars has further increased its agricultural importance (FAO, 1998). The mature bulb contains some starch, appreciable quantities of sugars, some protein, and vitamins A, B and C (Jilani *et al.*, 2010).

Onions can be grown under a wide range of climatic conditions but are more successful under mid-season without extremes of heat or cold and excessive rainfall. Onions have a wide range of climatic and soil adaptation and they are cultivated both under irrigation and rain fed conditions (Rabinowitch and Currah, 2002). Ethiopia has diversified agro-climatic conditions which is suitable for the production of a broad range of vegetables and flowers, and allows successful production of onion crop (FAO, 1998). Out of 15 vegetables listed by Food and Agricultural Organization, onion stands second to tomato in terms of total annual production (FAO, 2012).

The production of onion is becoming important with the expanding irrigated agriculture and with the growing awareness on the economic importance of the sector as source of income, improved food security, sources of raw materials for industries, medicinal value, nutritional value and employment opportunity because it demands large labor force (Lemma *et al*., 2006). It contributes substantially to the national economy apart from overcoming local demand. Currently, onion is important cash crop for the farmers in Ethiopia; and hence the crop is produced in different parts of the country for local consumption and for export market. However, due to the various constraints the average productivity of onion in Ethiopia is 10.7 t ha^{-1} (CSA, 2013) which is far below the world average of 19.5 t ha^{-1} (FAO, 2011).

The potential (attainable) yield ranges between 25-35 t ha^{-1} of properly cured dry bulbs at the research centers in the country, whereas in the farmers field the average yield ranges between 11-15 t ha^{-1} (Lemma and Shimeles, 2003). The national productivity is also lower compared to other major African onion producers such Egypt, Algeria, Morocco and South Africa with corresponding national yield of 25, 13.6, 18.2 and 21.1 t ha^{-1}, respectively (Bosch *et al.*, 2002). The reasons behind indicate a number of constraints that cause low productivity of onion in Ethiopia. The low yield of onion in the country is reported to be due to use of inappropriate fertilizer rate, lack of improved varieties, and poor management practices (Lemma and Shimelis, 2003). Takele (2004) also reported that soil fertility and water availability are the most serious limiting constraints for onion crop production. Among these constraints, inappropriate use of mineral fertilizers and improper use of seedling age are the most important limiting management factors in Alage district.

The area under onion production in the country is increasing from time to time mainly due to its high profitability per unit area. In the past five years the production area of Ethiopia changed from 17,588 to 22,035.8 ha and production changed from 169,316 tons to 236,922 tons. The increase in production area and production was 25 % and 40 %, respectively. Thus, it is high time that proper agronomic management strategies are developed and extended in order to enhance productivity and realize the potential economic benefit from the crop (CSA, 2011).

Application of fertilizer is important for production of onion. Among the nutrients, nitrogen and phosphorus play the most important role for vegetative growth and root development of the crop which ultimately helps in increasing bulb size and total yield (Rai, 1981). However, most of the P present in soils is in unavailable forms and added soluble forms of P are quickly fixed by many soils (Tisdale *et al*., 1995). In most soils, the amount of P in the available form at any one time is very low, seldom exceeding about 0.01% of the total P in the soil. Thus, available varying P rate must be supplemented in most soils by adding chemical fertilizers (Brady and Weil, 2002). Fertilizer practices for the onion crop vary widely in Ethiopia.

Phosphorus is essential for bulb formation and root development and when the availability is limited, plant growth is usually reduced. In onions, P deficiencies reduce root and leaf growth, bulb size and yield and can also delay maturation (Brewster, 1994), while, excess phosphorus inhibits the uptake of other essential nutrients (Abdisa *et al.*, 2011). In Ethiopia, 90-135 kg P_2O_5 ha^{-1} is used for bulb production in sandy loam soil (Lemma and Shimeles, 2003; Dawit *et al.*, 2004). Although phosphorus has no direct effect on photosynthesis, it plays important role in formation of nucleic acid and phospholipids, enzyme activation production of ADP and ATP (Thompson and Toreh, 1978).

Onions are generally established either by direct seeding or by bare root transplants. Compared to direct seeding, transplanted onions provide an immediate and complete stand. The effect of transplant age on yield is an issue often broached by growers of horticultural and agronomic crops in an effort to maximize production potential (Leskovau and Vavrina, 1999). Crop growth and bulb production is greatly influenced by age of seedlings for planting. Optimum stage of seedlings for transplanting is an important criterion for bulb production in onion (Vacchani and Patel, 1988; Singh and Chaure, 1999). Kanton *et al.* (2002) observed that maximum yield was produced from transplants that were 20 to 40 days old and 40 days old transplant produced the heaviest bulbs. Seven weeks old seedlings significantly contribute to the growth parameters like plant height, number of leaves, and fresh and dry weight of onion. Increase in yield by the use of older seedlings may be attributed to their better field establishment and capacity to withstand the adverse weather conditions (Mohanty *et al*., 1990). Therefore, age of seedling is an important factor that influences growth and higher bulb yield. Optimal age of seedling can produce better growth and yield performance of bulb (Maurya *et al*., 1997; Singh and Chaure, 1999).

In the study area (Alage), onion crop plays an important role in contributing to the household food security. In addition to the nutritional value, these crops generate employment opportunities for the poor households in the district area. The crop is also one of the most important cash crops that generate income for the farmers in the study area. Although production of onion variety is “Bombay Red” expanding, information on optimal phosphorus fertilizer application rate and proper age of seedling is scanty. Systematic study on fertilization to improve the growth and yield of bulb is lacking. The reasons behind improper use of seedling age and phosphorus fertilization are that sufficient information on agronomic package of onion is not available in Alage especially on management regarding proper transplanting age and phosphorus fertilization. There is also no location-specific fertilizer recommendation in the area. This has led to low yield and quality of onion, which has also negatively impacted the smallholder farmers’ income. Therefore, the present study was conducted with the following objectives:

- To determine the effects of seedling age on growth and yield performance of onion.
- To determine effects of phosphorus rate on growth and yield performance of onion.
- To asses possible interactions between seedling age and phosphorus rate on growth and yield performance of onion.

2. LITERATURE REVIEW

2.1. Description of Onion Plant

Onion is an herbaceous biennial monocot grown for its bulb as an annual and only carried forward into a second year when seeds are required. Onions are grown mainly for their bulbs, although the green shoots of salad onions are also an important crop. The demand for onion is worldwide and their use is not limited to any climate or associated with any nationality. It contributes significant nutritional value to the human diet and medicinal properties and is primarily consumed for their unique flavor or for their ability to enhance the flavor of other foods (Randle, 2000). Bulbs are truncate formed from thickened leaf bases, thin and fibrous outer layers, inner layers without blades, up to 10 cm in diameter. Leaves are alternate, produced from a flattened conical basal stem, cylindrical, glaucous, becoming hollow. Flowers are borne on a scape 30-100 cm in height, protected by a spathe, terminal umbels produce numerous cymes, each with 5-10 flowers, perianth segments 6, petalloid, green-white, ovate, up to 5 mm in length; stamens 6, alternating with perianth segments, ovary superior 3-locular, 2-ovules, style simple and becoming receptive after another dehiscence. Seeds are smooth, black, wrinkled when dry, embryo curved and germinate epigeal. Fruits capsule in shape and splitting longitudinally (Tindall, 1983).

There is wide variation in bulb characteristics of onion (Rabinowitch *et al*., 2002). They stated that bulb weight may be one kg in some southern European cultivars, and the shape covers a wide range from globose to bottle-like and to flattened disk-form. The color of the membranous skins may be white, silvery, yellowish, bronze, rose red, purple or violet. The color of the fleshy scales can vary from white to bluish-red. There is also much variation in flavor and keeping or storage ability of the bulbs (Rabinowitch *et al*., 2002). Greenwood *et al*. (1982) stated that onion cultivars can have different rooting system. They indicate that maximum average root density was found in the top 20 cm of soil but, 90% of the root system was concentrated in the top 40 cm soil depth, and only 2-3% of total root was recorded below 60 cm depth.

2.2. Climate and Soil Requirements of Onion

Onion is a cool season crop plant that has some frost tolerance, but is best adapted to a temperature range between 13 and 24^{o}C. Optimum temperatures for early seedling growth are between 23 and 27^{o}C; growth is slowed at temperatures above 30^{o}C. Acclimated plants are able to tolerate some freezing temperature (Rubatzky and Yamaguchi, 1997).

Several factors limit the production of onion in the tropical regions of the world, among which, temperature, photoperiod, moisture, salinity, acidity and nutrient availability are considered important production factors. Temperature is noted to be one of the most important environmental factors for onion dry bulb production in Ethiopia. The crop requires cool condition during the early part of its development and warm condition during bulbing, bulb maturity, harvesting and curing stages. High temperature favors bulbing and accelerates maturity then results in small, split, double and low yield and quality bulbs. At lower temperature there will be a delay in bulbing maturity at least by 2-3 weeks and yield will also be low (Brewster, 2002; Lemma and Shimeles, 2003). Bulb formation and subsequent growth in onion are principally governed by temperature and photoperiod. High temperature promotes bulb formation (Brewster, 1997). Day length is one of the climatic requirements that are necessary to ensure a good onion crop. Short day onions require 11.5 - 12.5 hour's day length threshold for bulbing. Intermediate day length onions require 12.5 - 13.5 hours day length threshold for bulbing. Long day varieties require 14 or more hours of day length before bulbing is initiated (George and Reid, 2001). Rainfall and humidity are important factors during the seedling stage, bulbing and harvesting. Cool conditions at the seedling results in more disease, while a cloudy condition at bulbing increases the risk of bolting. Dry hot weather is beneficial for drying of bulbs at the harvesting stage (Nick, 2005).

The soils used for onions range from light sands to heavy clay loams. Peat soils or sandy soils, if irrigation is available, are preferred and often used. Adequate moisture is critical for uniform seedling emergence. Soils with high water holding capacity are better able to provide moisture to the shallow rooting system but must also drain well to be suitable. Growth is retarded when available soil moisture is low, but onions are also sensitive to a high water table or water logging. Uniform moisture availability about 400-800 mm per crop is conducive to large bulb size and high yields. Favorable soil pH is about 6.5 – 8.0 in mineral soils and about 5.8 in peat soils (Rubatzky and Yamaguchi, 1997). Poorly drained soils are not recommended for onion production, especially because of frequent problems with bulb diseases at harvest time, which lead to problems in marketing (Corgan *et al.*, 2000). An adequate and uniform P supply is essential for productive root development, bulb yield and quality. To better accommodate the shallow root system, fertilizer banding near the plant is usually preferred to broadcast applications. High levels of P, more than for most vegetable, are needed for rapid growth and high yield (Rubatzky and Yamaguchi, 1997). Onion yields are severely affected by soil salinity, and it is the most sensitive crop in this respect (Allen *et al*., 1998).

2.3. Onion Growth

Onion is a shallow rooted, biennial plant that is grown as an annual. It has long, hollow leaves with widening, overlapping bases. The tubular leaf blades are flattened on the upper surface, and the stem of the plant also is flattened. Roots arise from the bottom of the growing bulb (Hamasaki *et al*., 1999). Sullivan *et al*. (2001) identified different growth stages of onion for bulb production as germination, leaf growth, bulbing (bulb initiation), bulb growth and maturation. Rapid leaf growth begins when the onion plant has three leaves and bulb initiation (bulbing) begins when 5 to 7 true leaves formed during the growing season. The bulbing growth stage is considered to begin when bulb diameter reaches twice that of the neck. Most onion varieties initiate bulbs after 6 to 8 leaves have been produced. The base of each leaf becomes one of the scales of the onion bulb, so the final bulb size depends in part on the number of leaves present at bulb initiation. The leaf base begins to function as a storage organ at bulb initiation, so the size of the leafy part of the plant also influences bulb size (Randall *et al*., 1999).

2.4. Insect, Disease and Weed Management

Onion thrips (*Thrips tabaci*) is a key insect pest of onion (Tadele *et al*., 2013). In Ethiopia, it is an important insect pest that influence onions yield by direct feeding as well as reducing the quality and quantity by rasping the leaves and other tissues of onion crops to release the nutrients. According to Alston and Drost (2008) report onion fields can be destroyed by onion thrips, especially in dry seasons and are the major problem on onion crops in Ethiopia. Yeshitila (2005) reported that onion bulb yield losses of 26-57% due to onion thrips.

Purple blotch (*Alternaria porri*) is a very severe disease in most onion growing regions in Ethiopia mainly during wet season. It attacks leaves, bulb and seed stalks and subsequently reduces quantity and quality of yield. In order to minimize the problem, using clean seed, growing onion under well drained soil, rotation with non-related crops, burning crop debris and more frequent chemical application are good practices (Lemma *et al*., 2009).

Onion is poor competent of weeds for nutrient and moisture because it is a shallow rooted crop, the vertically oriented leaves are also less competent for light with broad leaved weeds. Weeds, besides competing for the essential factors and reduce yield, may also harbor various insect and diseases that are continual threat to the crop and also reduce the uniformity of the mother bulb crop and make rouging more difficult. The critical period of weed competition is found to be 4-8 weeks after transplanting. At least three cultivation; the first at 15 days after transplanting, the second during side dressing and the third when onions started bulbing to lose the soil around the bulb is necessary (EIAR/WARC,2008).

2.5. Onion Production in the World and in Ethiopia and Its Importance

Onions are the second most valuable vegetables in the world, following tomato. In 2010-2011, the world's top producer of onion was China, contributing an average of 26.99% to the total production, followed by India 19.90%. The highest productivity of onion in world is of Turkey (30.3 t ha^{-1}) followed by Brazil (23.1 t ha^{-1}), China (22.0 t ha^{-1}) and Russian Federation (17.5 t ha^{-1}). India being a second major onion producing country in the world has a productivity of 14.2 t ha^{-1} only (IHD, 2011). Over the last 15 years the total surface area dedicated to onion crop in the world has doubled and presently reaching 2.74 million ha. Average world yield increased from 12.0 t ha^{-1} in the early 1960s to 17 in 2 t ha^{-1} in 2001. As a result, the increase in the cultivated area and the yield recorded, the world production of onion was about 3944 million tons per year (FAOSTAT, 2011).

Onion (*Allium cepa* L.) is an important bulb crop produced in Ethiopia. It is relatively a recently introduced crop in Ethiopia and it is fastly becoming a popular vegetable among the people. It was introduced to the agricultural community of Ethiopia in the early 1970s when foreigners brought it in. Though shallots are traditional crop in Ethiopia, onions are becoming more widely grown in recent years. Currently, the crop is produced in different parts of the country for local consumption and for export of flowers to European markets. The average annual sale of dry bulb and cut flowers from Ethiopian fruit enterprise alone was estimated to be about 6.2 million birr (ETFRUIT, 1992). Onion is grown by both small scale farmers and commercial growers especially under irrigation. Ethiopia has a great potential to produce the crop throughout a year both for domestic use and export market. Its higher yield potential, 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 is making onion increasingly important in Ethiopia (Lemma and Shimelis, 2003). Specifically to onion production and improvement, the Ethiopian Agricultural Research Institute has made efforts to generate different improved varieties. As a result of this effort the varieties Adama Red, Bombay Red, Red Creole, Melkam, Mermiru Brown, Nasik Red and Nafis are made available to farmers (Lemma and Shimelis, 2003; MoARD, 2010) and through extension and promotion of these varieties have grown extensively in small and commercial farms under both rain fed and mostly under irrigation. In the country, onion can be grown in altitudes between 500-2400 meters above sea level with optimum range between 700 - 2000 meters above sea level with optimum day and night temperature of 20-26^{o}c and 11-15^{o}c, respectively (EARO, 2004).

The area under this crop has been expanded even if the extent of their cultivation in the peasant sector is difficult to indicate numerically because it is scattered throughout the country and small plots commonly by the side of homestead. Current yields of onion crops in Ethiopia are low i.e. national average yield is approximately 10 t ha^{-1} compared to about 30 t ha^{-1} in other countries (Jilani, 2004). In 2013, the production of onion was about 21865 ha of land yielding a total production of 219919 tons with productivity (10.06 t ha^{-1}). The major onion production regions are Amhara, Tigray, Oromia, Benishngule-Gumuz, Gambela and South Nation Nationalities and Peoples Regions (SNNP) (CSA, 2013).

The majority of onion production is found in the Central Rift Valley of Ethiopia. In these areas, where vegetable production is widely cultivated as cash crop by small-scale, private and large-scale farmers, rainfall is unreliable and insufficient to support onion production. There are two rainfall season in the Central Rift Valley, a short rain season (March-April) being highly uneven and erratic in its distribution and undependable pattern for economic farming and the long rain season (July-September) being more dependable for agricultural farming. Therefore, to offset this deficit during dry season and maintain a high crop yield in this area irrigation is indispensable practice (MOWR, 2007).

2.6. Role of Phosphorus in Onion

Phosphorus (P) is claimed to be the second most important limiting plant nutrient (Tisdale *et. al.*, 1995). As its functions are not replaced by any other nutrient it said as essential nutrient for plant growth. It is known to be involved in several physiological and biochemical processes of onions; being components of membranes, chloroplasts and mitochondria and constituent of sugar phosphates, adenosine diphosphate (ADP), adenosine triple phosphate (ATP), nucleic acid, etc., phospholipids and phosphates. It also play a crucial role in energy transfer reactions and metabolic processes in onion maturity, bulb setting and bulb production (Miller and Donhaue, 1995). It is an essential component of deoxyribonucleic acid (DNA), the seat of genetic inheritance and of ribonucleic acid (RNA), which directs protein synthesis in onion. For most allium species, the total phosphorus content of healthy leaf tissue is not high, usually comprising only 0.2 and 0.4% of the dry matter (Brady and Weil, 2002). Adequate amount of phosphorus is essential for numerous metabolic processes. Among the significant functions enhances photosynthesis, reproduction, flowering, fruiting, including seed production and maturation. Root growth, particularly development of lateral roots and fibrous rootlets, is encouraged by phosphorus (Brady and Weil, 2002).

Phosphorus has by far the smallest quantities in solution or in readily soluble forms in mineral soils compared with all other macronutrients found in soils, generally ranging from 0.001 mg/L in rich, heavily fertilized soils. Plant roots absorb phosphorus dissolved in the soil solution, mainly as phosphate ions (HPO_4^{-2} and $H_2PO_4^-$), but some soluble organic phosphorus compounds are also taken up. The chemical species of phosphorus present in the soil solution is determined by the solution pH (Miller and Donhaue, 1995). It is an immobile nutrient and continued application of phosphate fertilizers tends in time to increase the levels of this nutrient in the soil and particularly its level in the liable forms that can release phosphorus to the soil solution (Piezynski and Logan, 1993). By holding the pH of soils between 6 and 7, the phosphate fixation can be kept at a minimum (Miller and Donahue, 1995). Due to the general immobility of phosphorus in the soil profile, fertilizer placement is generally more critical for P than N. Phosphate fertilizers are commonly placed in localized bands to prevent rapid reaction with the soil (Miller and Donahue, 1995). Several additional factors influence phosphorus availability. This includes temperature, compaction, moisture conditions, aeration, pH type and amount of nutrients (including phosphorus) status of soil (Sumner *et al*., 1986).

2.7. Effect of Phosphorus on Growth and Yield of Onion

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 (Fairhurst *et al*., 1999). Its deficiency reduces seedling height, tiller number, stem diameter, leaf size, and leaf duration and also delay maturation (Fageria *et al*., 2003; Ghaffor *et al*., 2003; Greenwood *et al*., 2001; Abdissa *et al.*, 2011). Similarly, Application of greater phosphorus promoted leaf length in onion plant (Jawar *et al*., 2016; Tesfaye, 2009; Salam *et al*., 2004). According to Ali *et al*. (2008), the different phosphorus levels resulted in significantly different plant heights where the tallest plants were observed at higher rates of applied phosphorus while the shortest plants were from the control plots. Singh *et al.* (2010) observed that different levels of nitrogen and phosphorus significantly affected the growth characters and total yield of onion. Similarly, the higher level of N + P fertilizer (90 kg N ha^{-1} + 103 kg P_2O_5 ha^{-1}) significantly increased plant height, number of leaves per plant, bulb and neck dimensions, and fresh and dry weights of whole plant and its different organs as compared with lower level (Fatma *et al.,* 2012). Aliyu *et al*. (2007) conducted an experiment to study the effect of phosphorus (0, 40 and 80 kg P_2O_5 ha^{-1}) and nitrogen levels on the growth and yield of onion. The results indicated that 40 kg P_2O_5 ha^{-1} had maximum plant height and number of leaves per plant in comparison with control treatments. Furthermore, Amans *et al.* (1996) reported significant effect of phosphorus on the number of leaves of onion. On the other hand, Birhanu (2016) reported that onion plant height, leaves number and length were not significantly affected by P fertilization; thus, lack of response to P may be attributed to the presence of adequate amounts of available P in the soil.

The study conducted in Wolaita by Tibebu *et al.* (2014) on four phosphorus levels (0, 23, 46 and 69 kg ha^{-1}); the study report indicated that the growth and yield parameters of phosphorus had significant differences in plant height, bulb diameter and harvest index. Maximum plant height of 36.86 cm was obtained from application of 69 kg P_2O_5 ha^{-1}, whereas the lowest plant height (32.11 cm) was recorded at control treatments; thus the mean plant height of onion is increased due to P fertilization. As the level of fertilizers increased from 0 to 115 kg P_2O_5 ha^{-1} and 114 kg N ha^{-1} the height of the plants were increased but the increased fertilizer application above these decreased the height of the plants (Getachew, 2014).

Jokhio *et al.* (2005), conducted an experiment in Pakistan, during 2000-2001 to investigate different plant spacing and two P levels (75 and 100 kg ha^{-1}) on the growth and yield of onion cultivars. P levels showed significant effect on horizontal bulb diameter, single bulb weight, bulb yield per plot and yield per ha, while a non-significant effect was recorded for vertical bulb length. The bulb length was higher with the application of phosphorus dose, may be due to the fact that the phosphorus improved the carbohydrate content of the plants and it extended root growth, which ultimately helped in the increased length of onion bulb (Khodadadi, 2012). A study conducted during 1999-2000 and 2000-2001 with onion by Dixit and Sharma (2004) to find out about productivity and uptake of phosphorus. They applied four P levels (0, 16.3, 32.6 and 48.9 kg ha^{-1}) and reported that P application up to 48.9 kg ha^{-1} significantly increased the yield contributing parameters such as bulb diameter, bulb length and bulb dry weight.

A field trial conducted by El-Rehim (2000) in Egypt on onion to find out the effect of five levels of phosphorus fertilization (0, 33, 66, 99 and 132 kg P_2O_5 ha^{-1}) on onion. Accordingly, the yield of onion bulbs, total and marketable yield, and average bulb weight increased, while percentage of missing plants doubled and bolters decreased as a result of increasing the rate of phosphorus fertilizer. A study by Muoneke *et al*. (2003) on three phosphorus rates (0, 30 and 60 kg ha^{-1}) on growth , yield and keeping quality of onions Northwestern Nigeria indicated that phosphorus rate at 60 kg ha^{-1} increased growth and yield, but did not influence the keeping quality of the bulbs.

According to the study conducted at MARC, in Ethiopia from 1988 to 1992 using equal levels of N and P_2O_5 (0, 46, 92 and 138 kg ha^{-1}) under heavy clay soils. The highest dry bulb yield (28.9 t ha^{-1}) was produced at 92 kg ha^{-1}, which was also 10% higher than the control treatments. At 92 kg ha^{-1}, there was better vegetative growth and the average bulb weight increased to 49 g/bulb at Melkassa (Lemma and Shimeles, 2003). A report by Hyder *et al.*

(2007) indicated that plant height, bulb length, bulb diameter and days to harvest were the most important yield contributing factors.

According to Shaheen *et al*. (2007) the highest application of phosphorus fertilizer (92 kg ha^{-1}) had a major effect on the productivity of onion plant, hence increased total bulb yield and its components. Application of phosphorus level positively and significantly affected bulb length, bulb diameter, average bulb weight, bulb dry matter content, marketable yield and total bulb yield (Aster, 2009; Aisha *et al*., 2007). Jilani (2004) observed that different dose of nitrogen and phosphorus affected the total yield of onion significantly, with the maximum yields of 25.4 t ha^{-1} and 26.6 t ha^{-1} achieved from plots receiving N : P at 200:150 kg ha^{-1} followed by plot receiving N : P at 160:150 kg ha^{-1} on clay loam soil. Vachhani and Patel (1993) also reported that increasing in phosphorus application increased bulb weight and size. The effect of phosphorus application increased bulb yield and its characteristics may be explained through the role of phosphorus (Singh *et al*., 2000). On the other hand, Dargie (2015) and Abdissa (2008) reported that phosphorus has shown non-significant effect on total dry biomass yield and harvest index of onion; thus, absence of response to P might be due to sufficient amount of available P which was found in the soil of the experimental site.

Zelalem *et al*. (2009) confirmed that higher level of P fertilization significantly influenced root dry weight of potato. The lowest harvest index of 54% was obtained from 0 kg P_2O_5 ha^{-1}; whereas the highest (63%) was obtained from 46 kg P_2O_5 ha^{-1}, which is statistically similar to 69 kg P_2O_5 ha^{-1}, but significantly different from the control treatments (Tibebu *et al*., 2014). Ahn (1993) indicated that P is concentrated in the fast growing parts of the plant and, therefore, it hastens the maturing period of crops. Similarly, Ottman (2009) reported that increased in P rate decreased time to heading, anthesis and maturity of plant. The maximum mean dry matter content of 38.1% was recorded at the highest rate of 69 kg P_2O_5 ha^{-1}, while the minimum values (33.2 %) were recorded at control and as the rate of P increases dry matter content of onion increased (Tibebu *et al.*, 2014). Woldetsadik (2003) stated that on a clay soil in a sub-humid tropical environment of Ethiopia under irrigation and rainfall condition, the shallot (*Allium ascalonicum*) crop through application of P slightly increased soluble solids, dry matter and pyruvate content of bulbs but the pyruvate content was significantly affected by applied P.

2.8. Effect of Seedling Age on Growth and Yield of Onion

A field trial conducted by Sharma (1998) on four seedling ages (4, 5, 6 and 7 weeks of old seedling) and nitrogen levels of onion. Plant height, number of leaves per plant and mean bulb yield increased significantly as seedling age at transplanting increase up to six weeks old. Similarly, Kumbhkar *et al*. (2016) reported that using seedling age of onion; plant height increased significantly as seedlings were transplanted at 8 weeks of seedlings. Sultan (2015) indicated that seedling age had significantly differences in plant height, leaf length, bulb diameter, bulb length and average bulb weight. Furthermore, Singh and Chaure (1999) and Bahadur and Singh (2005) found that onion transplanted at 7 weeks of seedlings age had the highest leaf length, number of leaves per plant, bulb length, average bulb weight and bulb yield were obtained. Bijarniya *et al*. (2015) also stated that maximum plant height (64 cm) and number of leaves per plant (10.95) were recorded from transplanting of 8 weeks old seedlings, whereas the minimum plant height (54.07 cm) and number of leaves per plant (9.39) were obtained from transplanting of 6 weeks old. It might be due to their more age and more stored photosynthates present in them as compared to 6 weeks old seedling, which resulted in better establishment and vigorous growth of plant. Furthermore, Muhammad *et al*. (2017) on three seedling ages (40, 50 and 60 days old) and nitrogen rates of onion. They found that seedlings transplanted at 40 days after sowing were able to gain maximum plant height, leaf number, leaf length, fresh bulb weight and high bulb yield as compared to other seedling age.

Kanton *et al.* (2002) conducted an experiment on days of seedling ages (30, 40, 50, 60 and 70 days old) at two locations in Ghana during the 1996/97 and 1997/98. The result indicated that the tallest plants were developed from 40 days old seedlings, whereas the shortest were developed from 30 and 70 days old. Harvest index, bulb weight and total biomass weight of onion decreased significantly as transplanting age above 60 days old seedlings. The heaviest onion bulb weight (57.2 g) was obtained from plants developed from 40 day old seedling, and the lightest (26.1 g) were recorded from plants developed from 70 days old seedling. Plants developed from 40 to 50 day old seedling produced the highest bulb yields. Vachhani and Patel (1988), conducted an experiment with seedling age at transplanting of onion seeds of the cultivar Pusa Red, which were sown at 4, 5, 6, 7, 8, 9 and 10 weeks old in field at 15 x 10 cm. The highest bulb yield of 46.25 t ha^{-1} was recorded from transplanting of 7 week old seedlings and the lowest bulb yield of 25.77 t ha^{-1} from transplanting of 4 weeks old seedlings. Similarly , Vachhani and Patel (1993) determined the effect of seedlings on the yield of onion bulbs on the onion cultivar Pusa Red by transplanting the seedlings in the field at intervals of 4, 5, 6 ,7 ,8 , 9, and 10 weeks. The field trials indicated that the highest bulb yield (46.23 t ha^{-}

^{1}) was recorded from the transplanting of 8 weeks old seedlings; however, the lowest yield (32.53 t ha^{-1}) was obtained at 10 week's old seedlings.

An experiment by Verma *et al*. (1971) tested transplanted seedling at the age of 4, 6, 8 and 10 weeks and observed that 8 weeks old seedlings gave the highest yield of bulb. Maurya *et al*. (1997) conducted an experiment to observe the effect of seedling age consisting of 30, 40, 50, 60, 70, 80 and 90 days old seedlings and found that 60 days old seedlings gave the highest (28.22 t ha^{-1}) bulb yield of onion followed by those planted at 50 days (23.89 t ha^{-1}).

Mohanty *et al*. (1990) conducted an experiment with onion on seedling ages (6, 8 and 10 week old seedlings) and time of transplanting (20 Nov., 20 Dec., 4 Jan. and 19 Jan.). The finding indicated the highest bulb yield (30.46 t ha^{-1}), bulb diameter (6.66 cm) and average bulb weight (126.54g) were obtained in the transplanting of 8 weeks old seedlings and decreased markedly with later planting dates. The average differences in bulb yield of 10 and 8 weeks old seedling over 6 weeks old seedlings were 95.75% and 52.94%, respectively. Herison *et al.* (1993) reported that increase in seedlings age (56 days old) resulted in larger bulbs under Michigan country (USA). On the contrary, Kanton *et al*. (2002) and Faruq *et al*. (2003) observed that the plants developed from younger seedlings were seemed to be more efficient in conversion to photosynthates into larger bulbs as indicated by higher bulb yields, which may be due to influence of prevailing climatic conditions of that region.

According to Liu *et al.* (1996) and FuLung and WooNang (1996) on seedling ages (35, 45, 55 and 65 days) and plant size of onion. The result indicated that 55 and 65 days old seedling were produced higher yields and matured earlier as compared to 45 days old seedlings.

Bijarniya *et al*. (2015) reported that minimum day taken for maturity (148.58) was recorded with transplanting of 8 weeks old seedlings, whereas the maximum days taken for maturity (154.92) was observed with transplanting of 6 weeks. Early maturity of bulbs might be due to vigorous growth of plant because of stored food in older seedlings which results in faster development and earlier maturity of bulb as compared to younger seedlings. Similarly, Bhonde *et al*. (2001) studied that the effects of seedling age and harvesting date on the yield and quality of onion. The data showed that the transplanting of 8 weeks old seedlings and harvesting at 125 days after transplanting gave greater yield and quality and the highest net returns compared with the other treatments. Furthermore, Deepika (2013) reported that plants produced from 30 day old seedlings took more time to mature than those obtained from 40, 50 and 60 day old seedlings. The younger seedling continued vegetative growth for a long time which was subject to favorable higher temperature for bulbing which may have enhanced the number of days to maturity (Butt, 1968). A field trial conducted by Latif (2006) and Latif *et al*. (2010) reported that dry matter content and average bulb weight of onion was significantly influenced by the age of seedling. The highest dry matter content of bulb (7.60%) was found by transplanting 50 days old seedling and the lowest dry matter content (4.61%) was obtained from 40 days. Muhammad *et al*. (2016) stated that the seedlings were transplanted under 60 days have high (12.28%) dry matter content as compared to early stages. An experiment by Sultan (2015) observed that the maximum dry matter content (17.65 %) was recorded from transplanting of 50 days old seedlings, while the minimum dry matter content (13.55 %) was obtained from transplanting of 60 days.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted at Alage Agricultural Technical and Vocational Education and Training (ATVET) College during the 2016/17 dry season under irrigation. The college is located 217 km south of Addis Ababa city and 32 km west of Bulbula town in the vicinity of Abidjata and Shalla lakes. It is situated between 7^0 65' N latitude and 38^0 56' E longitudes and at an altitude of 1600 meters above sea level in the agro ecology of dry plateau of the southern part of the Ethiopian rift valley system. The area is characterized by a bimodal rainfall pattern where short rainy season occurs during the months of March and April, and the main rain starts in June and extends to September. High amount of rainfall is received in the month of July and August. While the mean annual rainfall is 800 mm, the annual mean minimum and maximum temperatures are 11 ^{0}C and 29 ^{0}C, respectively (Agerie and Afework, 2013). The soil analysis result of the experimental site showed that the soil textural class is silt clay loam (Table 1).

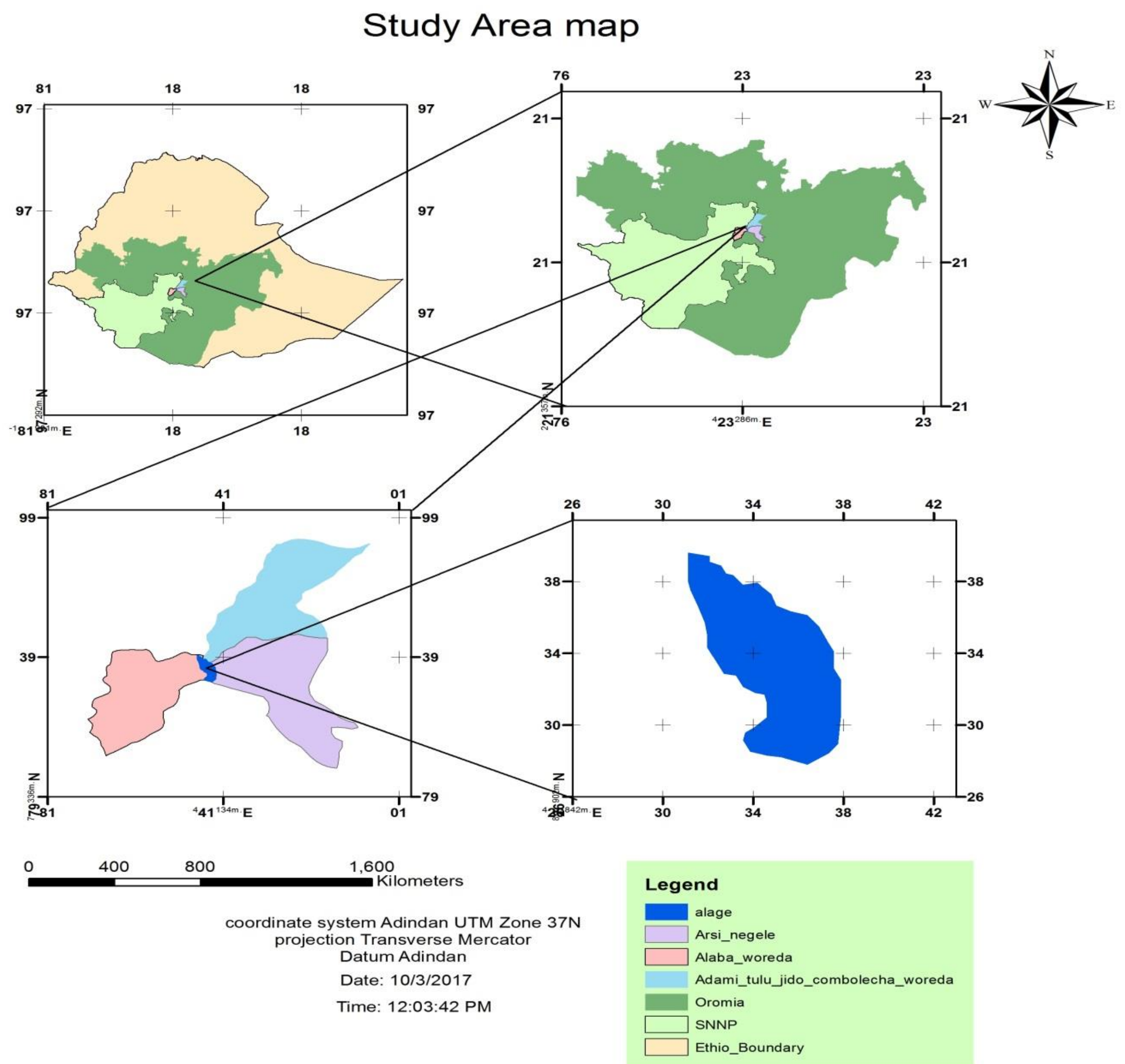

Figure 1: Location Map of study site, Alage in Central Rift Valley of Ethiopia**.**

3.2. Experimental Materials

3.2.1. Planting material

The plant material for this study was Bombay Red variety of onion. The variety is widely accepted by farmers for its early maturity and higher bulb yield in the study area. Its characteristics include dark green leaf color, medium leaf arrangement, thick, flat shape bulb, and light red and light pungent bulb. It was released by Melkasa Agricultural Research Center (MARC) in 1980. It is well adapted to areas of 700-2000 meter above sea level (EARO, 2004). Its yield ranges from 13-16 t ha^{-1} under farmers' condition and above 30 t ha^{-1} under research conditions (EARO, 2004). It is one of the most commonly and widely used improved variety in Central Rift Valley of Ethiopia and particularly at Alage.

3.2.2. Fertilizer

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

3.3. Treatments and Experimental Design

The experiment was comprised of 3 x 4 factorial combinations involving age of seedling and varying rates of phosphorus. Three age of seedlings (6, 7 and 8 week of seedling age) and four varying rates of P (0, 46, 92, and 138 kg P_2O_5 ha^{-1}) were laid out in randomized complete block design (RCBD) with four replications. Each treatment combination was assigned randomly to the experimental units within a block. Double row planting was done on ridges of about 20 cm height adopting recommended spacing of 40 cm between water furrows, 20 cm between rows on the ridge and 10 cm between plants within the row. There were 48 plots corresponding to the 12 treatment combinations with four replications. The unit plot size of the experiment was 2.0 m x 2.0 m (4 m^2). The blocks were separated by a distance of 1.0 m whereas the space between each plot within a block was 50 cm. In each plot, there were 10 rows, and in each row there were 20 plants. Totally, there were 200 plants per plot. The outer three rows at both sides of the plot and three plants at both ends of the rows were considered as border plants. The plants in the four central rows were used as net plot area to determine yield per plot and other parameters.

3.4. Agronomic Practices and Treatment Applications

3.4.1. Raising onion seedlings

Seedlings of ‘Bombay Red’ onion variety were raised in a nursery at Alage ATVET College demonstration site on sunken beds with size of 1 m x 10 m. The seed of ‘Bombay Red’ was obtained from Melkasa Agricultural Research Center, Horticulture Division. After four sunken nursery beds were prepared, seeds were sown on December 15/2016. The soil was cultivated to a fine tilth before sowing the onion seed. The seed was drilled in well pulverized sunken bed in rows 10 cm apart and lightly covered with soil in the required seedling age. Mulching with grasses was done until seedlings emerged. The mulch was removed after seedlings fully emerged (2-3 cm from the soil). All important cultural practices such as application of fertilizer (urea and DAP), watering, weed, diseases (Ridomil) and insect pest (Selecron) control activities, respectively were undertaken based on the recommendations made for the onion crop.

3.4.2. Management of experimental field

Before transplanting seedlings, the experimental field was ploughed and leveled by tractor; ridges and plots were made manually. Large clods were broken down in order to bring the land to a fine tilth, and then a total of 48 plots based on recommended size were prepared in which 12 plots were allocated in each of the four replications. Moreover, the required numbers of ridges and rows were marked in each plot. The seedlings were grown in the nursery with careful management and strict follow up until seedlings reached to the required stage as per the treatments. Seedlings were hardened before transplanting to the main field to enable them withstands the field conditions. One day before transplanting the seedlings, the nursery was irrigated to ensure uprooting the seedlings safely with little loss of roots. Seedlings were carefully transplanted on the experimental plots using double rows. After transplanting a light irrigation was given for better establishment of seedlings and subsequent irrigations were given to the crop as per requirement. The experiment was conducted under furrow irrigation method, which is the most commonly used irrigation system in the study area. A three to four days irrigation interval was maintained for the first four weeks. Thereafter, irrigation was applied at 7 days interval until 15 days to harvest, when irrigation was stopped completely (EARO, 2004).

The sources of the fertilizers were urea (46% N) and Triple Super Phosphate, (TSP) (46% P_2O_5) for supplying nitrogen and phosphorus, respectively. As per the recommendation made for the onion in the study area half 50 kg ha^{-1} dose of N was applied uniformly to all plots during transplanting. The remaining half 50 kg ha^{-1} dose of nitrogen rates of each treatment was side-dressed 45 days after transplanting for each of the seedling ages (EARO, 2004; SARC, 2008; Anisuzzaman *et al*., 2009). Phosphorus was applied as a single application as per specified rates at the time of transplanting based on the treatments. Weeding was done with hand hoe and by hand-pulling whenever necessary throughout the experimental period to keep the crop free from weeds, for better soil aeration and to break the crust. For the control of disease (purple blotch) and insect pest (onion thrips) the insecticide, Selecron 720 EC (0.5 l ha^{-1}) and the fungicides, Mancozeb 80 WP (3 kg ha^{-1}) and Ridomil (3.5 kg ha^{-1}) were used, respectively. All other agronomic practices were applied uniformly for all the plots as per the recommendation made for the crop (EARO, 2004).

3.5. Soil Sampling and Analysis

Pre-planting nine soil samples were taken randomly in a zigzag fashion from the experimental field at the depth of 0-20 cm for determination of physical and chemical properties of the soil. Nine soil samples were collected using an auger from the whole experimental field and combined to form a composite sample in a bucket. The soil was broken in to small crumbs and thoroughly mixed. From this mixture, a sample weighing one kg was filled in to a plastic bag. All the analyses were made at Horticoop Ethiopia P.L.C. soil and water analysis laboratory in Debre Ziet.

The soil was air dried and sieved through a 2 mm sieve. Then, soil pH was determined by diluting the soil in a 0.01 M $CaCl_2$ solution in the ratio of 1 soil volume to 2.5 volume of the $CaCl_2$ solution. Thus, twenty-five ml of the 0.01M $CaCl_2$ solution was added into soil sub samples each weighing 10g. After equilibrating for 2-3 hours, the suspensions were filtered and the pH measured by a glass electrode.

The soil samples were also analyzed for soil texture, total nitrogen, cation exchange capacity (CEC), exchangeable potassium, organic carbon and available phosphorous. The soil texture was determined by the modified Bouyoucos hydrometer method. Total nitrogen of the soil was determined by the micro Kjeldhal procedure as described by Dewis and Freitas (1975). Cation exchange capacity (CEC) and exchangeable potassium were determined by ammonium acetate using the procedure described by Jackson (1975). Organic carbon content of the soil was determined by Walkely and Black Method of wet combustion procedure (Walkley and Black, 1954). Available phosphorous content of the soil was determined by extraction with 0.5 M $NaHCO_3$ (Olsen *et al.*, 1954). Phosphorus in the extracts was determined with atomic absorption spectrophotomer calorimetrically according to the procedure of Olsen method (Olsen and Sommers, 1982).

3.6. Data Collection

Days to maturity was registered on plot basis. Harvesting of onion bulbs was done when 70% of leaves or necks fell down. Growth and yield components were recorded from twelve sample plants randomly taken from four central middle rows of each experimental plot. However, all plants in each net plot were harvested to collect data for bulb yield. A data on the following parameters were collected.

3.6.1. Phenology and growth parameters

Plant height (cm): Plant height was measured from the ground level up to the tip of the longest leaf using ruler. Plant heights of twelve randomly selected plants were measured in the four central rows of each plot at physiological maturity stage of the crop and the average was computed.

Leaf length (cm): Leaf length was recorded as the average length of the longest leaves in twelve randomly selected plants at maturity.

Leaf number per plant: Refers to the mean number of leaves produced by sampled plants at maturity stage. Total number of leaves of sampled plants was counted and divided by the number of plants to get mean leaf number per plant.

Days to maturity: It was recorded as the number of days from transplanting to a day at which more than 70% of plants in a plot showed neck fall and 2/3 leaves turned yellow (EARO, 2004).

3.6.2. Yield components and bulb yield

Bulb diameter (cm): The diameter of randomly selected sample bulbs from each treatment was measured at the widest point in the middle portion of the mature bulb. Diameters of bulbs were measured at harvest using a slide caliper.

Bulb length (cm): The height of the mature bulb was measured at harvest using a caliper from the bottom to the top of the bulbs of the random selected plants.

Fresh bulb weight (g): The average weight of twelve randomly selected mature bulbs was weighted using a digital sensitive balance.

Total biomass yields (t ha^{-1}): Refers to all above and underground biomass from net plot weighed after harvest using digital sensitive balance.

Bulb dry weight (g): Bulbs were chopped into small 1-2 cm pieces, mixed thoroughly, and two sub-samples each weighing 200g was weighed. The exact weight of each sub-sample was determined and recorded. Each sub-sample was placed in a paper bag and put in an oven until constant dry weight was attained. Each sub-sample was immediately weighed and recorded as dry weight.

Total bulb yield (t ha^{-1}): It was recorded from central rows per net plot. The harvested bulbs were weighed after curing and converted in to t ha^{-1}.

Unmarketable bulb (t ha^{-1}): These are under sized (<20g), physiologically disordered and pest damaged bulbs which were determined from weight of bulbs harvested from the middle of the plot using digital sensitive balance (Moray *et al*., 2012).

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

$$\mathrm{HI} = \frac{\text{total bulb dry weight}}{\text{total biomass dry weight}} \mathrm{X100}$$

3.6.3. Quality parameters

Bulb dry matter fraction (%): The fresh weights of the sampled bulbs were measured and oven dried at 70 ^{0}C for 72 hours to reach the constant weight. Then, the dry matter fraction was determined by dividing the oven dried bulb samples by their respective fresh weights.

$$\%\ \text{of bulb dry matter fraction} = \frac{\text{constant dry weight of bulb}}{\text{fresh weight of bulb}} \mathrm{X100}$$

Neck thickness (cm): The average neck thicknesses of twelve randomly selected plants in each plot were obtained by measuring the neck of bulbs at the narrowest point at the junction of bulb and leaf sheath using a slide caliper.

Marketable bulb yield (t ha^{-1}): It is yield of onion, bulbs which are not under sized, free from physiological disorder and pest damaged bulbs. It was determined from weight of bulbs harvested from the middle of the plot using digital sensitive balance and expressed in t ha^{-1}.

Bulb size distribution of marketable bulbs (t ha^{-1}): It was done based on the weight of bulbs from categories of bulb size for small (20 - 50 g), medium (50 – 100 g), and large (100 - 160 g) which were recorded per net plot and converted to t ha^{-1}.

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

3.7. Partial Budget Analysis

Partial budget analysis was conducted to assess the economic feasibility of the treatments. It is a method of organizing experimental data and information about the costs and benefits of various alternative treatments. Partial budget, dominance and marginal analysis were used. It was employed for economic analysis of fertilizer application and the mean price of onion and this was carried out for combined bulb yield data. The potential response of crop towards the added fertilizer and price of fertilizers during planting ultimately determined the economic feasibility of fertilizer application. The analysis was based on data collected from respective district office of trade and transport, cooperatives and from onion fields. At Alage, the cost of 100 kg phosphorus (TSP) was 1095 birr and onion price of 400 birr per 100 kg was used for the net benefit analysis.

A partial budget is a way of calculating the total costs that vary and the net benefits of each treatment (CIMMYT, 1988). Partial budget analysis is the process of examining only those costs and resource needs that change with a proposed adjustment. Based on this, yield was adjusted downward to the recommended level of 20% for all 12 treatments to get the adjusted net yield. The adjusted yield was multiplied by market price of one kg of onion bulb during harvesting time to obtain gross yield benefit. All variable costs were reduced especially the purchasing and application costs of fertilizers.

3.8. Method of Statistical Data Analysis

The collected data on various parameters under study were subjected to analysis of variance (ANOVA) using the GLM procedures of SAS (Statistical Analysis System) version 9.2 computer software program (SAS Institute Inc, 2008). Significance of differences between means was expressed using the least significance difference (LSD) test at $P < 0.05$ probability level. Correlation analysis was computed to determine associations between yield and yield related traits.

4. RESULTS AND DISCUSSION

4.1. Physico-Chemical Properties of the Experimental Soil

The results of the laboratory analysis of the physical and chemical properties of the composite experimental soil are presented in Table 1. The results revealed that the texture of the composite soil sample is silty clay loam. The soil had particle size distribution of 18% sand, 36% silt and 46% clay at the depth of 0 - 20 cm. The pH was slightly alkaline (pH=7.82). Brewster (1994) stated that for higher yield of onion, a pH of 6 - 6.8 is ideal. However, the pH of this soil is near optimum for onion crop production although it is not ideal. According to the rating of Walkley and Black (1954) and Dewis and Freitas (1975), the soil of the study area is medium in organic carbon as well as total nitrogen, respectively. The cation exchange capacity (CEC) of the experimental soil is also high according to the rating of Jackson (1975). According to the rating of Olsen *et al*. (1954), the available soil phosphorus content is low. This indicates that there was a requirement for application of phosphorus to the onion crop. The exchangeable potassium content is very high according to the rating of Landon (1991).

Table 1: Major soil characteristics of the experimental site before planting at Alage.

Soil properties	Unit	Values	Rating
Particle size (%)			
Sand	%	18	
Silt	%	36	
Clay	%	46	
Textural Class	-	Silty clay loam	
Ph	-	7.82	slightly alkaline
Organic Carbon	%	2.10	medium
Total Nitrogen	%	0.18	medium
Carbon : Nitrogen	-	11.75	
Available Phosphorus	mg/kg(ppm)	4.12	Low
Available Potassium	mg/kg(ppm)	1531.7	very high
Cation Exchange Capacity	meq/100g soil	31.8	High

4.2. Phenology and Growth Parameters

4.2.1. Plant height

Result from the analysis of variance revealed that the main effects of seedling age ($P < 0.01$) and phosphorus ($P < 0.001$) significantly influenced plant height of onion (Appendix 1). However, the two factors did not interact to influence plant height.

There was a significant difference in plant height among the various weeks of seedling age recorded at maturity (Table 2). The highest plant height (59.3 cm) was obtained from the plant when they were transplanted at 8 weeks of seedling age followed by the plants at 7 weeks of seedling age (57.27 cm); while the shortest (55.26 cm) was obtained under 6 weeks of seedling age. In general, the longer plant height at the oldest seedling might be due to their greater age and the more stored photosynthates present in them as compared to the youngest seedling age which resulted in better establishment and vigorous growth of plant.

This result is in agreement with that of Kanton *et al.* (2002), who found that significantly tallest plants of onion were recorded from the oldest seedling than the youngest one. Similarly, Bijarniya *et al*. (2015) reported that the more plant height at 8 weeks old seedling stage might be due to their greater stored food present in them as compared to the 6 old ones. This result is also in line with that of Sultan (2015) who found that the maximum plant height was recorded from 50 days old seedlings age and this might be due to the fact that 50 days old seedlings possibly received favorable condition for quickest growth than those of other age of seedlings. This result is also corresponds to the finding of Kumbhkar *et al*. (2016) who reported that using seedling age of onion, plant height increased significantly as seedlings were transplanted at 8 weeks of seedling.

Increasing the rate of phosphorus fertilizer from nil up to 92 kg P_2O_5 ha^{-1} resulted in a significant increase in plant height. However, increasing the rate of phosphorus from 92 kg P_2O_5 ha^{-1} to 138 kg P_2O_5 ha^{-1} did not change the height of the onion plants. The tallest mean plant heights were attained at 92 kg P_2O_5 ha^{-1}(60.35 cm), while the shortest plant height (53.58 cm) was obtained under the control treatment. The mean height of onion plants grown at the rate of 92 kg P_2O_5 ha^{-1} exceeded the mean height of plants grown at the rates of 46 and 0 kg P_2O_5 ha^{-1} by about 7 and 13% in the order mentioned here (Table 2). This might be attributed to the fact that phosphorus enhances plant vigor and strength of the stem of the plant (Bahadur *et al*., 2002).

The result of this study confirms the findings of Ali *et al*. (2008), Muoneke *et al*. (2003), Aliyu *et al*. (2007) and Tibebu *et al.* (2014) who reported that different phosphorus levels resulted in significantly different plant heights where the tallest plants were observed at higher rates of applied phosphorus, while the shortest plants were from the control plots. The result also agreed with the findings of Lemma and Shimeles (2003) who reported that at 92 kg P_2O_5 ha^{-1} there was better vegetative growth which resulted in increased heights of onion plants. Similarly, Getachew (2014) reported that as the level of fertilizers increased from 0 to 115 kg P_2O_5 ha^{-1}, the height of the plants were increased, but the increased fertilizer application above these decreased the height of the plants. This result is contrary to the finding of Birhanu (2016) who reported that onion plant height, leaves number and length were not significantly affected by P fertilization. The lack of response to P may be attributed to the presence of adequate amounts of available P in the soil.

4.2.2. Leaf length

Leaf length of onion plants was significantly affected by the main effects of seedling age ($P< 0.01$) and phosphorus ($P<0.001$) treatments (Appendix 1). However, it was not significantly affected by the interaction effect of those treatments.

This study indicated that, significant differences were observed among the seedling age treatments such that the 8 weeks of seedling age gave the longest (47.78 cm) onion leaves; while the shortest leaf length (44.24 cm) was obtained under 6 weeks of seedling age (Table 2). The result is supported by observations of Singh and Chaure (1999) who reported that longer leaves were recorded at old seedling age as compared to treatments of the young ones.

Young seedlings lead to retarded plant growth as it results to interfere with photosynthesis ability and nutrient uptake of plants and consequently, reducing cell division and growth and thus resulting in stunting of leaves. Muhammad *et al*. (2017) and Sultan (2015) also reported that the length of leaf was significantly influenced by the different age of seedling of onion.

Application of 138 kg P_2O_5 ha^{-1} gave significantly longer leaf length (47.57 cm) than the lower doses (0 and 46 kg ha^{-1}), whereas the 92 kg ha^{-1} P treatment did not significantly differ from 138 kg P_2O_5 ha^{-1} in leaf length (Table 2). The shortest leaf length (42 cm) was obtained under the control treatments. Also significant difference was observed between the 46 and 92 kg ha^{-1} P rates. In general, leaf length tended to show an increasing trend as phosphorus rate increases. The leaf length response to phosphorus fertilizer rate is in agreement with Fageria *et al*. (2003) and Greenwood *et al*. (2001) who reported that higher rates of phosphorus resulted in longer leaves of onion. Similar results were found by Jawar *et al.* (2016), Tesfaye (2009) and Salam *et al*. (2004) who reported that greater phosphorus dose promoted leaf growth in onion plant. The positive effect of phosphorus on leaf length might be due to the fact that it contains an essential component of nucleic acids, phospholipids, and some amino acids and absorbed phosphorus helped a direct stimulation of cellular activity in roots and leaves (Jawar *et al*., 2016).

Table 2: Main effect of seedling age and P fertilizer rates on mean plant height, leaf length, number of leaves per plant and days to physiological maturity.

Treatments	Plant height (cm)	Leaf length (cm)	Number of leaves per plant	Days to Maturity
Seedling age				
6 WSA	55.26[b]	44.24[b]	11.97	102.06[a]
7 WSA	57.27[ab]	45.49[b]	11.43	99[b]
8 WSA	59.3[a]	47.78[a]	11.89	96.75[c]
LSD(0.05)	**2.041**	**1.92**	**NS**	**1.07**
P_2O_5 (kg ha^{-1})				
0	53.58[c]	42[c]	10.44[c]	101.17[a]
46	56.17[b]	44.9[b]	11.44[b]	100[a]
92	60.35[a]	48.87[a]	12.58[a]	98.58[b]
138	59[a]	47.57[a]	12.59[a]	97.33[c]
LSD(0.05)	**2.36**	**2.22**	**0.96**	**1.23**
CV (%)	**4.95**	**9.86**	**5.82**	**1.49**

Means followed by the same letters within a column are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age.

4.2.3. Number of leaves per plant

The analysis of variance on number of leaves per plant showed that the main effect of phosphorus fertilizer application significantly ($P < 0.001$) influenced number of leaves per plant of the onion at physiological maturity (Appendix 1). However, neither the main effect of seedling age nor its interaction with phosphorus influenced this parameter of the onion.

The result indicated that, effect of different rates of phosphorus on the number of leaves per plant increased with the increase in phosphorus level. The highest number of leaves (12.59) was obtained from 138 kg P_2O_5 ha^{-1}, whereas the lowest leaf number (10.44) was obtained under the control treatment. Increasing the rate of phosphorus from nil to 92 kg P_2O_5 ha^{-1} significantly increased the number of leaves per plant of onion. But, the mean leaf number per plant did not show significant difference with further increase in phosphorus rate from 92 to 138 kg ha^{-1}. Thus, the mean leaf number per plant of onion treated with phosphorus at the rate of 92 kg ha^{-1} exceeded the leaf number per plant of onion treated with nil and 46 kg P_2O_5 ha^{-1} by about 21 and 10%, respectively (Table 2). This might be attributed to the role of P in plants, that it is used in dry matter distribution, which facilitates plant development.

The increase in the number of leaves as a result of the increased rates of phosphorus application may be attributed to the useful role of P for the process of cell division and meristematic growth. Vachhani and Patel (1993) also observed that increased application of phosphorus rate increased the number of leaves per plant. In harmony to this result, Aliyu *et al*. (2007) and Amans *et al.* (1996) reported that phosphorus had significant effect on the number of leaves of onion. Similarly, Fatma *et al*. (2012) reported that the higher level of P fertilizer at 103 kg ha^{-1} significantly increased plant height, number of green leaves per plant, bulb and neck dimensions and fresh and dry weights of whole plant and its different organs as compared with the lower level of 69 kg ha^{-1}.

4.2.4. Days to maturity

Days to maturity of onion were significantly ($P < 0.001$) affected by the main effects of seedling age and phosphorus treatments, but not significantly affected by the interaction effects of the treatments (Appendix 1).

The present result showed that, seedling age at 6 and 7 weeks took relatively longer days for onion bulb to mature as compared to the 8 weeks of seedling age. Onion plants with 8 weeks of seedling age reached maturity six and three days earlier than 6 and 7 weeks of seedling age, respectively (Table 2). This result is in agreement with that of Kumbhkar *et al.* (2016) and Bijarniya *et al.* (2015), who reported that onion seedlings that were transplanted at early stage were delayed to attain maturity. Early maturity of bulbs might be due to vigorous growth of plants because of stored food in older seedlings which results in faster development and earlier maturity of bulb as compared to other young seedlings (Bijarniya *et al.,* 2015). Similarly, the findings of Liu *et al.* (1996), FuLung and WooNang (1996) and Bhonde *et al*. (2001) indicated that 55 and 65 days old seedling were larger in size at transplanting and produced higher yields and matured earlier than 45 days old seedlings.

These results are also in accordance with those of Deepika (2013) who reported that plants produced from 30 day old seedlings took more time to mature than those obtained from 40, 50 and 60 day old seedlings. This may be explained on the basis of findings of Butt (1968) who reported that young seedlings do not respond to bulbing stimulus as rapidly as older ones, which might have attributed to more number of days to maturity in the present study.

Days to maturity was also significantly delayed (101 days) in plants from unfertilized plots by phosphorus, while plots received phosphorus at the rate of 138 kg P_2O_5 ha^{-1} matured earliest (97 days) followed by 92 kg ha^{-1} P rate (99 days) (Table 2). However, no significant difference was observed between unfertilized treatments and those received 46 kg P_2O_5 ha^{-1} plots. Generally, plants grown under higher phosphorus rates tended to be early matured. The result indicates that the shortened time required by the plants to reach maturity at higher rates of phosphorus fertilizers might be attributed to the role of P in plants, that it is used in dry matter distribution which facilitates plant development, as a result, early maturity of the plants. The significant function of phosphorus enhances photosynthesis, reproduction, flowering, fruiting, including seed production and maturation of plants (Brady and Weil, 2002). The current observation is in line with Ahn (1993) who indicated that P is concentrated in the fast growing parts of the plant; therefore, it hastens the maturing period of crops. Similarly, Ottman (2009) reported that increase in P rate decreased time to heading, anthesis and maturity of plants.

4.3. Yield components and bulb yield

4.3.1. Bulb diameter

Phosphorus had significant ($P<0.01$) effect on mean bulb diameter of onion plants. However, the main effect of seedling age as well as its interaction effect with phosphorus did not affect this parameter (Appendix 2).

Applications at 46, 92 and 138 kg P_2O_5 ha^{-1} gave similarly wider bulb diameters compared to the plants without added P. The increment in bulb diameter due to phosphorus application might be due to the fact that phosphorus improved the carbohydrate content of the plants and it extended root growth, which ultimately increased the blub size (Jawar *et al*., 2016).

The result of this research agreed with observation of Jokhio *et al.* (2005), El-Rehim (2000), Aster (2009), Aliyu *et al*. (2007) and Aisha *et al*. (2007), who reported that the application of phosphorus positively and significantly affected bulb diameter. Regarding the rates, Shaheen *et al*. (2007) reported that bulb diameter significantly increased with the increases of phosphorus fertilizer up to 92 kg ha^{-1}. Tibebu *et al*. (2014) also reported that the highest bulb diameter was obtained from 69 kg P_2O_5 ha^{-1}.

Table 3: Main effects of seedling age and P fertilizer rates on bulb length and bulb diameter at physiological maturity of onion grown at Alage.

Treatments	Bulb diameter (cm)	Bulb length (cm)
Seedling age		
6 WSA	4.39	4.46^{b}
7 WSA	4.32	4.52^{b}
8 WSA	4.49	4.98^{a}
LSD(0.05)	**NS**	**0.4**
P_2O_5 (kg ha^{-1})		
0	4.11^{b}	4.1^{c}
46	4.33^{ab}	4.41^{bc}
92	4.58^{a}	4.75^{b}
138	4.59^{a}	5.35^{a}
LSD(0.05)	**0.31**	**0.46**
CV (%)	**8.38**	**11.91**

Means followed by the same letters within a column are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age

4.3.2. Bulb length

The main effect of seedling age ($P < 0.05$) and phosphorus ($P < 0.001$) had significantly affected mean bulb length of onion plants, however, the interaction effect did not show significant differences ($P > 0.05$) (Appendix 2).

The result indicated that, at 6 weeks of seedling age, the bulb length was significantly reduced, but no significant difference was observed with 7 weeks of seedling age. Compared to the 6 and 7 weeks of seedling age treatments, 8 weeks of seedling age produced 12 and 10% longer bulbs, respectively. The highest bulb length (4.98 cm) was observed with transplanting of 8 weeks of seedling age, while the lowest bulb length (4.46 cm) was recorded in 6 weeks of seedling age (Table 3). This indicated that the 8 weeks of seedling age had maintained longer leaves and greater height which may have helped for more vegetative growth and bulb development and ultimately an increase in length of bulb. This result is in line with that of Singh and Chaure (1999) and Bahadur and Singh (2005) who observed that increase of bulb length at older seedling age as compared to treatments of the young seedling age. Similarly, Sultana (2015) reported that length of bulb increased in 50 days old seedlings, which were strong and larger in size at transplanting stage.

In response to rising the rate of phosphorus from nil to the 46, 92 and 138 kg P_2O_5 ha^{-1}, bulb length increased significantly. The highest bulb length (5.35 cm) was observed from 138 kg P_2O_5 ha^{-1} followed by those planted at 92 kg P_2O_5 ha^{-1}, while significantly smaller bulb length (4.1 cm) was obtained under the control treatments (Table 3). The significant increase in bulb length in response to the increment in the rate of P fertilizer may be linked to the increase in dry matter production and it's partitioning to the bulb. The result agreed with observation of Dixit and Sharma (2004) who reported that the highest bulb length was obtained from 110 kg P_2O_5 ha^{-1}. Similarly, application of phosphorus positively increases and significantly affected bulb length (Aster, 2009; Aisha *et al*., 2007). The bulb length was higher with the application of phosphorus dose and this might be due to the fact that the phosphorus improved the carbohydrate content of the plants and it extended root growth, which ultimately helped in the increased length of onion bulb (Khodadadi, 2012).

4.3.3. Fresh bulb weight

The main effect of seedling age ($P < 0.01$) and that of phosphorus rate ($P < 0.001$) significantly influenced the fresh bulb weight of the onion plants, but not by the interaction of the two main factors (Appendix 3).

The result revealed that, at 6 weeks of seedling age, the fresh bulb weight was significantly reduced, but no significant difference was observed with 7 weeks of seedling age (Table 4). Compared to the 6 and 7 weeks of seedling age treatments, 8 weeks of seedling age produced 6 and 9% larger bulbs, respectively. The highest fresh bulb weight (86.27g) was recorded from plots that were transplanted at 8 weeks of seedling age, while the least fresh bulb weight (81.28g) was obtained under 6 weeks of seedling age plots. The increased fresh bulb weight resulted by the old seedling age could be attributed to its less susceptibility to transplanting shock. It was possible that old seedling age took less time to recover from the transplanting shock in order to get established in the field (Latif, 2006; Latif *et al*, 2010). The result is supported by observations of Singh and Chaure (1999), Vachhani and Patel (1988) and

Mohanty *et al*. (1990) who reported that increased fresh bulb weight was obtained at old seedling age as compared to treatments of the young ones. Similarly, Muhammad *et al*. (2017) stated that fresh bulb weight increased in 40 days old seedlings, which were larger in size at transplanting stage.

When the rate of phosphorus was increased from 0 to 46 and 92 kg P_2O_5 ha^{-1}, there were significant increments in fresh bulb weight. When the rate of fertilizer was increased from 92 kg P_2O_5 ha^{-1} to 138 kg P_2O_5 ha^{-1}, the fresh bulb weight did not change significantly. Thus, the heaviest bulbs were produced already at 92 kg P_2O_5 ha^{-1}. The mean bulb weight of onion plants grown at the rate of 92 kg P_2O_5 ha^{-1} exceeded the fresh bulb weight of onion plants grown at the rates of 46 and 0 kg P_2O_5 ha^{-1} by about 11 and 33%, respectively (Table 4). The significant increase in fresh bulb weight in response to the increased phosphorus level might be attributed to the role phosphorus played in improving the carbohydrate content of the plants and extending root growth, which increased the diameter and length of blubs and ultimately blub size (Jawar *et al*., 2016).

Results of the present study are in line with the findings of El-Rehim (2000) who reported that irrigated onion plants benefited from application of phosphorus as compared to unfertilized crops where average bulb weight was increased. This finding is also in accordance with that of Lemma and Shimeles (2003) who reported that at 92 kg P_2O_5 ha^{-1}, there was better vegetative growth and the average bulb weight was 49 g/bulb at Melkassa. Similar results were also reported by Shaheen *et al*. (2007) who obtained that the highest application of phosphorus (92 kg ha^{-1}) fertilizer had a significant effect on the productivity of onion plant, hence increased average bulb weight. Similarly, Aster, (2009), Aisha *et al*.

(2007), Vachhani and Patel (1993), Aliyu *et al*. (2007) and Singh *et al*. (2000) reported that application of phosphorus level positively increased fresh bulb weight**.**

Table 4: Main effects of seedling age and P fertilizer rates on fresh bulb weight, total biomass yield, bulb dry weight and unmarketable and under sized bulb yield of onion grown at Alage.

Treatment	**Fresh bulb weight (g)**	**Bulb dry weight(g)**	**Total biomass yield (t ha^{-1})**	**unmarketable bulb yield (t ha^{-1})**	**Under sized bulb yield (t ha^{-1})**
Seedling age					
6 WSA	81.28^{b}	21.91	47.32	1.88	2.16
7 WSA	79.19^{b}	23.34	48.69	2.08	1.83
8 WSA	86.27^{a}	24.13	52.64	2.03	1.71
LSD(0.05)	**3.62**	**NS**	**NS**	**NS**	**NS**
P_2O_5 (kg ha^{-1})					
0	66.84^{c}	21.32^{c}	43.69^{b}	2.66^{a}	2.52^{a}
46	80.42^{b}	21.76^{bc}	49.05^{ab}	2.08^{ab}	1.7^{b}
92	88.89^{a}	24.2^{ab}	52.61^{a}	1.80^{bc}	1.67^{b}
138	92.83^{a}	25.22^{a}	52.86^{a}	1.45^{c}	1.35^{b}
LSD(0.05)	**4.18**	**2.45**	**7.21**	**0.57**	**0.54**
CV (%)	**6.13**	**12.77**	**17.51**	**34.75**	**33.99**

Means followed by the same letters within a column are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age.

4.3.4. Bulb dry weight

Phosphorus fertilizer application rate significantly ($P < 0.01$) influenced bulb dry weight. However, neither the main effect of seedling age nor its interaction with phosphorus influenced this parameter (Appendix 3).

The result indicated that, effect of different rates of phosphorus application on the dry bulb weight increased with the increase in phosphorus level. The highest bulb dry weight (25.22 g) was obtained from 138 kg P_2O_5 ha^{-1}, whereas the lowest bulb dry weight (21.32 g) was obtained under the control plots. Increasing the rate of phosphorus from nil to 92 kg P_2O_5 ha^{-1} significantly increased the dry bulb weight of onion. And also the mean bulb dry weight showed significant difference as further increase in phosphorus rate from 92 to 138 kg ha^{-1}(Table 4).

Results of the present study are in line with the findings Brady and Weil (2002) who reported that P is required in large quantities in young cells, such as root tips, where metabolism is high and cell division and development of bulb is rapid. The current finding is also in agreement with Zelalem *et al*. (2009) who reported that higher level of P fertilization significantly influenced root dry weight of potato. In line with the present finding Dixit and Sharma (2004) reported that the highest bulb dry weight was obtained from 110 kg P_2O_5 ha^{-1}. On the other hand, Abdissa (2008) found that phosphorus has shown no significant effect on bulb dry weight and average bulb weight; the absence of P response might be due to sufficient amount of available P which was found in the soil of the experimental site.

4.3.5. Total biomass yield

The analysis of variance revealed that the main effect of phosphorus fertilizer application significantly ($P<0.05$) influenced the total biomass yield of onion, compared to the control treatment. On the other hand, neither the main effect of seedling age nor its interaction with phosphorus influenced the total biomass yield of the crop (Appendix 4).

Increasing the rate of phosphorus from 0 to 46 kg P_2O_5 ha^{-1} significantly increased the total biomass yield (Table 4). However, further application beyond 46 kg P_2O_5 ha^{-1} did not increase the biomass yield. The total biomass yield of onion plants grown at a rate of 46 kg P_2O_5 ha^{-1} exceeded the total biomass yield of onion plants grown at rates of 0 kg P_2O_5 ha^{-1} by about 12%. The highest total biomass yield of 52.86 t ha^{-1} was obtained from the highest P rate (138 kg ha^{-1}) though not significantly different from those obtained at 46 and 92 kg P_2O_5 ha^{-1}, whereas the lowest total biomass yield (43.69 t ha^{-1}) was obtained under the control treatment.

This result is in line with that of Shaheen *et al*. (2007) who reported that application of phosphorus had a major effect on the productivity of onion plant, hence increased total biomass yield. This result is in disagreement with that of Abdissa (2008) who reported that phosphorus has shown non-significant effect on total dry biomass yield of onion; thus, absence of response to P might be due to sufficient amount of available P which was found in the soil of the experimental site.

4.3.6. Unmarketable bulb yield

The analysis of variance indicated that phosphorus application rate had significant ($P<0.01$) effect on unmarketable bulb yield of onion. However, neither the main effect of seedling age nor its interaction with phosphorus affected unmarketable bulb yield (Appendix 4).

The result of the study indicated that increasing the rates of application of phosphorus decreased the unmarketable bulb yield per hectare. Among all P rates the highest unmarketable bulb yield (2.66 t ha^{-1}) was recorded in the unfertilized plots, whereas the lowest (1.45 t ha^{-1}) was recorded at 138 kg ha^{-1} phosphorus rate though this was statistically at par with 92 kg ha^{-1}(Table 4). High unmarketable yield observed in low rates of phosphorus application have been associated with early bulb formation, severe stunting, and fewer large sized bulbs than those under high phosphorus rates. This result is contrary with that of Tibebu *et al*. (2014) who stated that phosphorus had no significant effect on unmarketable yield of onion and this might be due to adequate amount of available P which was found in the soil of the experimental site.

4.3.7. Total bulb yield

The main effect of seedling age as well as that of phosphorus significantly ($P < 0.001$) influenced the total bulb yield of onion. Additionally, the interaction effect of seedling age and phosphorus application rate significantly ($P < 0.05$) influenced the total bulb yield of the onion (Appendix 4).

At 6 weeks of seedling age, total bulb yield was significantly improved at 92 kg ha^{-1} (45.24 t ha^{-1}) P rate, further increasing phosphorus up to 138 kg ha^{-1} showed a decline in the total bulb yield by 29%, however, no significant difference was showed among the two phosphorus rates except those unfertilized plots and 92 kg P_2O_5 ha^{-1}, which were at par. Under 7 weeks of seedling age, the highest and lowest total bulb yields were recorded at 92 kg ha^{-1} phosphorus and control treatments, respectively. However, no significant difference was recorded among 46 and 138 kg P_2O_5 ha^{-1} treatments. In the 8 weeks of seedling age, P application rate at 92 kg ha^{-1} and 138 kg ha^{-1} improved total bulb yield by about 36 and 42%, respectively compared to that of untreated treatment. However, the two phosphorus rate (92 and 138 kg ha^{-1}) had no significant difference at the same seedling age of 8 weeks (Table 5). Generally, increased application rate of phosphorus produced higher total bulb yields with optimum seedling age (8 weeks seedling age). The high total bulb yield produced due to phosphorus application and old seedling age might be because of increase in photosynthetic area of the plant (plant height and number of leaves) which in turn increased the amount of assimilate that could be partitioned to the storage organs (increased bulb diameter and average bulb weight). This may lead to improved carbohydrate content of the plants and extended root growth, which consequently increased the total bulb yield. The total bulb yield was significantly and positively correlated with average bulb weight ($r = 0.68^{**}$), vegetative growth such as plant height ($r = 0.66^{**}$), leaf number ($r = 0.44^{**}$) and leaf length ($r = 0.58^{**}$) (Appendix 6). In harmony to this result, Verma *et al*. (1971) reported that transplanted onion at 8 weeks old gave the highest yield of bulb. Corresponding to this result, Maurya *et al*. (1997) found that 60 days old seedlings gave the highest bulb yield of onion (28.22 t ha^{-1}) followed by those planted at 50 days (23.89 t ha^{-1}).

Table 5: Interaction effects of seedling age and phosphorus rates on total bulb yield (t ha^{-1}) of onion grown at Alage.

Seedling age	P_2O_5 (kg ha^{-1})				
	0	46	92	138	**Mean**
6 WSA	24.27^{f}	35.48^{de}	45.24^{ab}	35.01^{de}	**35**
7 WSA	31.83^{e}	39.11^{cd}	43.43^{bc}	39.52^{cd}	**38.47**
8 WSA	35.47^{de}	39.54^{cd}	48.49^{a}	50.6^{a}	**43.53**
Mean	**30.52**	**38.04**	**45.72**	**41.71**	
LSD(0.05)	**4.43**				
CV (%)	**9.66**				

Means followed by the same letters within a column or row are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age.

4.3.8. Under size bulb yield (< 20 g)

Results from the analysis of variance revealed that the phosphorus fertilizer rate was found to be significant ($P < 0.01$) on under sized bulb yield. However, the seedling age and its interaction effect with phosphorus did not significantly affect under sized bulb yield of onion (Appendix 5).

The maximum under sized bulb yield was recorded when onion plants received no P fertilizer. Conversely, the minimum under-sized bulb yield was recorded at the rates of 46, 92 and 138 kg P_2O_5 ha^{-1} (Table 4). Phosphorus application decreased under sized bulb yield though effects were similar among the three rates. The increase in the yield of the under-sized bulbs under unfertilized plots might be related with lack of P, which may have reduced vegetative growth like leaf number and length and bulb size by decreasing synthesis and partitioning of photosynthetic to the bulbs (Ghaffor *et al*., 2003). Phosphorus is important for root development and when unavailable plant growth is usually reduced. Its deficiency in onions reduces root and growth of leaf, size of bulb, yield and delay maturation (Abdissa *et al*., 2011)

4.3.9. Harvest index

The analysis of variance showed that means of harvest index was significantly ($P < 0.05$) affected by the interaction effect of seedling age and phosphorus rate. Moreover, harvest index was significantly influenced by the main effects of seedling age ($P < 0.01$) and phosphorus application ($P < 0.001$) (Appendix 3).

Generally, increased rate of phosphorus produced higher harvest index with increased age of seedling (Table 6). The highest harvest index (91.75 %) was recorded under the 8 weeks of seedling age combined with application of 138 kg P_2O_5 ha^{-1}, while the lowest value (77.55 %) was obtained from transplanting of 6 weeks of seedling age with the control treatment. At 6 week seedling age, harvest index was significantly improved up at 92 kg ha^{-1} (90.07%) P rate, further increasing of phosphorus up to 138 kg ha^{-1} showed a decline in the harvest index. However, statically no significant difference was showed among the two phosphorus rate except those untreated plots and 46 kg ha^{-1} which were at par. Under 7 week seedling age, the highest and lowest harvest indices were recorded at 46 kg ha^{-1} phosphorus and control plots, respectively. However, no significant difference was recorded among 46, 92 and 138 kg P_2O_5 ha^{-1} P rates. In the 8 weeks of seedling age no significant difference was recorded among 0, 46, 92 and 138 kg P_2O_5 ha^{-1} treatments. Over all, differences among the three seedling age levels become progressively narrower with increasing rates of P application. The high harvest index produced due to P application and higher seedling age might be because of increased photosynthetic area of the plant (height of plants and number of leaves) which increased the amount of assimilate that could be partitioned to the storage organs (increased bulb length and average bulb weight) which consequently increased the harvest index.

Table 6: Interaction effects of seedling age and phosphorus rates on harvest index (%) of onion grown at Alage.

Seedling age	**P_2O_5 (kg ha^{-1})**				
	0	46	92	138	**Mean**
6 WSA	77.55^{c}	87.67^{ab}	90.07^{a}	89.7^{a}	**86.25**
7 WSA	83.83^{b}	91.03^{a}	90.1^{a}	91^{a}	**88.99**
8 WSA	89^{a}	90.2^{a}	89.15^{a}	91.75^{a}	**90.03**
Mean	**83.46**	**89.63**	**89.77**	**90.82**	
LSD(0.05)	**3.00**				
CV (%)	**3.5**				

Means followed by the same letters within a column or row are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age.

4.4. Quality Parameters

4.4.1. Bulb dry matter fraction

The main effect of seedling age ($P < 0.05$) and phosphorus ($P < 0.001$) had significantly affected on mean bulb dry matter fraction of onion plants, however, the interaction effect did not show significant differences ($P > 0.05$) (Appendix 3).

This study indicated that, significant differences were observed among the seedling age levels, in such a way that the 8 weeks of seedling age gave the highest (12.36 %) onion bulb dry matter fraction, while the lowest bulb dry matter fraction (10.98 %) was obtained under 6 weeks of seedling age. However, no statically significant difference was observed between 7 and 8 weeks of seedling age (Table 7). The dry matter fraction for different age of seedlings varied possibly due to variation of growth patterns and photosynthesis at growing phases. The results of the present study are in agreement with Latif (2006), Latif *et al*. (2010), Sultana (2015) and Bhonde *et al.* (2001) who reported that dry matter content of onion bulb was significantly influenced by the age of seedling. This might be due to the fact that the optimum age of seedlings planted had better growth, which resulted in higher production of dry matter content of bulb (Sultana, 2015). This result is also consistent with the findings of Muhammad *et al*. (2016) who reported that the seedling transplanted at 60 days have high dry matter percentage as compared to the seedling transplant in early stage and it might be attributed to the fact that as the bulb size decreased quantity of water content also decreased resulting in high percentage of dry matter.

Increasing the rate of phosphorus from nil to 46 kg P_2O_5 ha^{-1} not significantly increased the bulb dry matter fraction of onion. But, increasing the rate of phosphorus further from 46 to 92 kg ha^{-1} increased the dry matter fraction of onion plants. And also the mean dry matter fraction of plants did not show significant difference as further increase in phosphorus rate from 92 to 138 kg ha^{-1}. Thus, the mean dry matter fraction of onion treated with phosphorus at the rate of 92 kg ha^{-1} exceeded the bulb dry matter of onion plants treated with nil and 46 kg P_2O_5 ha^{-1} by about 15 and 13%, respectively.

Similar observations were reported by Woldetsadik (2003) who stated that on a clay soil in a sub-humid tropical environment of Ethiopia in shallot (*Allium ascalonicum*) crop, increased application of P slightly increased bulb dry matter content of onion. Similarly, Tibebu *et al*. (2014) reported that the rate of P application increased dry matter content of onion.

4.4.2. Neck thickness

Seedling age and P fertilization and their interaction did not significantly ($p > 0.05$) affect the formation of neck thickness of onion (Appendix 2 and Table 7). This could be due to the minimal direct effect of fertilization in the formation of thick-necked bulbs. Similar results were also recorded by Abdissa (2008), Abdissa *et al.* (2011) and Birhanu (2016). Brewester (1987) reported that neck-thickness is a physiological event that is influenced by seasons, sites and cultivars, not by fertility.

Table 7: Main effects of seedling age and P fertilizer rates on bulb dry matter fraction (%) and neck thickness (cm) of onion grown at Alage.

Treatments	Bulb dry matter fraction (%)	Neck thickness(cm)
Seedling age		
6 WSA	10.98^{b}	1.03
7 WSA	11.89^{a}	1.03
8 WSA	12.36^{a}	1.02
LSD(0.05)	**0.9**	**NS**
P_2O_5 (Kg ha^{-1})		
0	10.68^{b}	0.97
46	10.91^{b}	1.03
92	12.33^{a}	1.02
138	13.05^{a}	1.08
LSD(0.05)	**1.04**	**NS**
CV (%)	**10.64**	**10.55**

Means followed by the same letters within a column are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age.

4.4.3. Marketable bulb yield

Marketable bulb yield of onion was significantly affected ($P < 0.001$) by the seedling age and phosphorus rate. Similarly, significant interaction effect of seedling age and phosphorus was observed on the marketable bulb yield of onion ($P<0.05$) (Appendix 4).

Under 6 weeks of seedling age, marketable bulb yield increased by about 100% at 92 kg ha^{-1} phosphorus compared to lowest yield (21.63 t ha^{-1}) recorded from untreated plots (Table 8). Further increase of phosphorus to 138 kg ha^{-1} did not significantly show variation, rather it showed a drop by about 30% and leveled off with yields from control plots and those fertilized at 46 kg ha^{-1} phosphorus. At 7 weeks of seedling age, the highest marketable bulb yield (40.79 t ha^{-1}) was produced at 92 kg ha^{-1} P rate while the lowest marketable bulb yield (28.09 t ha^{-1}) was obtained from control treatments. Significant differences were recorded among yields at 46, 92 and 138 kg ha^{-1} P rate under the 7 weeks age. At 8 weeks of seedling age, the control plot had notably reduced yield of marketable bulb (32.08 t ha^{-1}) as compared to the three phosphorus rates. The highest marketable bulb yield (48.33 t ha^{-1}) was recorded at 8 weeks of seedling age combined with 138 kg ha^{-1} phosphorus rate; though statically at par to that obtained from 92 kg P_2O_5 ha^{-1} under similar seedling age (Table 8).

From the present result it can be deduced that old seedling age and higher phosphorus rate help to increase the vegetative growth of the plant which has improved assimilate availability for storage and led to an increased average bulb weight that gave an advantage to increase the marketable bulb yield. The value in Appendix 6 indicated positive and highly significant correlation of marketable bulb yield with plant height (r=0.66**), leaf number per plant (r=0.44**), leaf length (r=0.58**), average bulb weight (r=0.68**), bulb diameter (r=0.42**) and bulb length (r=0.46**). In harmony to this result, Hyder *et al*. (2007) also showed that plant height has positive indirect effect on marketable bulb yield and bulb sizes. This might be due to the fact that the phosphorus improved the carbohydrate content of the plants and it extended root growth, which ultimately increased the number of blub and blub size (Turkoglu, 2008).

Table 8: Interaction effects of seedling age and phosphorus rates on marketable bulb yield (t ha^{-1}) of onion grown at Alage.

Seedling age	**P_2O_5 (kg ha^{-1})**				
	0	46	92	138	**Mean**
6 WSA	21.63^{g}	33.25^{def}	43.22^{ab}	33.17^{def}	**32.82**
7 WSA	28.09^{f}	36.07^{cde}	40.79^{bc}	37.51^{cd}	**35.62**
8 WSA	32.08^{ef}	36.78^{cde}	45.84^{a}	48.33^{a}	**40.76**
Mean	**27.27**	**35.37**	**43.28**	**39.67**	
LSD(0.05)	**4.43**				
CV (%)	**10.26**				

Means followed by the same letters within a column or row are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age.

4.4.4. Bulb size distribution of marketable bulb yield

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

The analysis of variance of small bulb size distribution of onion showed that the main effect of phosphorus fertilizer application had a significant influence ($P < 0.001$). However, neither the main effect of seedling age nor its interaction with phosphorus influenced this parameter of onion (Appendix 5).

Increasing the phosphorus application rate significantly decreased the production of small sized bulb yield as presented in Table 9. Thus, the highest small sized bulb yield was obtained from onion plants grown at the rate of 0 kg P_2O_5 ha^{-1} (5.93 t ha^{-1}). In contrast, the lowest small sized bulb yield of onion was recorded in response to the application of higher phosphorus rate at 138 kg ha^{-1} and 92 kg ha^{-1}. For instance, the small sized bulb yield obtained in response to the application of 0 kg P_2O_5 ha^{-1} exceeded small sized bulb yield of plants grown with 138 kg ha^{-1} application by 96% (Table 9). The increment in small size bulb yield of onion in response to the application of nil phosphorus rates may have resulted in reduction in below ground bulb size like bulb weight, bulb length and diameter due to less availability of nutrients.

4.4.4.2. Medium-sized bulb yield (50-100g)

Seedling age and phosphorus fertilizer rate exhibited highly significant ($P < 0.001$) variation on medium bulb size yield of onion. However, it was not significantly affected by the interaction effect of those treatments (Appendix 5).

This study indicated that, significant differences were observed among the seedling age treatments in such a way that the 8 weeks of seedling age gave the highest (23.16 t ha^{-1}) medium sized bulb yield; while the lowest medium sized bulb yield (18.15 t ha^{-1}) was obtained under 6 weeks of seedling age (Table 9). The size from 7 and 8 weeks age were not statistically different. The results are similar to the finding of Deepika (2013) who reported that yield of medium bulbs increased at optimum transplanting seedling age.

The production of medium sized bulb yield of onion was significantly increased by increasing the phosphorus application rate though the upper two rates were statistically at par. Hence, higher medium sized bulb yields were achieved from onion plants grown with the application of 138 kg P_2O_5 ha^{-1} (26.12 t ha^{-1}) and 92 kg P_2O_5 ha^{-1} (25.07 t ha^{-1}). On the other hand, zero application of phosphorus produced the lowest medium sized bulb yield (11.22 t ha^{-1}) (Table 9). This result is in agreement to the findings of Brewster (1994) who reported that increased phosphorus levels used to improve bulb size and increased the number of marketable bulbs in onion.

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

The analysis of variance showed that the main effect of seedling age ($P < 0.05$) and phosphorus rate ($P < 0.001$) were significantly affected large sized bulb yield of onion. However, the interaction effect of those treatments not significantly affected (Appendix 5).

The results indicated that significant effect of different seedling age on large sized bulb yield was observed. The maximum large sized bulb yield was observed under 8 weeks of seedling age (17.49 t ha^{-1}), while the minimum large sized bulb yield was recorded under seedling age of 6 weeks (14.45 t ha^{-1}) (Table 9). The greater bulb yield of large size achieved from older seedlings might be attributed to better plant growth in taller and leafier plants and superior bulb dimension achieved by plants vigour from older seedlings compared to their younger counterparts. Similarly, Herison *et al.* (1993) reported that increase in seedlings age (56 days old) resulted in larger sized bulb yields (USA). In the contrary, Kanton *et al*. (2002) and Faruq *et al*. (2003) observed that the plants developed from younger seedlings seemed to be more efficient in conversion photosynthates into larger bulbs as indicated by higher bulb yields, which may be due to influence of prevailing climatic conditions of that region.

Similar to medium sized bulb yield, large sized bulb yield increased significantly in response to the increased application of phosphorus rate (Table 9). The maximum large sized bulb yield (23.74 t ha^{-1}) was obtained in response to the application of 138 kg P_2O_5 ha^{-1}, but no significant different was observed with application rate of 92 kg P_2O_5 ha^{-1}. On the other hand, the minimum value (5.08 t ha^{-1}) was achieved from the nil phosphorus rates.

Table 9: Main effects of seedling age and P fertilizer rates on marketable bulb size distribution of onion

Treatments	small sized bulb yield (t ha^{-1})	medium sized bulb yield (t ha^{-1})	Large- sized bulb yield (t ha^{-1})
Seedling age			
6 WSA	4.17	18.15^{b}	14.45^{b}
7 WSA	4.39	21.51^{a}	16.86^{ab}
8 WSA	3.72	23.16^{a}	17.49^{a}
LSD(0.05)	**NS**	**2.30**	**2.54**
P_2O_5 (kg ha^{-1})			
0	5.93^{a}	11.22^{c}	5.08^{c}
46	4.26^{b}	21.37^{b}	12.80^{b}
92	3.16^{c}	25.07^{a}	23.44^{a}
138	3.03^{c}	26.12^{a}	23.74^{a}
LSD(0.05)	**0.76**	**2.67**	**2.94**
CV (%)	**22.35**	**15.28**	**21.75**

Means followed by the same letters within a column are not significantly different at ($P < 0.05$); LSD = least significance difference; CV (%) = coefficient of variation and WSA = weeks of seedling age.

4.5. Partial Budget Analysis

From the result of this finding, the average marketable yield of the 12 treatments was obtained. According to CIMMYT (1988), the average marketable yield was adjusted down wards by 20%. This is for the reason that, researchers have assumed that using the same treatments the yields from the experimental plots and farmers' fields vary, thus average marketable yields should be adjusted downward. The purchasing price of phosphorus (TSP) fertilizer was 10.95 Birr kg^{-1} and six laborers were used for fertilizer application. The field price of onion during the harvesting season was 4 Birr kg^{-1} and the cost for daily labors during the season was 50 Birr per day. All the total variable costs were summed up and subtracted from gross benefits which were taken as a net benefit.

The partial budget analysis revealed that the highest net benefit of Birr 152829 was recorded from the combination of 138 kg P_2O_5 ha^{-1} and 8 weeks of seedling age with marginal rate of 1481%. This was followed by net benefit of Birr 145372.3 from the phosphorus rate of 92 kg P_2O_5 ha^{-1} and 8 weeks of seedling age with the marginal rate of return of 5657%. This means that for every Birr 1.00 invested in 92 kg P_2O_5 ha^{-1} and 8 weeks of seedling age, producers can expect to recover the Birr 1.00 and obtain an additional 56.57 Birr. Whereas, the lowest net benefit (Birr 69200 ha^{-1}) was recorded from control treatments (0 kg P_2O_5 ha^{-1}) combined with 6 weeks of seedling age (Table 10). The minimum acceptable marginal rate of return (MRR %) should be between 50% and 100% (CIMMYT (1988)). Thus, the current study indicated that marginal rate of return is higher than 100% (Table 11). Hence, the most economically attractive yield of the onion crop in the study area was that the combinations of 92 kg P_2O_5 ha^{-1} application and 8 weeks of seedling age with low cost of production and higher benefits.

The yield from the combination of 138 kg P_2O_5 ha^{-1} with 8 week old seedlings still meets the 100% marginal rate of return threshold value. However, this treatment will not be a viable option because the yield from this combination was statistically at par with that obtained from 92 kg P_2O_5 ha^{-1} and 8 weeks old age.

Table 10: Partial budget analysis for phosphorus rate and seedling age experiments of onion at Alage.

Treatments		**Average yield ($t\ ha^{-1}$)**	**Adjusted yield ($t\ ha^{-1}$)**	**Gross benefit (Birr ha^{-1})**	**Total cost that vary(Birr ha^{-1})**	**Net benefit (Birr ha^{-1})**
Seedling age	**P rate (kg ha^{-1})**					
6	46	33.25	26.6	106400	803.7	105596.3 D
7	46	36.07	28.86	115440	803.7	114636.3 D
8	46	36.78	29.42	117680	803.7	116876.3
6	92	43.22	34.58	138320	1307.4	137012.3 D
7	92	40.79	32.63	130520	1307.4	129212.3 D
8	92	45.84	36.67	146680	1307.4	145372.6
6	138	33.17	26.54	106160	1811	104349 D
7	138	37.51	30	120000	1811	118189 D
8	138	48.33	38.66	154640	1811	152829
6	0	21.63	17.3	69200		69200 D
7	0	28.09	22.47	89880		89880 D
8	0	32.08	25.66	102640		102640 D

Table 11: Marginal analysis, seedling age and phosphorus rates experiment in Alage.

Treatments		Total cost that vary (Birr ha^{-1})	Marginal cost (Birr ha^{-1})	Net benefit (Birr ha^{-1})	Marginal net benefit (Birr ha^{-1})	Marginal rate of return (%)
Seedling age	P rate (kg ha^{-1})					
8	46	803.7	-	116876.3	-	-
8	92	1307.4	503.7	145372.6	28496	5657
8	138	1811	503.6	152829	7456.4	1481

5. SUMMARY AND CONCLUSIONS

Onion (*Allium cepa* L.) is a relatively recently introduced vegetable crop and it is rapidly becoming popular among producers and consumers in Ethiopia. It also a widely recognized cash crop, successfully produced under rain fed as well as irrigated conditions. The area under onion production in the country is increasing from time to time. Despite area increases, the productivity of the crop is much lower due to different problems. However, lack of information and adoption of appropriate fertilizer rates and transplanting time are among the major problems that cause low productivity of onion. Therefore, it was necessary to determine optimum transplanting age and phosphorus fertilizer rate as there are practices of both over and under irrigation and application of fertilizers to Bombay Red onion variety grown in the study area.

The experiment was carried out at Alage Agricultural Technical and Vocational Education and Training College (Alage), Central Refit Valley of Ethiopia during 2016/17 season. It comprised three seedling ages (6, 7 and 8 weeks of seedling age) and four varying rates of phosphorus (0, 46, 92 and 138 kg P_2O_5 ha^{-1}), arranged in randomized complete block design (RCBD) with four replications. Bombay Red onion variety was transplanted on double rows with spacing of 40 cm x 20 cm x 10 cm. Twelve sample plants were randomly taken from each plot for determination of growth and bulb characters. Maturity and yield data were taken on net plot basis.

The analysis of variance showed that plant height, leaf length, days to maturity, bulb length, fresh bulb weight, bulb dry matter fraction, medium bulb size and large sized bulb yield were significantly influenced by the main effect of seedling age and phosphorus fertilizer rates. However, leaf number per plant, bulb diameter, bulb dry weight, total biomass yield, unmarketable bulb yield, small size bulb and under sized bulb yield were significantly affected only by the main effects of different varying rates of phosphorus fertilizer. Seedling age and P fertilizer rate as well as their interaction did not significantly affect the formation of neck thickness of onion. From this study, significantly taller plant height, leaf number per plant, leaf length and early bulb maturity was obtained at the seedling age of 8 weeks and 92 kg ha^{-1}phosphorus rate. However, bulb length, fresh bulb weight, total biomass yield, bulb dry weight and bulb dry matter fraction were recorded in the treatments of 8 weeks of seedling age and 138 kg ha^{-1} phosphorus rate. However, the result of this study showed that at 92 and 138 kg P_2O_5 ha^{-1} rate there was no significant variation in each parameter.

The seedling age, phosphorus rate and interaction effect had significant effects on the harvest index, marketable bulb yield and total bulb yield. The lowest harvest index (77.55 %), marketable bulb yield (21.63 t ha^{-1}) and total bulb yield (24.27 t ha^{-1}) were recorded at treatment combination of 6 weeks of seedling age with 0 kg ha^{-1} P rates. On the other hand, the highest harvest index (91.75%), marketable bulb yield (48.33 t ha^{-1}) and total bulb yield (50.6 t ha^{-1}) were produced at treatment combination of 8 weeks of seedling age with 138 kg ha^{-1} P rate, but no significant difference was observed in these parameters at 92 kg P_2O_5 ha^{-1} combinations with same seedling age. However, the combination of 8 weeks of seedling age fertilized with 92 kg ha^{-1} P rate also gave statistically comparable yield to the highest value. Moreover, when P rates increased from 0 to 46, 92 and 138 kg ha^{-1}, unmarketable bulb yield was decreased by about 28, 48 and 83%, respectively.

Cost benefit analysis indicated that the highest net benefit (Birr 152829 ha^{-1}) with highest cost (1811 Birr) was recorded from the combination of response to phosphorus rate of 138 kg ha^{-1} and at 8 weeks of seedling age with marginal rate of return (1481%). However, the highest net benefit of Birr 145372.3 with least cost of production about Birr 1307.7 were obtained from the treatment interaction of 92 kg P_2O_5 ha^{-1} and 8 weeks of seedling age with MRR of 5657%. The lowest net benefit was obtained from the combination of control plots with 6 weeks of seedling age.

Therefore, from the present study it can be concluded that, the most economically attractive yield of the onion crop in the study area was obtained by the combinations of 92 kg P_2O_5 ha^{-1} applications and 8 weeks of seedling age with low cost of production and higher benefits. However, as the experiment was done for only one season and single location, it has to be repeated over seasons and locations to make a conclusive recommendation.

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7. APPENDICES

Appendix 1: Mean square values from analysis of variance for the effect of seedling age and phosphorus fertilizers on plant height (cm), number of leaves per plant, leaf length (cm) and days to maturity of onion grown at Alage.

Source of Variation	Degree of freedom	Mean square values			
		Plant height	Leaf number	Leaf length	Days to maturity
Replication	3	12.92	1.70	2.12	3.57
SA	2	65.21**	1.39ns	51.74**	113.77***
P	3	109.23***	12.85***	111.04***	33.41***
SA*P	6	6.89 ns	1.03 ns	8.74ns	4.41ns
Error	33	8.05	1.36	7.11	2.197
CV (%)		4.95	9.86	5.82	1.49

* =Significant at (P<0.05), **= highly significant (P< 0.01), ***= (P<0.001) and ns =non-significant (P >0.05), SA= seedling age, P= phosphorus rate and CV (%) = coefficient of variation.

Appendix 2: Mean square of analysis of variance for the effect of seedling age and P on bulb length (cm), bulb diameter (cm) and neck thickness (cm) of onion grown at Alage.

Source of Variation	Degree of freedom	Mean square values		
		Bulb diameter	Bulb length	Neck thickness
Replication	3	0.31	0.33	0.013
SA	2	0.13ns	1.29*	0.0001ns
P	3	0.61**	3.43***	0.027ns
SA*P	6	0.12ns	0.4ns	0.009ns
Error	33	0.14	0.31	0.01
CV (%)		6.78	11.91	10.55

* =Significant at (P<0.05), **= highly significant (P< 0.01), ***= (P<0.001) and ns =non-significant (P >0.05), SA= seedling age, P= phosphorus rate and CV (%) = coefficient of variation.

Appendix 3: Mean square of analysis of variance for the effect of seedling age and P fertilizer rates on fresh bulb weight (g), bulb dry weight (g), bulb dry matter fraction (%), harvest index (%) of onion grown at Alage.

Source of Variation	Degree of freedom	Mean square value			
		Fresh bulb weight	Bulb dry weight	Bulb dry matter fraction	Harvest index
Replication	3	123.23	3.75	0.32	1.67
SA	2	211.61**	20.27 ns	7.95*	60.2**
P	3	1588.53***	42.55**	15.47***	135.16***
SA*P	6	49.17ns	2.37 ns	0.35 ns	29.54*
Error	33	25.38	8.72	1.56	9.56
CV (%)		6.13	12.77	10.64	3.5

* =Significant at (P<0.05), **= highly significant (P< 0.01), ***= (P<0.001) and ns =non-significant (P >0.05), SA= seedling age, P= phosphorus rate and CV (%) = coefficient of variation.

Appendix 4: Mean square values of analysis of variance for the effect of seedling age and P fertilizer rates on total biomass yield (t ha^{-1}), total bulb yield (t ha^{-1}), marketable bulb yield (t ha^{-1}) and unmarketable bulb yield (t ha^{-1}) of onion grown at Alage.

Source of Variation	Degree of freedom	Mean square values			
		Total biomass yield	Marketable bulb yield	Unmarketable bulb yield	Total bulb yield
Replication	3	457.76	74.64	1.13	71.99
SA	2	219.58 ns	259.39***	0.18ns	293.91***
P	3	122.41*	569.86***	3.13**	501.04***
SA*P	6	54.95ns	44.96*	0.07ns	46.74*
Error	33	75.27	13.92	0.48	14.21
CV (%)		17.51	10.26	34.75	9.66

* =Significant at (P<0.05), **= highly significant (P< 0.01), *** (P<0.001) and ns =non-significant (P >0.05). SA= seedling age, P= phosphorus rate and CV (%) = coefficient of variation.

Appendix 5: Mean square values of analysis of variance for the effect of seedling age and phosphorus fertilizer rates on marketable bulb size distribution of onion grown at Alage.

Source of Variation	Degree of freedom	Mean square values			
		Small bulb size	Medium bulb size	Large bulb size	Under sized bulb yield
Replication	3	2.68	5.47	6.33	1.16
SA	2	1.88ns	104.14***	41.20*	0.85ns
P	3	21.66***	553.91***	977.5***	5.46**
SA*P	6	0.45ns	3.23ns	3.32ns	0.31ns
Error	33	0.84	10.24	12.52	0.42
CV (%)		22.35	15.28	21.75	33.99

* =Significant at (P<0.05), **= highly significant (P< 0.01), ***= (P<0.001) and ns =non-significant (P >0.05), SA= seedling age, P= phosphorus rate and CV (%) = coefficient of variation.

Appendix 6: Simple correlation coefficients of growth parameters, bulb character and yield of onion at Alage under seedling age and phosphorus rate.

Variables	PH	LL	LN	DTM	TBiY	TBY	MBY	UNBY	BDMF	HI	BDW	FBW
PH	1											
LL	0.73**	1										
LN	0.37*	0.49**	1									
DM	-0.63**	-0.58**	-0.2ns	1								
TBiY	0.34*	0.36*	0.44**	-0.17ns	1							
TBY	0.66**	0.58**	0.44**	-0.57**	0.48**	1						
MBY	0.66**	0.59**	0.48**	-0.55**	0.48**	0.99**	1					
UNBY	0.10ns	-0.17ns	-0.25ns	-0.04ns	-0.11ns	-0.07ns	-0.18ns	1				
BDMF	0.58**	0.49**	0.40**	-0.62**	0.2ns	0.54**	0.53**	-0.01ns	1			
HI	0.49**	0.46**	0.36*	-0.64**	0.23ns	0.56**	0.58**	-0.19ns	0.4**	1		
BDW	0.46**	0.39**	0.42**	-0.54**	0.21ns	0.47**	0.46**	0.08ns	0.93**	0.39**	1	
FBW	0.66**	0.61**	0.60**	-0.49**	0.47**	0.68**	0.72**	-0.38**	0.56**	0.59**	0.50**	1
BD	0.33*	0.34*	0.36*	-0.07ns	0.35*	0.42**	0.46**	-0.38**	0.39**	0.05ns	0.28ns	0.51**
BL	0.44**	0.36*	0.33*	-0.60**	0.18ns	0.43ns	0.46**	-0.37**	0.53**	0.63**	0.53**	0.62**
NT	0.05ns	0.00ns	0.13ns	-0.18ns	0.15ns	0.01ns	0.05ns	-0.34*	-0.04ns	0.36*	-0.05ns	0.22ns
SBS	-0.6**	-0.61**	-0.66**	0.48**	-0.4**	-0.63**	-0.67**	0.34*	-0.45**	0.57**	-0.37**	-0.76**
MBS	0.62**	0.68**	0.54**	-0.55**	0.4**	0.65**	0.67**	-0.23ns	0.5**	0.64**	0.41**	0.75**
LBS	0.65**	0.65**	0.51**	-0.51**	0.44**	0.68**	0.71**	-0.31*	0.51**	0.48**	0.41**	0.77**
UBS	-0.39**	-0.52**	-0.35*	0.37**	-0.14ns	-0.49**	0.27ns	-0.30*	-0.40**	-0.2ns	-0.43**	-0.27ns

*, ** and ns indicates that significant, highly significant and non-significant difference at probability levels of 5% and 1%, respectively and PH, LL, LN, DTM, TBiY, TBY, MBY, UNBY, BDMC, HI, BDW, FBW = Plant height, leaf length, leaf number per plant, days to maturity, total biomass yield, total bulb yield, marketable bulb yield, unmarketable bulb yield, bulb dry matter fraction, harvest index, bulb dry weight and fresh bulb weight, respectively.

Appendix 6: Simple correlations (CONTINUED)

Variables	BD	BL	NT	SBS	MBS	LBS	UBS
BD	1						
BL	0.18ns	1					
NT	-0.07ns	0.39**	1				
SBS	-0.38**	-0.54**	-0.18ns	1			
MBS	0.42**	0.44**	0.29*	-0.62**	1		
LBS	0.44**	0.52**	0.25ns	-0.71**	0.76**	1	
UBS	-0.27ns	-0.32*	-0.16ns	0.48**	-0.55**	-0.59**	1

BD, BL, NT, SBS, MBS, LBS, USB = bulb diameter, bulb length, neck thickness, Small bulb sized, Medium bulb sized, Large bulb sized, under sized bulb yield, respectively.

8. BIOGRAPHICAL SKETCH

The author was born on May 12, 1988 at Estie Woreda District in South Gondar Zone, Ethiopia. He attended elementary education (grade one to six) at Zegora Elementary School from 1997-2002, junior secondary education (grade seven to eight) at Mekane - Eysus School from 2003-2004, and secondary education at Mekane-Eysus Secondary School from 2005-2008. He joined Debre-Markos University in December, 2008 and graduated with B.Sc. degree in plant science in June, 2011. Immediately after graduation in 2011, he was employed by South Gondar, Estie Woreda Office of Agriculture and Rural Development as a field crop production expert, where he worked up until 30 September 2014. In October 2014, he was employed by Ministry of Agriculture as an instructor in Alage Agricultural Technical and Vocational Education and Training College. He continued working at Alage ATVETC up until he joined the School of Graduate Studies of Hawassa University in 2015 to pursue a study leading to the degree of Master of Science (MSc) in Agronomy.