EFFECT OF NITROGEN AND PHOSPHORUS RATES ON GROWTH, YIELD, YIELD COMPONENTS AND QUALITY OF POTATO (*Solanum tuberosum* L.) AT DEDO, SOUTH WEST ETHIOPIA

MSc. THESIS

BY

BIRTUKAN BELACHEW

JULY 2016

JIMMA, ETHIOPIA

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A Thesis Submitted to the School of Graduate Studies

Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Horticulture (Vegetable Science)

MSc. THESIS

BY

Birtukan Belachew

July 2016

Jimma, Ethiopia

DEDICATION

I dedicate this thesis work to my mother Itenesh Alemayehu and my child Natna'el Mekonen.

STATEMENT OF THE AUTHOR

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Date of Submission: July, 2016

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BIOGRAPHICAL SKETCH

The author was born on October 16, 1982 in Dedo District Jimma Zone of Oromia Regional State. She attended her primary school education at Dedo Junior School from 1988 to 1995. She then attended junior secondary school and high school at Jimma Senior Secondary School from 1996 to 1999. In 2000, she joined Agarfa ATVET College of agriculture and graduated on August 25, 2000 with certificate in General Agriculture.

After her graduation, she was employed by Jimma zone, Dedo District Bureau of Agriculture and Rural Development as an Extension Agent from 2000 to 2003. In 2003, she joined Holeta ATVET College of agriculture and graduated on August 24, 2005 with Diploma in **Plant science**. After her graduation, she was employed again by Jimma zone, Dedo District Bureau of Agriculture and Rural Development as an Extension Agent from 2005 to 2007. Then after, she joined Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) in 2008 in regular In-service program and attended her undergraduate study and graduated on June 6, 2009 with B.Sc. degree in **Horticulture**. After graduation she worked in Jimma Zone, Dedo District Bureau of Agriculture and Rural Development as Vegetable expert. In 2013/14 academic year, she joined the graduate studies program of the same college to pursue her MSc study in Horticulture (**Vegetable Science**).

ACKNOWLEDGEMENTS

First and above all, I would like to offer lots of thanks to my God, the savor, and Saint Virgin Mary for their compassionate help in all aspects of my life. This Research work would not have been possible without the generous help of the different people and organizations and I am extremely grateful to them for their time, support, advice and interactions.

I am highly indebted to my major advisor, Dr. Amsalu Nebiyu and co-advisor, Dr. Amare Hailesilassie for their constructive advice, guidance, support and their valuable comments from early stage of proposing the research work to the final thesis write up are unforgettable. I would like also to express my sincere gratitude to LIVES (led by ILRI/IWMI) project and Dedo District Bureau of Agriculture and Rural Development for faciliting leave of absence in all the study time.

My sincere acknowledgment is also extended to irrigation Bureau staff (Gossaye A/fita) for facilitating and providing me the experimental plot and for unreserved advice and technical support during my research work.

I want to express my gratitude and deepest appreciation to all my families for their consistent encouragement throughout the Thesis work and all rounded help. In addition, I would like to thank my friends, Mahbuba Shesuliman, Birkisa A/jobir and Nejib Mohammed for their concern, moral support and fruitful guidance during proposal preparation and research work. Last, but not least, I would like to acknowledge Jimma University College of Agriculture and Veterinary Medicine for all material support and educating me leading to my M.Sc. Degree.

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LIST OF ABBREVIATIONS AND ACRONYMS

AGRISNET	Agriculture Information System Network
ANOVA	Analysis Of Variance
BOARD	Bureau of Agriculture and Rural Development
CIP	International Potato Center
DAP	Di-Ammonium Phosphate
EIAR	Ethiopian Institute of Agriculture Research
FAO	Food and Agricultural Organization of United Nations
FAOSTAT	Food and Agricultural Organization of the United Nation Statistics
HARC	Holeta Agricultural Research Centre
IAR	Institute of agricultural Research
LSD	Least Significant Difference
MOA	Ministry of Agriculture
NSRC	National Soil Research Center
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
TSP	Triple Super Phosphate

ABSTRACT

EFFECT OF NITROGEN AND PHOSPHORUS FERTILIZER RATES ON GROWTH, YIELD, YIELD COMPONENTS AND QUALITY OF POTATO (*Solanum tuberosum* L.) AT DEDO, SOUTH WEST ETHIOPIA

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Co- advisor : Amare Hailessilasie (PhD)

Potato (Solanum tuberosum) is one of the most important tuber crops produced in Ethiopia. However, production and productivity of the crop is far below the world average due to poor crop, soil fertility and water management practices. An experiment was therefore conducted to study the effect of different Nitrogen (N) and Phosphorus (P) levels on growth, yield and quality of potato. Treatments consisted of four levels of N (0, 55, 110 and 165 kg N ha^{-1}) and four levels of P (0, 45, 90 and 135 kg P ha^{-1}) laid out in Randomized Complete Block Design (RCBD) in a 4x4 factorial arrangement with three replications. Data were collected on growth and yield parameters and analyzed using SAS 9.2 software. Results revealed that application of N and P fertilizer significantly ($P < 0.05$) influenced plant height, days to 50% flowering, main stem number, days to physiological maturity, total tuber number, marketable tuber number, total tuber yield, marketable tuber yield, average tuber weight and tuber dry matter percentage. Combined application of 0 N and 90P and 55N and 90P shorten the days to 50% flowering. Combined application of 165 kg N/0 kg P ha^{-1}and control treatment delayed the days to flowering. Increasing P application from 0 to 135 kg ha$^{-\ 1}$(the highest level P) significantly increased main stem number per hill (from 3.63 to 5.19). Increasing rate of P from 0 to 135 kg ha^{-1} increased the main stem number by 42.97%. The highest plant height (71.6cm) was measured at the combination of 165 kg N ha^{-1} and 135 kg P ha^{-1}, while the lowest plant height (44 cm) was recorded from the control. Increasing p application from 0 to 135 kg ha-^{1} shortens number of days to physiological maturity by 9 to10 days as compared to the control. The maximum total tuber number was recorded for the highest level of nitrogen and phosphorus (13.7/hill), and the minimum total tuber number (8.53/hill) was obtained from the control. The highest marketable tuber number (9.79) per hill was obtained for the combined application of 165 kg N^{1}and 135 kg P ha-^{1}while the lowest (5.03) was recorded for the control. Increasing level of nitrogen from 0 to 165 kg ha^{-1} increased average tuber weight by 50.56%. The highest total tuber yield was recorded for combined application of 165 kg N and 135kg P ha^{-1} (42.27 t ha-^{1}) and the lowest (12.91 t ha-^{1}) was obtained at the control plot. Combined application of 165 kg and 135 kg P ha^{-1} gave the highest marketable tuber yield (36.13 t ha^{-1}) and the lowest value (19.18 t ha-^{1}) was recorded for the control. The highest average tuber weight (78.97g) was observed for 165 kg N ha-^{1} while the lowest (52.45g) was obtained from the control. The highest dry matter (27.27%) percentage of potato tuber was recorded from plots that received the combination of N 110 kg ha-^{1} and P 90 kg ha-^{1}, while the lowest (22.17%) tuber dry matter percentage was obtained at the combination of highest (165 kg ha-^{1}) level of nitrogen and zero level of Phosphorus. In conclusion the results of this study showed that different nitrogen and phosphorus rates and their interactions have sound and promising impact on growth and yield of potato. Therefore, on the basis of the results of the present study, farmers can be more benefited from using 110 kg ha-^{1}of nitrogen in combination with 135 kg phosphorus. But the economic threshold level needs to be investigated further.

Key words: Nitrogen, Phosphorus, potato, yield parameters physical quality parameters

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is a crop of the world's major economic importance and number one non-grain food commodity (Rykaczewska, 2013). It is the third most important food crop in consumption in the world after rice and wheat (Hielke *et al*., 2011; Birch *et al*., 2012; Hancock *et al*., 2014), with a global cultivation exceeding 19.34 million hectare of land in more than 158 countries in the globe with an estimated annual production of 364 million tons (FAOSTAT, 2014).

Potato is one of human kind's most valuable food crops and it is a major part of the diets of more than a billion consumers worldwide (Mondal, 2003). It is regarded as high-potential food security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops such as, maize (Adane *et al*., 2010). It is an important food and cash crop in eastern and central Africa, playing a major role in the national food security and nutrition, poverty alleviation, income generation, and provides employment in the production, processing, and marketing sub-sectors (Lung'aho et al., 2007). In Ethiopia, the total area cropped by potato increased from 40,000 hectares in 1996 to 160,000 in 2006 (Gildemacher et al., 2009). In 10 years, potato productivity has progressed from 7 to 11 t ha^{-1}. In 2014/15 cropping season in Ethiopia, approximately 1,288,146 million farmers grew the crop in mid and highlands of the country where the crop covered more than 0.45% of the area under all crops and contributed 2.24% to the total crop production in the country (CSA, 2008). Nevertheless, potato account for 31.05% of the total area of root crop and 16.88% of the total root crop production (CSA, 2014).

Potato was introduced to Ethiopia in 1858 by a German Botanist called Schimper (Pankhurst, 1964; Horton, 1987). Based on FAO data, potato production in Ethiopia has been increasing from 280, 000 tons in 1993 to around 525, 000 tons in 2007 (FAO, 2008). This can be accounted for the development of high yielding varieties, wider adoption by farmers and use of potato blight (*Phytophthora infestans/ Phytophthora blight)*, resistance

variety together with improved agronomic practices. However, potato soil nutrient requirements, for example in terms of Nitrogen (N) and Phosphorus (P), application rates were given less attention under irrigated conditions (CSA, 2008). Evaluation of the impact of improved practices, such as optimum fertilizer application on productivity, nutrient recovery and water productivity were not also focus areas of research in Ethiopia. Compared to the huge potential and yield gaps, the claimed increase in yield indicated above is very low (Endale *et al.,* 2005).

According to FAOSTAT, (2008) about 70% of cultivated agricultural land of Ethiopia is suitable for potato production due to the availability of diverse climate and soil conditions. In relation to climate, for example, there are long frost free periods, which allow production during both the rainy and off seasons. More than 3.5 billion m^3 water resources of the county is also potential resource which can offer opportunities for off-rainy season potato production. Generally, these are good opportunities that worth exploring to increase the current low productivity and low crop quality level. Some of the main contributing factors for the low production and utilization of potato are, pests and diseases, lack of appropriate agronomic practices such as balanced and optimum nutrition and water inputs, lack of good quality seed etc. The research support in terms of provision of improved agronomic practices is weak (Burton, 2008).

Application of Nitrogen and phosphorus fertilizers has shown good yield responses for different crops across different locations, indicating low nitrogen and phosphorus status of the soils (Berga *et al*., 1994a; Yohannes, 1994). In addition to that lack of optimum nitrogen and phosphorus application rates, there are a number of production problems accounting for low yields of potato in Ethiopia. These constraints include limited supply of high quality seed tubers of potato (Gildemacher *et al*., 2009), inappropriate agronomic practices and inadequate storage (Tekalign, 2005), and limited knowledge resulting in poor seed tuber selection (Lung'aho *et al*., 2007). This situation would become more critical in potato production in view of the fact that the crop is one of the heavy feeders of soil nutrients (Powon, 2005).

Different recommendations have been reported by different researchers at different locations. According to Bereke (1988), application of 150/66 kg ha^{-1} of N/P_2O_5 under rain-fed condition resulted in a yield advantage of 32% over the unfertilized control. Getu (1998) has found that the optimum fertilizer rates for potatoes were 87 kg N and 46 kg P_2O_5 on clay soil of Haramaya. According to Mulubrhan (2004*)*, application of 165 kg N and 90 kg P_2O_5 ha^{-1} is needed for optimum potato production on vertisols of Mekelle area. For example, the current rate of nitrogen fertilizer application practiced across the country is based on a blanket recommendation released from Ethiopian research centers, which means it does not take varieties, soil types, climate and associated factors into consideration. Zelalem *et al*., (2009) have suggested 138 kg N and 20 kg P ha^{-1} as an appropriate rate for optimum productivity of potato variety Gore-Biella on the vertisols of Debere Berehan in the central highlands of Ethiopia under rain fed conditions. Practically, in different farming systems, varieties are cultivated by applying blanket recommendation, which is equal to 110 kg N ha^{-1} Zelalem et al. (2009).

This blanket application can lead to excessiveness or deficiency in relation to plant nutrient requirement. When excessive nitrogen is applied, it may adversely affect crop yield; increase the cost of production and the environment can be polluted, especially soil and ground water can be highly affected due to nitrate leaching (Madramootoo *et al*., 1992; Honisch, 2002). Use of under dose of nitrogen may also bring about significant yield reductions. This gives an insight to conduct trials for different varieties to develop optimum rate of fertilizer application, to enhancing economic return and maintain environmental health. Blanket national recommendation of 165 kg urea and 195 kg DAP ha^{-1} is used without considering the fertility status of the soil, the type of variety and season of production in different areas of Ethiopia (Taye, 1998).

1.1. Problem statement

Dedo district is one of the potential potato producing areas in Jimma Zone as it has suitable soil and climatic conditions and about 4162.9 of land in the destrict was covered by potato with average productivity of 9.5t/ha under irrigated condition in 2014/2015, which is very low compared to world productivity (17t/ha) of potato. An off-season production using small scale irrigation facilities is now in place in the study area and

hence farmers in the area produce potato for both purposes as cash and food crop under irrigation and rain fed conditions. However, there is no a complete recommendation for N and P fertilizers for irrigated systems of the area and, hence, information is lacking on the optimal nitrogen and phosphorus fertilizer rates. This remains a hurdle for local farmers to peruse improved potato production practices. The current level of productivity is very low and we hypothesize also that the yield associated environmental performances of the potato farming system could be low. In view of these problems this research considers to shade light on effect of different level of nitrogen and phosphorus fertilizer on productivity and associated parameters such as growth, tuber yield, size distribution, and related yield attributes of potato, and without considering the fertility status of the soil and the type of crop cultivar, blanket national recommendation is being used in the selected district. Since there is limited information on soil fertility studies for potato production in the area, soil nutrient management practices in the district is based on traditional practices and experiences from other regions. Therefore, direct investigation of the response of potato to applied nitrogen and phosphorus fertilizers under this specific agro-ecology is required to come up with optimum fertilizer recommendations so as to help farmers increase productivity of the crop in the area. In view of this, the present study was conducted at Dedo with the following objective

1.2.Objective

- To determine the effect of nitrogen and phosphorus fertilizers and their interaction on growth, yield, yield components and tuber quality of potato
- To determine optimum rate of N and P fertilizers for potato production in Dedo district

2. LITERATURE REVIEW

2.1. The Potato Crop

The plant potato was first domesticated in the area around Lake Titicaca, which is located 3800 meters above sea level on the border of modern-day, Bolivia and Peru, in the Andes mountain range of South America (Hielke et al., 2011) and today it is cultivated in 158 Countries in the tropical, subtropical and temperate zones of the world (FAO, 2010; FAOSTAT, 2014). It was introduced to Ethiopia by the German Botanist Schimper in 1858 (Tekalign, 2005 and FAO, 2014).

Cultivated potato (*Solanum tuberosum* L.) belongs to the Solanaceae family together with other crops like tomato and peppers. It is an annual dicotyledonous, when grown for botanical seed, but is treated as a perennial because the vegetative propagation from tuber for commercial purpose (Mosley et al., 2000). It has pinnately compound pattern alternate leaves on its above ground stem and specialized underground storage stems or tubers (Decoteou, 2005).

A potato plant is moderately frost tolerance and a C_3 plant with a low light saturation point (Hausler *et al.*, 2001). Potato has five distinct growth stages: sprout development, vegetative growth, tuberization (tuber formation), tuber bulking, and tuber maturation. It has an indeterminate growth pattern and produces a fibrous adventitious root system. This develops just above the nodes on underground portion of the stem (Dwelle and Love, 1993).

The tuber is not only the principal mean for potato propagation, but also a major human food source. Vegetative reproduction ensures a uniform crop, contrary to what would happen with sexual propagation. Sexual propagation of potato is accomplished by planting its true seed, but a high variability exist between this seed and that is why it is not commonly used. However, sexual seed is becoming more and more popular; especially in places were disease pressure is very high and maintaining disease free seed is becoming a problem (Mosley *et al.*, 2000). Potato tubers are actually a modified stem with approximately 70 -75% content of water and a remaining 25-30% of dry mater. They have nodes or eyes from which the new growth begins. The new stems growing from each eye are called sprouts. Sprouts grow from the tuber after a period of dormancy after they are harvested, this varies largely between cultivars. After this

dormancy is broken, sprouts grow and when planted, they give rise to the plant stems and from there all the vegetative part of the plant. Underground, lateral shoots called stolons are formed, from which the new tubers will be form (Mosley *et al.,* 2000).The main stem of the potato plant terminates in a flower cluster. Flower bud abortion may occur at a very early stage of development; but in any case apical growth of the main stem ceases with formation of the flower buds (Alemkinders and Struik, 1994).

2.2. Botany

Potato has a relatively shallow, fibrous root system with the majority of the roots in the surface 30 cm depth. The root system develops rapidly during early growth and achieves maximum development by mid-season. Thereafter, root length, density and root mass decrease as the plant matures. Rooting depths of 1.2 m or more have been reported for potato under favorable soil conditions (Tanner et al., 1982). Potato can persist in the field by vegetative means (as tubers) from one season to the next (Anonymous, 2004).Contrary to popular belief, the potato is not a storage root, but rather a specialized underground stem. If a whole tuber or a piece of tuber containing one or more eyes is planted, the buds sprout and develop a plant above the ground. Well before plant emergence, the developing sprout grows adventitious roots, which constitute the root system. Also, developing from the underground portion of the stem is stolons (rhizomes), which may bear new tubers at their tips (Ewing, 1997).The potato tuber is an enlarged portion of an underground stem although these stems sometimes grow aboveground as well, in which case they are termed stolons (Anonymous, 2013).

The potato tuber contains all the characteristics of normal stems, including dormant buds (eyes), rudimentary leaves (eyebrow scars lining the eyes) and lenticels (surface pores). Note that the buds are in a spiral pattern on the tuber and tend to be concentrated on the seed or apical end (opposite end of stem attachment) of the tuber (Thomas et al., 2006). The main stem of potato plant terminates in a flower clusters. The clusters bear white, pink, red, blue, or purple flowers with yellow stamens. Flower bud abortion may occur at a very early stage of development; but in any case apical growth of the main stem ceases with the formation of the flower buds. The cessation of growth of the main shoot axis may not be obvious because sympodial growth of one or more auxiliary branch just below the apex permits further extension above the flower cluster (Alemkinders and Struik, 1994).

Branching may occur at any node, but branching is most common at the base of the plant. Some branches arise from underground nodes on the main stem. Without disturbing the soil, it is difficult to distinguish these from stems that have arisen from separate eyes of the seed tuber. Other axillary branches arise from nodes just above the soil level. The extent of axillary branching, both sympodial and basal, is of crucial importance in determining yield potential. Propagation from tubers produces offspring, which are genetically identical, unless the chances of mutations have occurred. This means that all tubers of a given cultivar should be uniform unless they have become infected with a disease organism (Ewing, 1997). Although potato is cultivated worldwide, it belongs to just one botanical species, *Solanum tuberosum* L. ; the tubers come in more than 5 thousands of varieties with great differences in size, shape, color, texture and cooking characteristics and taste (FAO, 2010; CIP, 2014).

2.3. Environmental and Cultural Requirements of Potato Crop

Potato prefers a cool climate for growth and development. Best suited altitudes ranged between 1500-2800 m.a.s.l. However, for healthy tuber production, particularly for planting purpose, it should strictly cultivate in high altitude areas. For high yields, the total crop water requirements about 500 to 700 mm (MOA, 2011). Potatoes can be grown on all soil types, except heavy water-logged clays, but for optimum yields need a well-drained loam or sandy loam, relatively free from stones. Better tuber yields have been obtained from potatoes grown at soil reaction ranging from pH 5.0 to 7.0 (AGRISNET, 2010).

A temperature ranged between 15-25^{o}C is ideal for potato tuber development (Mondal and Chatterjee, 1993). At higher temperatures the plant fails to initiate tuber formation and at low temperatures vegetative growth is restricted by frost (Horton, 1987). The number of tubers produced per plant is higher at lower than at higher temperature. The seed tubers produced at higher temperatures (34 ^{0}C) are low yielding compared to seed tubers produced at cooler temperatures (7.7^{0}C) (Mondal and Chatterjee, 1993).

Very shallow planting of seed tubers may result in inadequate soil moisture around the seed piece and in production of tubers so close to the soil surface that greening caused by exposure

to light is a problem. On the other hand, planting too deep will slow tubers to emerge and may be more subject to attack by various diseases. As a result planting ought to be deeper on lighter soils than on heavy soils (Alexander *et al*., 2001). A good rule of thumb is never to have more than 10 cm of soil above the tip of the developing sprout (Ngungi, 1982).

Following the introduction of the potato to Ethiopia, it was gradually adopted by Ethiopian farmers (Kidane-Mariam, 1980). The first available potatoes were probably of a very limited genetic base, hence, vulnerable to diseases and pests, and were limited to the colder highlands until wider adoption of the potato occurred at the end of the nineteenth century in response to a prolonged famine (Gebremedihin *et al.,* 2001). The area of potato cultivation was estimated at 30,000 ha, with an average yield of approximately 5 tons per hectare (Gebremedihin *et al.*, 2001). However, potato cultivation declined in the early 1980s, due in part to widespread infestation of the late blight, *Phytophtho ra infestans*. Starting from 1991, potato production has resumed its increasing trend. Gebremedihin *et al*. (2001), reported that the area of potato was 50,000 ha by the mid 1980's and 160,000 ha in the early 2001's; with average yields around eight tons per hectare. An upward trend in potato production might be partly due to the continuing increase in population and subsequent decline in the average size of farm holdings, hence, pressure for agriculture to become more labor intensive. Ethiopia is the 11th top potato producing country in Africa (FAO, 2006).

2.4. Importance of Potato

Potato is consumed in different forms such as boiled or fried and many different processed products, like chips, French fries, flakes, powder, potato papad, etc., which are enjoyed across the generations and continents (Pandey *et al*., 2009).

Moreover, the protein content of potato is similar to that of cereals and is very high in comparison with other roots and tubers. In addition, the potato is low in fat and rich in several micronutrients (Lutaladio and Castaldi, 2009). Potato also has substantial amounts of vitamins, minerals such a crop is undoubtedly very important for countries like Ethiopia, where inadequate protein and supplies of calories are the apparent nutritional problems (Berga et al., 1994).

Traditionally, consumers select potatoes by visual characteristics, such as tuber size, shape, and color and skin brightness in the fresh market. However, there has been an increasingly higher interest on the part of consumers for use of the nutrient rich potato, because population based epidemiological studies have stressed the important role of diet (especially mineral malnutrition) and lifestyle in the emergence of some degenerative chronic diseases, such as cancers and cardiovascular diseases, in both developed and developing countries (Andre *et al*., 2007).
Phytochemicals present in potato is thought to neutralize cancer causing agents and cell damaging molecules called "free radicals" (Suszkiw, 2007). For human consumption, the potato tubers are not eaten raw but cooked to break down the starch. Nutritional component that is found in potato has a beneficial influence on human organism, as it protects against cardiovascular disease and cancer as well as reduces blood cholesterol level (Astley, 2003). Potato is also rich in antioxidants that are associated with many health benefits, including lower incidences of heart disease, reductions in some types of macular degeneration and cataracts (Brown, 2005).

Humans require at least 25 mineral elements for their well-being (White and Brown, 2010) and these mineral elements enter the food chain through plants. Potato is also an excellent source of these elements (White *et al*., 2009). Potato is generally not rich in Calcium, but can be a valuable source of trace elements, such as Selenium and Iodine (Karenlampi and White, 2009). Each potato cultivar has the unique tuber appearance and nutritional composition (Storey and Davies, 1992).

Potato produces food that is more nutritious more quickly, on less land, and in harsher climates than any other major crops up to 85% of the plant is edible human food, compared to around 50% in cereals. Potato is rich in carbohydrates, making it a good source of energy. It has the highest protein content (around 2.1% on a fresh weight basis) in the family of root and tuber crops, and protein of a fairly high quality, with an amino-acid pattern that is well matched to human requirements. A single, medium-sized potato tuber contains about half the daily adult requirement of vitamin c and significant amount of vitamin B, iron, potassium, and zinc (FAO, 2014). Potato is the world's most important tuber vegetable with a vital but often

underappreciated role in the global food system. Potato as a staple food supplies the energy and nutritional needs of more than a billion people worldwide. Potato cultivation and post-harvest activities constitute an important source of employment and income in rural areas and for women in developing countries. It can be used as a food security crop, as a cash crop, as animal feed, and as a source of starch for many industrial uses. In honor of its versatility, nutrition and emerging status in the developing world, the United Nations named 2008 the International Year of the Potato (FAO, 2009).

The International Year of the Potato (IYP) in 2008 was a celebration of one of humanity's most important and universally loved staple foods. Potato is the leading vegetable and an important food and cash crop (CACC, 2003), especially in the high and mid-altitude areas. As being one of the principal cash crops, it gives valuable returns to growers and farmers due to its wide market demand nationally and internationally for different kinds of utilization. Potato is, therefore a potential crop for strengthening food security in developing countries like Ethiopia, where inadequate food production has frequently frustrated developmental efforts (MoA, 2007).

2.5. Potato Production and its Major Growing Areas in Ethiopia

Ethiopia is endowed with suitable climatic and edaphic conditions for quality potato production. About 70% of the available agricultural land are located at an altitude of above 1500 meters above sea level and receives an annual rainfall of more than 600 mm, which is suitable for potato production (FAO, 2014; Tekalign, 2003). The national average yield is 13.69 tons ha-1 (CSA, 2014/15), which is lower than the world's average of 16.4 t ha-1 (FAO 2014; FAOSTAT, 2014). The total acreage of potato in Ethiopia is about 67,361.87 ha with an annual production of 921,832.070 tons (CSA, 2014/15).

Adoption of the crop by Ethiopian farmers occurred very gradually for several decades (Kidane-Mariam, 1980). Cultivation was limited to potato growing voluntarily in fields in the cold highlands until wider adoption of the potato occurred at the end of the nineteenth century in response to a prolonged famine (Gebremedihin et al., 2001). Potato production in Ethiopia has increased considerably through the twentieth century. In 1975, the area of potato

cultivation was estimated at 30,000 hectares, with an average yield of approximately five tons per hectare (Gebremedihin et al., 2001). However, potato cultivation declined in the early 1980s due in part to widespread infection by late blight, *Phytophthora infestans/ Phytophthora blight* (Tesafahun and Boris 1985).

Gebremedihin *et al*. (2001) estimated that the area of cultivation had reached 50,000 hectares by the mid 1980's (an estimate still cited as of 2003 (FAOSTAT, 2010), but that by 2001, Ethiopia's potato area grew to 160,000 hectares, with average yields around eight tons per hectare. An upward trend in potato production might be due partly to the continuing increase in population and subsequent decline in the average size of farm holdings, hence the pressure for agriculture to become more labor intensive (Gebremedihin *et al*., 2001). The major problems of potato production in Ethiopia include drought, erratic rainfall, high temperature, frost and high disease and insect pressure; among those all constraints soil fertility is the one which limited its productivity (Temesgen, 2008).

Potato is ideally suited for places where land is limited and labor is abundant, conditions that characterize much of the developing countries. Moreover, potato is a highly productive crop. It produces more food per unit area and per unit time than wheat, rice and maize. Potato’s short growth cycle also adds its value to securing food availability at the household level by improving farm productivity through permitting double crop production per annum. As Kabira et al. (2006) also indicated, potato plays an important role in national food and nutrition security, poverty alleviation, and income generation and provides employment in production to consumption continuum. Moreover, it matures in 3-4 months and can yield up to 40 t ha-1.

In Ethiopia, potato is grown in four major areas: the central, the eastern, the north-western and the southern regions. Together, they cover approximately 83% of the potato farmers (CSA 2008/2009). Regional distribution of potato depicted that Oromia, Amhara and SNNPR constitutes 56.79, 26.30 and 15.92% respectively (CSA 2014/15). Oromia is the major potato producing region due to the ecological suitability of areas.

2.6. Role of Nitrogen Fertilizer in Potato Productivity and Potato Plant Nutrition

Nitrogen is the most limiting nutrient in crop production and is higher in concentration than all other mineral nutrients in most plants (Foth and Ellis, 1996). It makes up 1 to 4 percent of dry matter of the plant. Nitrogen is taken up from the soil in the form of nitrate (NO_3^-) or ammonium (NH_4^+). In the plant N combines with compounds produced by carbohydrate metabolism to form amino acids and proteins. Being the essential constituent of proteins, it is involved in all the major processes of plant development and yield formation. A good supply of nitrogen stimulates root growth and development as well as the uptake of other nutrients (Brady and Weil, 2002). Plants obtain readily available N forms from different sources.

Potato at the beginning of its growth requires a lot of available nitrogen. Nitrogen is needed to take up carbon. Sufficient nitrogen increases both plant growth and leaf surface and tuber size and causes crop to become tolerant to leaf blot disease (Hassanpanah *et al*., 2009). Potato is sensitive both to N deficiencies and excesses. Effective fertility management is critical to profitable production of potatoes. The crop is highly responsive to N fertilizer, but N fertilizer use efficiency is low (Rourke, 1985; Porter and Sisson 1991). Optimum use of N by plant decreases leaching of nitrogen and improves tuber germination and steady leaf area. Excess nitrogen at the last stage of growth causes development of stem and leaves instead of tubers as a result of high amounts of amino acids and amides, not changing to protein. Excess nitrogen has negative effect on tuber yield and quality; deficiency the photosynthesis decreases because lower leaves of plant become yellow and falls (Hassanpanah *et al*., 2009).

According to Hopkins *et al.* (2008) also reported that Potatoes require a steady supply of nutrients. Deficiencies or fluctuations of soluble nutrients (especially N) cause poor vine health, increased pathogen and insect susceptibility, reduced tuber yields, and diminished tuber quality. Potatoes require high amounts of fertilizer not only because of high nutrient demand, but also because they have a shallow, inefficient rooting system to explore soil nutrient from wider surface area.

2.7. Role of Phosphorus Fertilizer in Potato Productivity and Potato Plant Nutrition

Phosphorus is claimed to be the second most often limiting plant nutrient (Tisdale *et al*., 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 both plants and animals. Phospholipids, which play critical roles in cellular membranes, are another class of universally important phosphorus-containing compounds. For most plant species, the total P content of healthy leaf tissue is not high, usually comprising only 0.2 to 0.4% of the dry matter (Brady and Weil, 2002). Plants absorb phosphorus in the form of HPO_4^{-2} and $H_2PO_4^-$ (Tisdale *et al.*, 1995).

The physical and chemical properties of soils influence the solubility of phosphorus and its adsorption reactions in soils. These include the nature and amount of soil minerals, soil pH, cation effect and anion effect, extent of phosphorus saturation, reaction time and temperature, flooding and fertilizer management (Tisdale *et al.,* 1995). Moreover, availability of phosphorus from fertilizers may be affected by the soil reaction, the degree of soil phosphorus deficiency, rate and method of application, needs of the specific crops, certain soil differences. The maximum availability of phosphorus for plant utilization is known to occur at soil pH between 6.5 and 7.5 (Mengel and Kirkby, 1987).

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

Biswas and Mukherjee (1993); Miller and Donahue (1995) and Tisdale *et al.* (1995) have reported that the use of P fertilizer becomes imperative because the concentration of P in many soils is very low and it is also liable to different chemical reactions that make it unavailable to plants. Plants supplied with adequate amount of P were reported to form good root system, strong stem, mature early and give high yield whereas plants grown on P deficient soils showed stunted growth, low shoot to root ratio, poor fruit and seed formation, purpled colored leaves with reddish coloration of the stem. Biochemically, deficiency causes changes in functions of the plant including accumulation of sucrose and reducing sugars and sometimes of starch (Rending and Taylor, 1989).

Potatoes are responsive to P fertilization on soils testing low in P, but yield increases from applied P have also been found on soils testing very high in P (Sanderson *et al.*, 2003). Excess P can move through runoff and erosion and potentially affect the quality of surface waters. Therefore, understanding the need for P in potato production systems is important. Because P is relatively immobile in soil (Tisdale and Nelson, 1995) and because of its importance for early crop growth, banded application of Phosphorus at planting is recommended (Rosen and Eliason, 2005). Yield response to fertilizer P has received the most attention, but there are also reports that P can affect the number of tubers and tuber size distribution. Increases in tuber set with P application have been found by Sanderson *et al.* (2003).

Sharma and Arora (1987) also reported that Potato tuber yield is known to be influenced by P fertilizers through its effect on the number of tubers produced, the size of the tubers and the time at which maximum yield is obtained. They showed that yield response to increasing levels of P fertilizer was generally positive up to a particular level, above which the response became negative. They also noted that excess use of P fertilizers is usually associated with reduced tuber weight by hastening the maturation period and reducing tuber size. Applied P has been found to increase the yield of small and medium size tubers (Hanley *et al.,* 1965). Though P had a positive effect on tuber yield, the percentage of yield increase due to P was smaller than the yield increase due to N. This could probably be explained by the fact that P leads to faster closure of canopy and shorten the growing period (Somerfield and Knutson, 1995). The other possible reason is that applied P may not be available to the plants at a rate similar to N fertilizer because of problem of soil fixation to satisfy first the soil demand of Phosphorus.

2.8. Effect of N and P on Potato growth Parameters

2.8.1. Stem number

Potatoes are mainly propagated by vegetative methods (cloning). A potato plant usually is made up of more than one stem. Each individual stem gives rise to both below and aboveground biomass. This means that a single stem produces its own roots, stolons, tubers, foliage and inflorescences thus behaving as a single production unit. A number of definitions have been put across to define stem density. The stem density of a potato crop is the number of stems per unit area and differs significantly from the plant population mostly given in

recommendations. The density of the potato crop consists of two components. The first component is the number of plants generally referred to as plant density and the second, is the number of stems per plant.

Plant density refers to the number of tubers planted per unit area while stem density refers to the number of stems arising from each tuber mainly because each tuber has a numbers of "eyes", each of which can produce a stem. Each stem from a single eye can be regarded as an independent production unit.

Thus, a sufficient number of strong stems should be develop per seed tuber. Investigations on stem density levels have also provided an insight in to yield and quality of harvested tubers.

. A comprehensive understanding of this concept can be used to manipulate the production of ware and seed potatoes (*Admire et al., 2014a*). The general crop performance, harvestable yield and tuber size are strongly influenced by stem number per hectare (*shayanowako et al., 2014*).

The number of stems per plant is reported to be under the influence of storage condition of tubers and number of sprouts (Allen, 1978), physiological age of the seed tuber (Iritani, 1968), variety (Lynch and Tai, 1989) and tuber size (Harris, 1978; Gulluoglu and Arıoglu, 2009*)*. Iritani *et al.* (1972) also reported increase in stems per plant with increases in seed size.

Beukema and Zaag (2001) reported that the number of main stem arising from a seed is important because it influences the number and size of tubers at harvest. Similarly, Gray and Hughes (1978) observed close relationships between the number of main stems or aboveground stems and total yields and graded tuber yields. These investigators claimed that high stem number per plant favored high tuber yield through effect on haulm growth and tuber number per plant. Hassanpana*h et al.* (2009) also observed main stem number per plant had positive correlation with marketable tuber weight.

Despite the fact that stem density is one of the most important yield components in potato; it was not significantly influenced by mineral nutrients. This could be due to the fact that the trait is much influenced by the inheritance of the potato crop (Mulubrhan, 2004; Zelalem *et al.*, 2009). This showed a mix picture when suggestion from Hossain *et al.* (2003) and

Hassanpanah *et al.* (2009) who reported the increase in stem number due to applying nitrogen fertilizer is taken into account.

2.9. Effect of N and P on Potato yield Parameters

2.9.1. Tuber number

The number of tuber set by the plant is determined by stem density, spatial arrangement, variety and environment (Allen, 1978). The number of tubers set per potato plant largely governs the total tuber yield as well as the size categories of potato tubers. Increasing stem density over a wide range either by planting larger seed tubers or more seed tubers for most varieties resulted in increased number of tubers per unit area (Allen, 1972; Gray and Hughes, 1978).

Different investigators have reported contradicting results regarding the effect of mineral nutrition on the number of tubers set per plant. For instance, Sharma and Arora (2014) reported no significant difference in the total number of tubers per square meter of land area as a result of N, P and K fertilizer application, while Gunasena and Harries (1969); Lynch and Row berry (1997) and Sharif (2005) reported significant difference in tuber number due to nitrogen fertilization. Jenkins and Mahamood (2003) also observed that the number of tubers varied considerably as a result of N fertilization, and doubled when N level was increased to higher levels. Zamil *et al*. (2010) have found that the higher dose nitrogen (254 kg N ha^{-1}) results in significantly higher total tuber number in Potato tubers. Similarly, Freeman *et al.* (1998); Jenkins and Ali (2000); Maier *et al.* (2002a) and Sanderson *et al.* (2003) noted that the application of P increased the number of tubers set per unit area.

In addition, Zelalem *et al*. (2009) have found that application of 207 kg N/ha and 60 kg p /ha increased marketable tuber number by 95.6% and 43.5% respectively, as compared to the control. Mulubrhan (2004) also reported that the application of Nitrogen and Phosphorus increased the tubers number of potato per unit area.

2.9.2. Potato yield response to N and P fertilizers

Growing healthy potatoes for maximum yield and quality requires that all the essential nutrients be supplied at the right rate, the right time, and the right place. The total nutrient requirement is determined by a combination of plant, soil, and environmental factors. Many of these factors can be carefully controlled, but other factors (such as rainfall, temperature, and sunlight) cannot be. The main consideration is to manage those factors that can be controlled and keep the plants in the best condition to withstand whatever environmental stresses may occur (Robert, 2006).

Potato plants have high requirement for mineral nutrition (Harris, 1978). Millard and Marshall (1986) reported that tuber yield improvement as a result of N fertilization could be attributed to increased radiation interception during the first part of the season and lower rates of decline in photosynthetic efficiency of the canopy during the later part. The increase in the application of N fertilizer up to a certain level increases the potato yield, but since then, it has no effect on the increase in yield (Westerman *et al*., 1985).

Nizamuddin *et al*. (2003) observed optimum tuber yield when nitrogen fertilizer was applied at the rate of 200 kg ha-1. Guler (2009) and Zamil et al. (2010) also reported that the maximum tuber yield was obtained when the crop received 300 and 254 kg nitrogen per ha, respectively. They also noted a reduction in tuber yield when N was applied above the aforementioned rates. The yield reduction due to excess rates of N may be explained by the fact that excessive N application stimulates shoot growth more than tuber growth which may result in deterioration of canopy structure and physiological conditions (Sommerfeld and Knutson, 1965; Berga *et al*. 1994a; Mulubrhan, 2004; Zelalem *et al*., 2009) and Israel et al. (2012) also observed significant and consistent yield increment with an increased in the level of nitrogen.

Potato tuber yield is also known to be influenced by P fertilizers through its effect on the number of tubers produced, the size of the tubers and the time at which maximum yield is obtained (Sharma and Arora, 1987). They showed that yield response to increasing levels of P fertilizer was generally positive up to a particular level, above which the response became negative. They also noted that excess use of P fertilizers is usually associated with reduced

tuber weight by hastening the maturation period and reducing tuber size. Applied P has been found to increase the yield of small and medium size tubers (Hanley *et al*., 1965). Zelalem et al. (2009) reported that application of 60 kg P ha-1 increased marketable tuber number by 43.5% over the control. Similarly, Mulubrhan (2004) noted that increasing P application from 0 to 39.6 kg ha-1 highly significantly increased total tuber yield by 24.27%. He also indicated the existence of a room for further increases in tuber yield through application of more P fertilizers beyond 39.6 kg ha-1.

Soltanpour and Cole (1978) found that application of N and P fertilizers increased leaf, stem and tuber growth rates and, consequently yields. Zelalem et al. (2009) also found that N and P fertilization significantly influenced the productivity of potato measured in terms of marketable and total tuber yield. Increasing N application from 0 to 207 kg N/ha brought about 176 and 119% marketable and total tuber yields increases, respectively. Similarly, application of 60 kg P ha-1 increased marketable and total tuber yield by about 66 and 50%, respectively over the control. Though P had a positive effect on tuber yield, the percentage of yield increase due to P was smaller than the yield increase due to N. This could probably be explained by the fact that P leads to faster closure of canopy and shorten the growing period (Sommerfeld and Knutson, 1965). The other possible reason is that applied P may not be available to the plants at a rate similar to N fertilizer because of problem of soil fixation to satisfy first the soil demand of Phosphorus (Zelalem et al., 2009).

The result of a study conducted by Jamaati-e-Somarin et al. (2010) showed that variation in tuber yield due to nitrogen treatments were related to the tuber weight increment. Similarly, Mulubrhan (2004) reported that application of N significantly increased average tuber weight by 62% as N application increased from 0 to 165 kg ha-1. Similarly, Guler (2009) indicated that mean tuber weight increased with increasing N rate. It was lowest in control and highest in the 300 kg N ha-1. Zelalem et al. (2009) also reported that average tuber weight progressively increased with increasing N rate up to 138 kg/ha and tended to decrease at the highest rate of 207 kg ha-1.

Average tuber weight is the most important yield component of potato, contributing to the total tuber yield (De la Morena *et al*., 1994). Increasing the yield of tubers with applied nutrients (N

and K) was associated with increase in the number of tubers in the medium and large grades at the expense of small tubers (Sharma and Arora 1987). Patricia and Bansal (1999) indicated that the increase in the weight of tubers with the supply of fertilizer nutrients could be due to more luxurious growth, more foliage and leaf area and higher supply of photosynthesis which may have induced formation of bigger tubers thereby resulting in higher yields.

2.10. Tuber Quality Parameters

2.10.1. Specific gravity (TSG)

According to Warren and Woodman (1994) specific gravity has been considered the most practical index of mealiness in potatoes. Similarly, Tesfaye *et al.*(2013) reported that specific gravity is the measure of choice for estimating dry matter (DMC) and starch content (SC) and ultimately for determining the processing quality of potato varieties. Potatoes of high dry matter contents, more typically expressed as high specific gravity, are important in processing industry in terms of finished product yield, oil uptake and quality (Sayre *et al.*, 1975).

Painter and Augustine (1976) and Kleinkopf *et al*. (1981) reported that the specific gravity of tubers decreased with increasing rates of N fertilizer. Similar result was reported by Mulubrhan (2004) that increasing the application of N from 0 to 165 kg ha^{-1} reduced specific gravity from 1.076 to 1.069. On the other hand, Robert and Cheng (1988) and Simret *et al. (*2010) noted that non-significant difference in specific gravity of tubers due to nitrogen treatment.

Conflicting results have been reported regarding the effect of P fertilization on tuber specific gravity of potato. Human (1961) noted an increase in specific gravity in response to an increase in applied P. However, Zandstra *et al.* (1999) reported a reduction in specific gravity as the rate of phosphorus fertilizer increased. As opposed to the above findings, Lujan and Smith (1994) and Zelalem*et al.* (2009) reported non-significant effect of phosphorus on the specific gravity of tubers. Similarly Adhikari and Sharma (2004) and Dubetz and Bole (1975) reported that high levels of P did not influence specific gravity.

2.10.2. Dry matter content (DMC)

Dry matter accounts for as much as 60 to 80% of the tuber dry weight and is the major storage component of tubers and Freshly harvested potatoes contain about 80% water and 20% dry matte (Kolbeand Stefan-Beckmann, 1997). It is often necessary to know the dry matter content of potato tubers since this largely governs the weight of processed products, which can be obtained from a given weight of raw tubers. It is also one of the determinants of tuber quality, both for processing as well as cooking. High dry matter has been reported to be desirable because of less sugar content and water accumulation (Nelson and Shaw, 1976). Storey and Davies (1992) have been observed that tubers with high dry matter content required less energy input during frying or dehydration to remove water resulted in greater product yield per unit fresh weight than tubers with lower solid content and absorbed less oil during frying. They also noted the tuber dry matter content was influenced by a wide range of factors that affected the growth and development of the crop, including most importantly, environmental factors such as intercepted solar radiation, soil temperature, available soil moisture and cultural treatments(Storey and Davies, 1992).

No consistent effect of phosphorus fertilization on the nitrogen containing components of potato tubers has been observed. Mulder and Bakema (1956) have found that non-protein nitrogen content was higher with phosphorus deficiency, while Marchenko (1959) has found that P and K fertilization had little effect on nitrogen content.

Kandi (2011) reported a reduced percent dry matter of potato tubers as nitrogen rates increased. Similar findings were reported by Wilcox and Hoff (1970) and Painter and Augustine (1976). Similarly, Asefa (2005) has indicated that increasing rate of nitrogen and phosphorous application significantly decreased specific gravity and dry matter content of potato tuber. Other finding reported by Cucci and Lacolla (2007) that dry matter percentage increased shifting from the control to the application of 200 kg N ha^{-1} and 50 kg P ha^{-1} from 23.0 to 26.2% and decreased at the highest N level, without any difference being observed with the change in the P rate.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted at Dimaserte Kebele, in Dedo District of Jimma Zone, South West Ethiopia. The site was selected based on the fact that it represents potential potato production areas in the District. The site is located at $7^0$13' -$7^0$39' N latitude and $36^0$43' - $37^0$12' E longitude and is 22 km south of Jimma town. Total population size is about 308,544 of which 50.4% is male and 49.6% .The District shares its boundaries with Omo Nadda district in the east, Kersa District in the North, Seka Chokorsa District in the west and Southern Peoples Nations and Nationalities Regional State (SPNNR) to the South. The altitude of this district ranges from 880 to 2400 meters above sea level. Major peaks include Haro Gebis, Walla, and Derar Korma mountains. Perennial rivers include the Unta, Kawa, Waro and Offele. A survey of the land in this District shows that 63.1% is arable or cultivable 38.4% was under annual crops, 13.6% pasture, 9.3% forest, and the remaining 14% is considered swampy, degraded or otherwise unusable. Teff (*Eragrostis tef*, maize (*Zea mays*) and vegetables are important cash crops in the area (CSA, 2007)

Table 1: Soil physical and chemical properties of the experimental site before planting

Properties	Value	Rating
Physical properties		
Sand	22%	
Silt	50%	
Clay	28%	
Texture class	Clay loam	
Chemical properties		
Total N (%)	0.166	medium
Available P (ppm)	3.03	low
pH (water 1:2.5)	6	Slightly acidic
Organic carbon (%)	2.5	medium

Note: Rating of nutrients is based on Frank (1990)

3.2. Experimental Material, Treatments and Experimental Design

The treatments consisted of a 4 × 4 factorial combinations of both four levels of N (0, 55, 110 and 165 kg ha^{-1}) and four levels of P (0, 45, 90 and 135 kg ha^{-1}). Urea (46%) and DAP (46% p_2o_5 and18%N were used as source of nitrogen and Phosphorus. The plot with zero level of

both nitrogen and phosphorus was used as a control treatment. The national fertilizer recommendation for potato production (110 kg N ha^{-1} and 90 kg P_2O_5 or 40 kg P ha^{-1}) was used as a benchmark in the experiment (Table2).

Table 2: Detail fertilizer treatment combinations

Nitrogen(N) rate	Phosphorus(P) rate			
	0	45	90	135
0	N0,P0	N0,P45	N0,P90	N0,P135
55	N55,P0	N55,P45	N55,P90	N55,P135
110	N110,P0	N110,P45	N110,P90	N110,P135
165	N165,P0	N165,P45	N165,P90	N165,P135

Potato variety Belete (CIP-393371.58) obtained from Holeta Agricultural Research Center (HARC) was used for the experiment. It was released in 2009/2003E.C. Agronomic and Morphological Characteristics of the variety is, shown in Table 3;

Table 3; General description of potato variety Belete

Variety	Belete
Released year	2009/2003E.C
Altitude	1600-2800 m.a.s.l
Rain fall (mm)	750-1000mm
Fertilizer rate (kg)	165 kg N and 195kg P
Soil type	Fertile & Silt loam or sandy loam texture
Seed rate	18-20qt per hectare
Spacing	75cm b/n row&30cm b/n plant
Days to maturity	110-120 days
Tuber Yield	47.19 t/ha in the research field

Source: MoARD (2009)

The experiment was laid out in a Randomized Complete Block design (RCBD) in 4x4 factorial combinations with three replications. Each experimental plot was 3m wide and 3m long. The distance between replications and plots was maintained at 1m and 50 cm, respectively. The spacing between rows and plants within a row was 0.75 m and 0.30 m, respectively. Cultivation, weeding, and ridging was done as per the recommendation of potato (MoA, 2011)

3.3. Experimental procedures

Land preparation was carried out in January 2015. Medium size and well sprouted tubers were used for planting. Half of the N and the whole P fertilizer rate was applied during the time of planting; and the remaining half of the N dose was applied during the first earthling-up (45 days after planting) as side dressing. Weeds were managed by hoeing and hand weeding. Earthling-up was done two times before flowering to initiate tuber bulking and one time after flowering to prevent exposure of tubers to direct sunlight.

3.4. Data Collection

To determine effect of N & P rates on yield and quality of potato, data were collected on growth, yield components, yield and quality of potato as follows.

3.4.1. Growth parameters

3.4.1.1. Days to 50% flowering:

Days to 50% flowering was recorded when the number of days taken for 50 % of the plant population in each plot produced flowers (Shiri-e-Janagrad et al., 2009).

3.4.1.2. Number of stems per hill

Number of stems per hill was recorded as an average count of five hills per plot at flowering. Only stems arising from the mother tuber were considered as main stems (Zelalem et al., 2009).

3.4.1.3. Plant height

Plant height was determined by measuring the height of the plant from the base of the main shoot to the apex at full blooming stage (Zelalem *et al.*, 2009).

3.4.1.4. Days to70% maturity

Days to physiological maturity was recorded when the leaves of 70% of the plants in the plot turned yellowish and the plants showed senescence of haulms (Zelalem et al., 2009).

3.4.2. Yield parameters

3.4.2.1. Marketable tuber number per hill

Mean number of tubers produced from ten plants of middle rows. It was counted at harvest and those tubers which are healthy, large sized and greater than 50g were considered as marketable tubers (Tekalign, 2005).

3.4.2.2. Unmarketable tuber number per hill

It was recorded by counting average number of tubers of ten plants, and rotten, diseased, insect infected, and green tubers and those with less than 50g, weight were regarded as unmarketable tuber (Zelalem et al., 2009).

3.4.2.3 Total tuber number per hill:

Mean number of tubers produced from the middle rows, was counted at harvest and expressed as number of tubers per hill (Zelalem et al., 2009).

3.4.2.4. Marketable tuber yield (t ha $^{-1}$)

Mean weight of marketable tubers produced from the middle rows, was recorded at harvest by weighing tubers which were healthy and greater than 50g. The value were taken in kg/plot and converted to t ha^{-1}(Zelalem et al., 2009).

3.4.2.5. Unmarketable tuber yield (t ha^{-1})

Mean weight of unmarketable tubers produced from middle rows was recorded at harvest and those rotten, turned green and less than 50g, were considered to determine unmarketable tuber yield, (kg/plot) and converted into t ha^{-1} (Zelalem et al., 2009).

3.4.2.6. Total tuber yield (t ha^{-1})

It was recorded as the sum of both marketable and unmarketable tuber yields. The total tuber yield (kg/plot) was weighed and converted to tones per hectare t ha^{-1}(Zelalem et al., 2009 and Mohammad et al., 2013).

3.4.2.7. Average tuber weight (g)

It was recorded by dividing total fresh weight of tubers by the total number of fresh tubers per plot (Zelalem *et al*., 2009).

3.4.3. Tuber quality parameters

3.4.3.1. Specific gravity of tubers

Tuber specific gravity (TSG) was measured by taking three kg clean tubers from each plot. This sample was weighed in air and reweighed underwater method (Klein Kopf *et al*., 1987). TSG was calculated based on the following formula.

$$\text{specific gravity} = \frac{\textbf{Weight of tuber in the air}}{\textbf{Weight in air} - \textbf{Weight in water}} \ldots\ldots\ldots\ldots\ldots\ldots 1$$

3.4.3.2. Tuber dry matter content (%)

Dry matter yield was determined following the method described by Zelalem *et al*. (2009) by taking five healthy tubers from randomly chosen five plants per harvestable plot. Sample tubers were washed, chopped and mixed. Then 200g of sample was taken and pre dried at a temperature of 60°C for 15 hrs; and further dried at 105°C in an oven until constant weight was attained and expressed in percent.

$$Dry\ matter(\%) = \frac{\text{dry weight(g)}}{\text{Fresh weight(g)}} * 100 \ldots\ldots\ldots\ldots\ldots..2$$

3.4.4. Soil sampling and analysis

Soil samples were collected from 0-30 cm depth to evaluate different soil chemical and physical properties (Table 3). At the beginning of the experiment, 15 samples were randomly collected by using an auger and composited. Then, soil samples were also taken from each treatment at harvesting. The samples were air dried, crushed with mortar and sieved to pass through 2 mm mesh. Soil organic carbon was determined by the wet oxidation method as described by Walkley and Black (1947). Determination of total nitrogen of the soil samples was performed by the Kjeldahl method (Lewis and Friets, 1984).Where available P content was determined using standard procedure of Olsen (1954). Soil pH: was determine in 1:2.5

soil to water ratio using a glass electrode attached to digital pH meter. Organic matter (%): was recorded based on the oxidation of organic carbon with acid potassium di-Chromate (K2C2O7-2) medium using the Walkley and Black method as described by Lewis and Freits (1984).Available Phosphorus (ppm) was determined.

3.5. Data analysis

The collected data on different growth and yield parameters were subjected to analysis of variance (ANOVA) by using SAS version 9.2 statistical software (SAS, 2008). All pairs of treatment means were compared using Least Significant Difference (LSD) test at 5% level of significance. The correlation analysis was performed to determine simple correlation coefficient between growth and yield components as affected by N and P applications.

4. RESULTS AND DISCUSSION

The results of the investigation are discussed as follows.

4.1. Growth Parameters

ANOVA showed that the interaction effect and main effect of N and P was significant ($P< 0.01$) for days to 50% flowering, main stem number, plant height, days to 70% maturity.

4.1.1. Days to 50% flowering

Variance analysis (Appendix Table 1) showed that interaction of nitrogen and phosphorus fertilizers highly significantly ($P<0.01$) influenced days to 50% flowering, while the main effect was statistically non-significant ($P>0.05$). Increasing application of nitrogen from 0 to 165 kg ha^{-1} shorten the days to 50% flowering of potato from 52.26 to 64.36 days (Table 4). Mean separation result indicated that days to flowering at application of 55 and 110 kg N ha^{-1} was significantly lower ($P<0.05$) than those of unfertilized control, and nitrogen application of 165 kg ha^{-1} (Table 4). Days to 50% flowering of potato was statistically similar for treatment combination of 165/0 and 0/0, 55/0, and 0/45, 55/45 and 110/135, 0/90, 55/90, and 110/45 kg N and P ha^{-1}.The combined application of 0/90 and 55/90 kg N and P ha^{-1} shorten the days to 50% flowering of potato.

Treatment that received 165/0 and the control delayed the days to flowering. Nitrogen rates higher than 110 kg ha^{-1} and Phosphorus rates less than 45 kg ha^{-1} also delayed days to flowering and maturity of potato that could be explained by their higher tendency of initiating vegetative growth such as higher plant height and higher number of stems per hill (Tables 4).

This result is in line with the findings of Cole (1975) and Zelalem *et al*. (2009) who reported that application of higher rate of nitrogen fertilizer delayed days to flowering and maturity. Application of N at a rate of 55 kg or 0 kg ha^{-1} with 90 kg ha^{-1} P reduced the time required by the potato plant to attain 50% flowering stage. Optimum phosphorus applications mostly enhance early crop development and that the responses to phosphorus application decrease

with time (Jenkins and Ali, 1999; Ekelof, 2007). Sommerfeld and Knutson (1965) also reported that phosphorus leads to faster closure of canopy and shorten the growing period.

Table 4; Interaction Effect of N and P Fertilizer on days to 50% flowering, of Potato in Dedo, South –West Ethiopia

	Phosphorus (kg ha-1)			
Nitrogen (kg ha-1)	0	45	90	135
0	64.36a	52.70bcd	49.90e	51.36cde
55	52.400bcd	50.16de	50.10e	51.37cde
110	54.26bc	49.76e	53.60bcd	50.67de
165	62.03a	55.70b	54.16bc	52.00cd
LSD (0.05)	2.9			
CV (%)	5.51			

4.1.2. Main stem number

Main stem number per hill was highly significantly ($P<0.0001$) and significantly ($P<0.05$) influenced by nitrogen and phosphorus, respectively. However, the interaction of nitrogen and phosphorus was not significant ($P >0.05$) (Appendix Table 1). Increasing application of nitrogen from 0 to 165 kg ha^{-1} increased main stem number per hill from 3.14 to 5.35. The maximum main stem number (5.35) per hill was recorded at 165 kg N ha^{-1} and the minimum main stem number (3.14) per hill was obtained from the control (Fig.1). Increasing rate of nitrogen from 0 to 165 kg ha^{-1} increased the main stem number by 54.26%. The mean result of stem number was not statistically different between treatments 110 and 165 kg N ha^{-1}. An increase in nitrogen level up to 110 kg N ha^{-1} brought about an increase in stem number per hill; however, further increase in nitrogen level was not statistically different between treatments in main stem number of potato. This might be related to the fact that main stem number is mostly dependent on the number of sprout per tuber.

In agreement with the present finding, *Nizamudin et al. (2003)*, *Hassanpanah* et al. *(2009*) and Alam et al. (2007) have reported that the lowest stem number of potato was obtained from unfertilized control. Shakh et al. (2001) have also reported that increased in stem number with

an increase in nitrogen application (180 kg N ha^{-1}). Similarly, Jamaati-e-Somarin et al. (2009) reported that increasing nitrogen level up to 110 kg N ha^{-1} increased the stem number; but further increases in nitrogen fertilizer level did not affect it any more. Stem number did not have considerable variation within its growth period because it is a character which is mainly dependent on tuber size. Similar to nitrogen, increasing the level of applied phosphorus significantly increased main stem number per hill of potato (Fig.1). Increasing phosphorus application from 0 to 135 kg ha^{-1} increased main stem number per hill from 3.63 to 5.19. The maximum main stem number (5.19) per hill was recorded at 135 kg P ha^{-1} and the minimum main stem number (3.63) per hill was obtained from the control (Fig.1). Increasing rate of phosphorus from 0 to 135 kg ha^{-1} increased the main stem number by 42.97%.

Stem number per hill at 90 kg P ha^{-1} (4.38) was not statistically different from that at 135 kg ha^{-1} (5.19) (Fig.1). Similar results have been reported by Rosen and Bierman (2008), who showed that phosphorus applications increased the number of stems per hill compared with the zero phosphorus level (control). Maier et al. (2002a) have also reported a significant increase in stem number per plant with phosphorus fertilization in a greenhouse study which might be related to the fact that adequate amount of phosphorus forms good root system, strong stem and good growth. High stem number per plant favored high tuber yield through effect on haulm growth and tuber number per plant (Gray and Hughes, 1978).

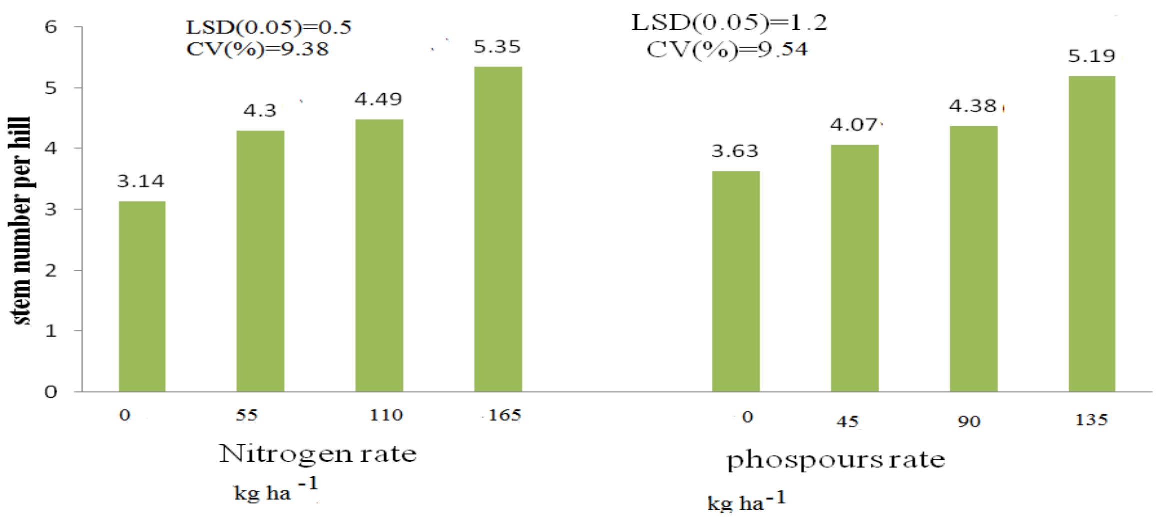

Figure 1: Mean stem number of potato as influenced by nitrogen and phosphorus rates.

4.1.3. Plant height

Interaction of nitrogen and phosphorus highly significantly ($P < 0.01$) affected mean plant height of potato (Table 5). The maximum plant height (71.6cm) was measured for the combination of 165 kg N and 135 kg P ha^{-1}, which was not significantly different from the treatment that received 110/90, 165/90 and 110/135 kg N and P ha^{-1}. While the minimum plant height (44 cm) was recorded for the control plot (Table.5). Similar trend was also observed for the combinations of 55/90, 55/135, 110/45,165/45 kg N and P ha^{-1}. A good supply of nitrogen stimulates root growth and development as well as the uptake of other nutrients (Brady and Weil, 2002).

The interaction showed that the contribution of application of phosphorus fertilizer alone in increasing plant height was almost none, while plant height increased with increasing phosphorus fertilizer levels when combined with the application of 110 and 165 kg N ha^{-1}. Increasing the rates of both N and P from zero to the maximum have increased plant height by 63% over the control. This effect might be due to the obvious role of nitrogen in enhancing vegetative growth and seemed to be more enhanced due to the presence of Phosphorus.

Results of the present experiment are in agreement with the finding of Sharma *et al*. (2014) who have reported that plant height increased with increasing fertilizer levels of nitrogen and phosphorus. This could be attributed to the enhanced availability of nutrients to the crop which may have resulted in increased photosynthetic efficiency and increased metabolic activities of the plant with an increase in fertilizer level. Similarly, Jamaati-e-Somarin *et al*. (2009) and Yibekal, (1998) have also reported that, the highest rate of 200 kg N ha^{-1} gave the highest plant height of potato, as it was observed in the present experiment that application of the highest nitrogen and phosphorus rate gave the highest plant height (71.6cm) than those of nitrogen rates applied alone. Mulubrhan (2004) and Zelalem *et al. (*2009) have also reported that increasing application of nitrogen and phosphorus highly significantly increased the height of potato plants.

Table 1. Interaction effect of N and P on plant height (cm) of potato in Dedo, South-West Ethiopia

Nitrogen(kg ha^{-1})	Phosphorus(kgha^{1})			
	0	45	90	135
0	44.03^{g}	50.40^{f}	54.57^{e}	57.46^{d}
55	57.76^{d}	59.70^{c}	61.60^{b}	66.60^{b}
110	58.20^{c}	62.70^{b}	68.46^{a}	69.47^{a}
165	58.26^{c}	65.13^{b}	69.03^{a}	71.76^{a}
LSD(0.05)	**3.4**			
CV (%)	**14.03**			

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level of significant.

4.1.4. Days to 70% maturity

The main effect of N and P was significant ($P < 0.05$) for days to70% physiological maturity of potato plants. Increasing nitrogen application from 0 to110 kg ha^{-1} shortened the number of days to physiological maturity by 6-8 days as compared to the control (Figure 2). Similarly increasing phosphorus application from 0 to 90 kg ha^{-1} shortened the number of days to physiological maturity by 9-10 days. Days to physiological maturity were statistically similar for the treatments of 45 kg P and 90 kg P ha^{-1}(Figure 2).

In line with this, the main role of nitrogen is in swift development of shoot and allows the plant to quickly complete its canopy and exploit the growth period as much as possible. (Honeycutt *et al.*, 1996) In addition to that Nitrogen increases photosynthesis/respiration ratios through increasing mature leaf number and increases assimilate accumulation in tubers and hence yield (Jenkins and Nelson, 1992). This implies that increase in nitrogen application rate up to the optimum level increased leaf number per plant and tuber yield, but applying greater amount of nitrogen stimulated foliage growth and delayed tuber formation or phonological change, as reported by Honeycutt *et al.*, (1996) and Jamaati-e-Somarin *et al.*, (2008). These conditions might be directly related to physiological maturity of potato plants, indicating that optimum nitrogen application facilitate plant maturity, however, highest level delay the process.

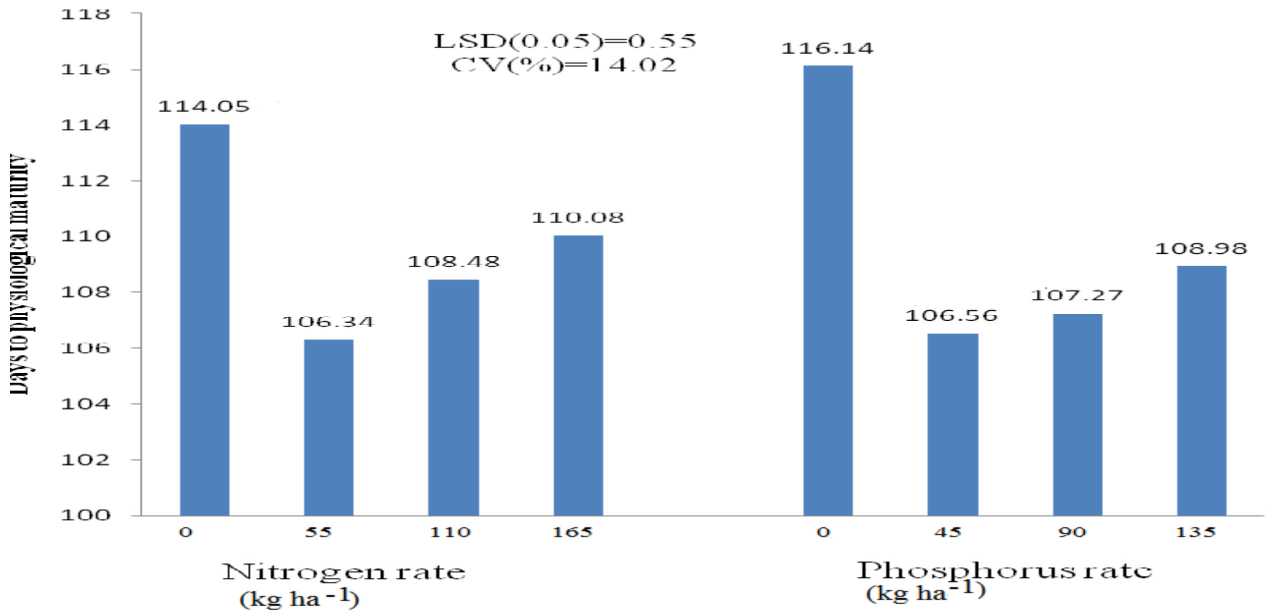

Figure 2: number of days to 70% physiological maturity of potato as influenced by nitrogen and phosphorus rates.

4.2. Yield and yield components

The interaction effect of N and P was significant (P< 0.01) for all the yield and yield component parameters total tubers number per hill (NT), marketable tuber number (MT), unmarketable tuber number (UMT), total tuber yield (TY), marketable tuber yield (MY), unmarketable tuber yield and average tuber weight (ATW).

4.2.1. Marketable tuber number per hill

Marketable tuber numbers hill^{-1} was highly significantly (P < 0.01) influenced by the interaction effects. The highest marketable tuber number (9.79) per hill was obtained from 165 kg N, and 135 kg P ha^{-1}) (Table6). While the lowest value (5.03) was recorded from the control treatment.

Increasing rates of both N and P from zero to the maximum increased marketable tuber number per hill by 94.6% over the control. Marketable tuber number was statistically similar for treatment combinations of 110/0,165/0, 55/90, and 0/45 kg N and P ha^{-1} (Table, 6). The increase in marketable tuber number with an increase in applied nitrogen was associated with a decreased in the number of small sized tubers (un- marketable tuber) due to an increase in the weight of individual tubers.

Increasing the rate of phosphorus application linearly and significantly increased the marketable tuber number. Thus, the highest value was observed at the application of 90 and 135 kg P ha^{-1} whereas the lowest was obtained from the control plot (Table 6). The increase in tuber numbers per hill in response to increased application of phosphorus is consistent with the results of Rosen *et al*. (2008).

The present finding is in agreement with the findings of Mulubrhan (2004) and Israel *et al.* (2012) who have reported that marketable tuber number increased with increasing rate of nitrogen fertilizer. Israel *et al.* (2012) have noted that increasing rate of nitrogen application from 0 to 165 kg N ha^{-1}, increased marketable tuber number per hill. Similarly, Simret *et al*. (2010) also reported that marketable tuber number increased when nitrogen supply was raised from 0 to 100 kg ha^{-1}, but did not change in magnitude beyond this level. Increasing the level of applied phosphorus from 0 to 135 kg P ha^{-1} also increased marketable tuber number per hill over the control.

Table 6: Interaction of N and P fertilizers on marketable tuber number per hill of potato plants in Dedo, South-West Ethiopia

	Phosphorus (kg ha^{-1})			
Nitrogen(kg ha^{-1})	0	45	90	135
0	5.03^{d}	5.50^{cd}	5.21^{cd}	6.13^{c}
55	5.69^{cd}	6.52^{c}	7.01^{bc}	7.75^{b}
110	7.11^{bc}	7.31^{b}	8.64^{a}	9.19^{a}
165	6.86^{c}	7.93^{d}	8.52^{a}	9.79^{a}
LSD(0.05)	**0.38**			
CV (%)	**19.1**			

Means followed by the same letters within columns and rows are not significantly different from each other at 5% level.

4.2.2. Unmarketable tuber number

Unmarketable tuber number was significantly affected by interaction of nitrogen and phosphorus levels. The highest unmarketable tuber number (8.63) per hill was obtained from

the control plot and the lowest value (3.9) was recorded for 110 kg N with 45 kg P ha^{-1}(Table 7).

Higher rates of N (165/0,110/0 kg N ha^{-1}) and P (0/90 and 0/135 P ha^{-1}) increased the unmarketable tuber numbers of the plant. However, application rates of 110/45, 55/90 and 55/135 kg N and P ha^{-1}decreased the number of unmarketable tubers produced per hill (Table 7).

High number of unmarketable tubers was observed for the control treatment. However, increment in unmarketable tuber number was observed as nitrogen application increased from 0 to 165 Kg N ha^{-1}. This could be due to the effect of nitrogen in accelerating the growth of aboveground part of plants and re-absorption in the tubers, which often leads to reduced tuber size and weight so the tubers become unmarketable.

On other hand when the phosphorus level increased from 0 to 135 kg P ha^{-1}, unmarketable tuber number per hill was reduced. This may be due to the phenomenon that phosphorus also increases above ground biomass via photosynthesis and net assimilation processes and no re-absorption evidently took place from the tubers, leading to increased tuber size and weight so the tuber could be marketable (Boral and Milthorpe, 1962).

Table 7: Interaction of N and P on un- marketable tuber number per hill of potato plants in Dedo, South-West Ethiopia

Nitrogen (kg ha-1)	Phosphorus (kg ha-1)			
	0	45	90	135
0	8.63a	5.73c	7.23b	7.20b
55	5.73c	5.63c	3.93d	4.33cd
110	7.43ab	3.90d	3.96d	4.93cd
165	8.20ab	4.367cd	5.23cd	4.26cd
LSD(0.05)	**1.62**			
CV (%)	**17.7**			

Means followed by the same letter within a column for each treatment are not significantly different from each other at 5% level

4.2.3. Total tuber number per hill

The interaction of highest level of nitrogen and phosphorus increased total tuber number by 60.6%. The maximum total tuber number was recorded for the combination of 165 kg N and135 kg P ha^{-1} (13.7/hill) and the minimum value (8.53/hill) was obtained from the control (Table 8). Increment of total tuber number per hill at 165 kg and 135 kg P ha^{-1} was statistically similar to 110 kg N and 135 kg P ha^{-1}. Similarly, increasing the level of applied phosphorus significantly increased total tuber number per hill (Table 8). Total tuber number was statistically similar in treatment combinations of 55/0, 110/0, 165/0, 110/45 and 165/45kg N and P ha^{-1} (Table 8).

The increment of total tuber number per hill with increasing nitrogen fertilizer levels could be explained by the maintenance of photosynthetically active leaves for longer duration and the formation of more new leaves than with lower or no nitrogen supply (Millard and Marshall, 1986). Increase in photosynthetic activity and translocation of photosynthesis to the sink might have helped in the initiation of more tubers. As reported elsewhere, nitrogen application to potatoes before tuber initiation increases the number of tubers per plant and mean fresh tuber weight (Kanzikwera et al., 2001).

P is relatively immobile in soil (Tisdale and Nelson, 1995) and because of its importance for early crop growth; banded application of phosphorus at planting is recommended (Rosen and Eliason, 2005). Yield response to fertilizer P has received the most attention, but there are also reports that P can affect the number of tubers and tuber size distribution. Increases in tuber set with P application have been found by Sanderson et al. (2002).

Potato tuber yield is also known to be influenced by P fertilizers through its effect on the number of tubers produced, the size of the tubers and the time at which maximum yield is obtained (Sharma and Arora, 1987). They showed that yield response to increasing levels of P fertilizer was generally positive up to a particular level, above which the response became negative. They also noted that excess use of P fertilizers is usually associated with reduced tuber weight by hastening the maturation period and reducing tuber size. Applied P has been found to increase the yield of small and medium size tubers (Hanley et al., 1965). .

In agreement with the present finding, Zelalem *et al*. (2009); Guler (2009); Zamil (2010) and Israel et al. (2012) have reported a significant tuber number increment in response to nitrogen fertilizer application. Guler (2009) and Zamil et al. (2010) have also observed the maximum tuber yield when potato plants received 300 and 254 kg nitrogen per ha. Similarly, Rosen and Bierman (2008) have reported that phosphorus fertilizer treatments significantly increased total number of tubers per hill. Sanderson et al. (2002) and Israel et al. (2012) have also noted that application of phosphorus increased the number of tubers set per unit area. On the other hand, De La Morena et al. (1994) have observed the absence of strong relationship between rates of nitrogen application and tuber number.

Table 8: Interaction of N and P on total tuber number of potato per hill in Dedo, South-West Ethiopia

	Phosphorus (kg ha-1)			
Nitrogen(kg ha-1)	0	45	90	135
0	8.53c	8.73c	9.37c	10.17bc
55	10.53b	11.13b	11.70b	12.03ab
110	10.76b	12.07ab	12.50ab	13.00a
165	10.83b	12.23ab	12.90ab	13.70a
LSD(0.05)	**1.3**			
CV (%)	**23.4**			

Means followed by the same letters within a columns and rows are not significantly different at 5% level.

4.2.4. Marketable tuber yield t ha^{-1}

The interaction of nitrogen and phosphorus was highly significantly ($P<0.0001$) influenced the marketable tuber yield. Combined application of nitrogen at the rate of 165 kg and 135 kg P ha^{-1} gave the highest marketable tuber yield (36.13 t ha^{-1}) while the lowest marketable tuber yield (19.18 t ha^{-1}) was recorded for the control plot (Table 9).

Increasing rate of nitrogen and phosphorus increased marketable tuber yield by 88.3%. Application of nitrogen at 110 kg ha^{-1} and 165 kg ha^{-1} had no significant ($P>0.05$) difference in

marketable tuber yield (Table 9). This result is in line with the finding of Simret *et al*. (2010) who reported that the optimum marketable tuber yield was attained at 100 kg N ha^{-1}, signifying that increasing nitrogen fertilizer more than this level would be wasteful for ware potato production. Zelalem *et al*. (2009) also reported that nitrogen application beyond 138 kg ha^{-1} did not bring significant yield advantage. According to Wilcox and Hoff (1970), the positive effect of nitrogen fertilizer on potato growth and yield was noted in its impact on promoting the number of tubers produced per plant, the average weight of tubers, and the establishment of optimum leaf area index and leaf area duration.

Phosphorus fertilization also significantly increased marketable tuber yield. Increasing application of phosphorus increased marketable tuber yield per hectare. The maximum marketable tuber yield was recorded at 135 kg P ha^{-1} and the minimum was obtained from the control plot. Increasing application of phosphorus from 0 to 135 kg ha^{-1} increased marketable tuber yield by 98 % over the control (Table 9).There was statistically significant difference in marketable tuber yield for phosphorus levels of 45, 90 kg and 135 kg P ha^{-1}. The increment in marketable tubers yield due to nitrogen and phosphorus application was found to be consistently significant up to the rate of 110 kg N and 135 kg P ha^{-1}, showing that these mineral nutrients can contribute much to obtain healthy and marketable size tubers.

Table 9: Interaction of N and P fertilizers on marketable tuber yield of potato (t ha^{-1}) in Dedo, South-West Ethiopia

Nitrogen kg ha-1	Phosphorus kg ha-1			
	0	45	90	135
0	3.7^{j}	14.6^{i}	17.57^{hi}	21.32^{f}
55	15.34^{hi}	21.04^{fg}	22.4^{ef}	26.04^{cd}
110	18.92^{hi}	25.32^{d}	29.93^{bc}	33.70^{b}
165	19.66^{gh}	26.74^{c}	32.67^{b}	36.13^{a}
LSD (0.05)	**3.35**			
CV (%)	**22.74**			

Means followed by the same letters within column and rows are not significantly different at 5% P level.

4.2.5. Unmarketable tuber yield (t ha^{-1})

Unmarketable tuber yield was significantly affected by the main and interaction effects of nitrogen and phosphorus (Table 10 and Appendix Table 2). This finding suggests that unmarketable tubers may be controlled more importantly through manipulating other factors such as disease incidence, pest incidence, harvesting practice, and the like rather than mineral nutrition (Berga *et al*., 1994a).

Table 10: Interaction of N and P fertilizers on, unmarketable tuber yield of potato (t ha^{-1}) in Dedo, South-West Ethiopia

Nitrogen kg ha^{-1}	Phosphorus kg ha^{-1}			
	0	45	90	135
0	9.21^{a}	4.08^{c}	3.70^{cd}	1.78^{d}
55	4.76^{bcd}	4.26^{bcd}	5.46^{bc}	4.86^{bcd}
110	3.70^{cd}	6.26^{b}	5.03^{bc}	5.37^{bc}
165	3.40^{cd}	4.63^{bcd}	5.01^{bc}	6.137^{b}
LSD(0.05)	**2.94**			
CV (%)	**22.56**			

Means followed by the same letters within column and rows are not significantly different at 5%P level.

4.2.6 Total tuber yield (t/ha)

The interaction of nitrogen and phosphorus was highly significant (P<0.0001) for total tuber yield per hectare. Increasing the rate of both nitrogen and phosphorus consistently increased total tuber yield from 12.91 to 42.27 t ha^{-1}. The highest total tuber yield was recorded for the combined application of 165 kg N and 135kg P ha^{-1} (42.27 t ha-^{1}) and the lowest value (12.91 t ha^{-1}) was obtained from the control (Table 11). Application of nitrogen above 110 kg N ha^{-1}, and phosphorus application above 90 kg ha^{-1} could be recommended for total tuber yield of potato. Statically similar result of total tuber yield was recorded at combined application of 55/0, with 0/45, 110/0 with 0/90, 165/90 with 110/135 kg N and P ha^{-1} (Table 11). Similar to the present finding, an increase in total tuber yield in response to nitrogen fertilization has been reported by several researchers such as Westerman *et al*. (1994a); Maier *et al*. (1994b) and Berga *et al*. (1994) who observed a maximum tuber yield harvest at the rates of 165 kg N and

90 kg P ha^{-1}. Similarly, Mulubrhan (2004); Zelalem et al. (2009) and Guler (2009) have reported highly significant increases in total tuber yield in response to increased level of nitrogen application. Westerman and Kleinkopf (1987) also noted that increase in the application of nitrogen fertilizer up to a certain level increases yield of potato but since then, it has no effect on the increase in yield. Reduction in yield due to high rate of N application could be explained by a phenomenon that extra nitrogen application often stimulates shoot growth at the expense of tuber initiation and bulking (Sommerfeld and Knutson, 1965).

Application of phosphorus also highly significantly increased total tuber yield of potato. In general, different rates nitrogen and phosphorus fertilizer application had yield advantage (Table 11). In line with the present finding, Mulubrhan (2004) and Israel (2012) have reported that increasing phosphorus application increased total tuber yield.

Table 11: Interaction of N and P fertilizers on total tuber yield (t ha^{-1}) of potato in Dedo, South-West Ethiopia

	Phosphorus kg ha^{-1}			
Nitrogen kg ha^{-1}	0	45	90	135
0	12.91j	18.68i	21.27hi	23.10gh
55	20.10i	25.30fg	27.86ef	30.90de
110	20.85hi	31.92cd	34.96bc	39.07b
165	23.06gh	31.37d	37.70b	42.27a
LSD (0.05)	**3.35**			
CV (%)	**13.38**			

Means followed by the same letters within column and rows are not significantly different at 5% P level.

4.2.7. Average tuber weight

The average tuber weight was found to be significantly (P<0.01) affected by nitrogen and phosphorus fertilizer, however, the interaction of nitrogen and phosphorus was not significant (P>0.05) (Appendix Table 2, and fig.3). Increasing level of nitrogen from 0 to 165 kg ha^{-1} increased average tuber weight by 50.56%. The highest average tuber weight (78.97g/tuber) was observed for 165 kg N ha^{-1}, while the lowest (52.45g/tuber) was for the control plot

(Fig.3). Average tuber weight progressively increased with increasing nitrogen rate up to 165 kg ha$^{-1.}$ Similarly, phosphorus application highly significantly increased average tuber weight. Increasing rate of phosphorus from 0 to 135 kg ha^{-1} increased average tuber weight by 27.24%.The maximum average tuber weight (76.45g/tuber) was recorded for the highest level of phosphorus (135 kg P ha^{-1}),the minimum (60.08g/tuber) was obtained from the control treatment (Fig.3). In agreement with the present finding, Mulubrhan (2004); Guler (2009); Jamaati-e-Somarin *et al*. (2010) and Israel *et al*.(2012) have reported a significant increase in average tuber weight in response to nitrogen application. Jamaati-e-Somarin *et al.* (2010) have also showen that variation in tuber yield due to nitrogen treatments was related to the tuber weight increment. Similarly, Mulubrhan (2004) and Israel *et al.* (2012) have reported that average tuber weight increased in response to the application of phosphorus. The increase in average tuber weight of potato with the supply of fertilizer nutrients could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthesis, which helped in producing bigger tubers, hence resulting in higher yields.

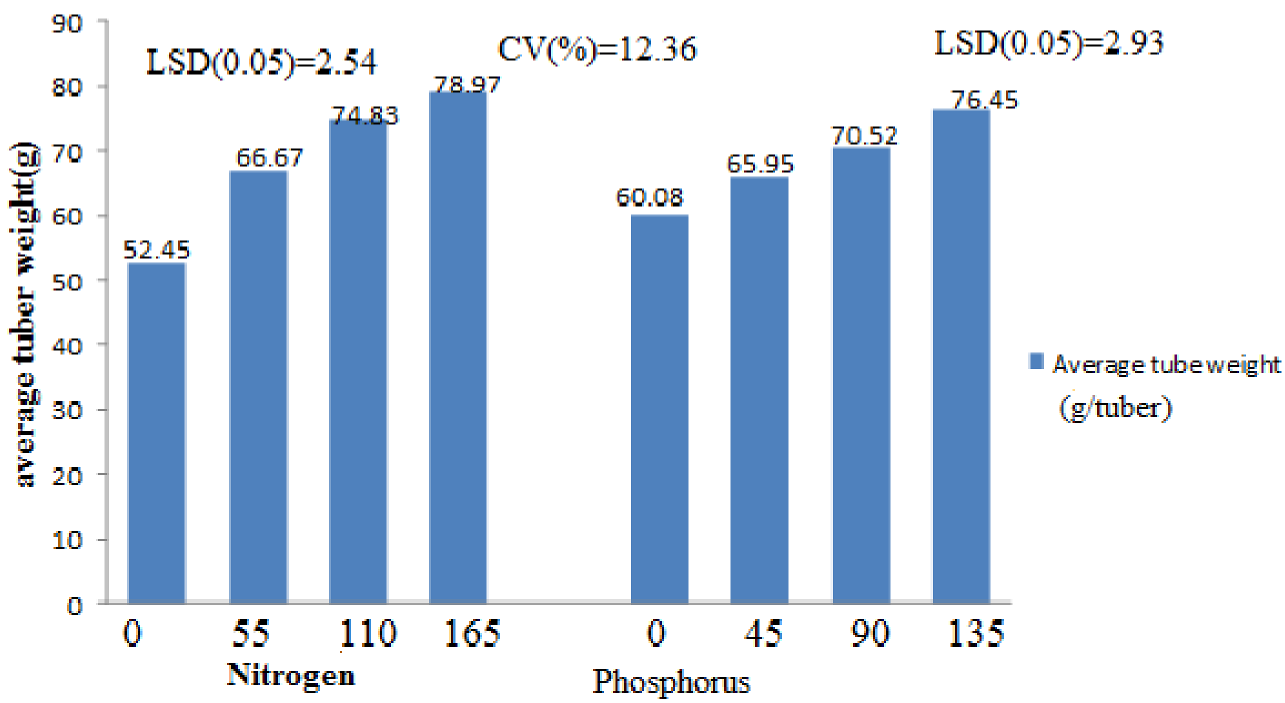

Figure 3: Mean average tuber weight g/tuber of potato as influenced by nitrogen and phosphorus rates.

4.3. Tuber Quality Parameters

4.3.1. Specific gravity

Specific gravity of tubers was significantly affected by the interaction of nitrogen and phosphorus levels, (Table 12 and Appendix 3). Increasing nitrogen application at the combination of 55/0, 110/0, 0/45, 0/90, and 0/135 and had no significant difference or effect. The highest specific gravity (1.16%) of potato tubers was recorded for the plot that received a combination of zero kg ha^{-1} N and 135 kg ha^{-1}, P while the lowest (1.06%) value was obtained fromthe combination of five treatments: 55/45,110/45,165/45,165/135 and 110/135 kg N and P ha^{-1} (Table 12). Similar to this result Robert and Cheng (1988) and Simret *et al.* (2010) have noted a non-significant difference in specific gravity of tubers due to nitrogen treatment. Zelalem *et al.* (2009) have also reported non-significant effect of phosphorus on the specific gravity of potato tubers. Furthermore, Dubetz and Bole (1975) and Adhikari and Sharma (2004) have also observed that high levels of phosphorus did not influence specific gravity of potato tubers.

Table 12: Interaction effect of N and P fertilizers on specific gravity of potato tubers (g/cm^3)

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})			
	0	45	90	135
0	1.10^{ab}	1.13^{a}	1.16^{a}	1.12^{a}
55	1.15^{a}	1.06^{b}	1.09^{b}	1.15^{a}
110	1.14^{a}	1.06^{b}	1.07^{b}	1.06^{b}
165	1.10^{ab}	1.06^{b}	1.06^{b}	1.08^{b}
LSD(0.05)	**0.7**			
CV (%)	**3.2**			

Means followed by the same letter(s) for each treatment combination are not significantly different from each other at 5% p level.

4.3.2. Dry matter content of potato tubers

The interaction of nitrogen and phosphorus significantly ($P < 0.05$) influenced dry matter content of potato tubers (Table 13). The highest dry matter percentage (27.27%) of potato tuber was recorded for plots that received the combination of 110 kg ha^{-1} N and 90 kg ha^{-1},P while the lowest value (22.17%) was obtained from the combination of highest (165 kg ha^{-1}) level of nitrogen and zero level of Phosphorus (Table 13). This could be attributed to delay

tuber initiation and maturity due to high rates of nitrogen. As a result, tubers tend to be harvested immature with low dry matter percentages.

The interaction effects show that the least percent dry matter content (22.17%) of potato tubers recorded for the application of the highest rate of N (165 kg ha^{-1}) alone was significantly improved to 26.46%, when this level was combined with 90 kg P ha^{-1}(Table 13). Therefore, the results of the present study suggest that higher application rate require higher level of phosphorus for maintaining percent dry matter content of potato tubers at higher levels in the district. These results are in agreement with the findings of Cucci and Lacolla (2007) who have observed a significant increase in the tuber dry matter percentage with increasing nitrogen and phosphorus levels up to 200 kg N and 50 kg P ha^{-1}.The authors also reported that dry matter percentage decreased at the highest nitrogen level, without any difference being observed with the change in the phosphorus rate.

Table 13: Interaction effect of N and P on percent dry matter content of potato tubers

Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})			
	0	45	90	135
0	24.58^{abc}	26.03^{a}	22.25^{c}	23.34^{b}
55	25.92^{ab}	22.96^{bc}	24.53^{abc}	24.85^{ab}
110	24.91^{abc}	22.83^{bc}	27.27^{a}	23.25^{b}
165	22.17^{c}	22.47^{bc}	26.46^{a}	23.35^{b}
LSD(0.05)	**2.63**			
CV (%)	**6.54**			

Means followed by the same letter(s) for each treatment combination are not significantly different at 5% P level.

4.4. Correlatuib analysis

The correlation analysis was performed to determine simple correlation coefficient between growth, yield and quality parameters as affected by N and P application. The present finding has indicated that plant height was positively correlated with main stem number and days to

flowering (r = 0.49). Marketable tuber number was significantly and positively correlated with number of main stem (r = 0.38**), plant height(r = 0.48**) and total tuber number (r = 0.90**). Many yield components and plant height contributed to marketable tuber yield increment because marketable tuber yield was found to be strongly and positively associated significantly with number of main stem(r = 0.58**), plant height(r = 0.94**), days to flowering (r = 0.50**), days to maturity (r = 0.66**), marketable tuber (r = 0.56**) and total tuber yield (r = 0.98**). The present finding indicated that yield components and plant height contributed to total tuber yield increment because total tuber yield was highly and positively correlated with plant height (r = 0 .94**), main stem number (r = 0.44**), days to flowering (r = 0.44*), and marketable tuber number (r =.43**). The present finding also showed that average tuber weight was significantly and positively correlated with plant height (r = 0.94**), number of main stem (r = 0.44**), marketable tuber (r = 0.49**), marketable yield (r = 0.91) and total tuber yield (r =-0.44**). It is inversely (negatively correlated) related with days to flowering and days to maturity (r = -0.65**) (Table14).

Table 14: Correlatuib analysis on growth, yield, yield components and quality parameters of potato

PAR.	FLD	NMS	PHT	DOM	MT	UMT	NT	MY	UMY	TY	ATW
FLD	1										
NMS	-.541**	1									
PHT	-.400**	.495**	1								
DOM	.676**	-.373**	-.632**	1							
MT	-0.284	.381**	.479**	-0.095	1						
UMT	-0.016	0.043	-0.278	.374**	.620**	1					
NT	-0.17	0.239	0.117	0.151	.903**	.897**	1				
MY	-.502**	.501**	.937**	-.664**	.556**	-0.194	0.207	1			
UMY	.345*	-.377**	-0.189	0.174	-.700**	-.651**	-.750**	-.290*	1		
TY	-.440**	.439**	.936**	-.654**	.424**	-.353*	0.047	.975**	-0.076	1	
ATW	-.445**	.437**	.941**	-.651**	.492**	-0.26	0.135	.908**	-0.187	.907*	1

NMS=number of main stem, PHT=plant height, DOM=days to maturity, NT=number of tuber, MT=marketable tuber, UMT=unmarketable tuber, TY=total tuber yield, MY=marketable yield, UMY=unmarketable yield, ATW=average tuber weight, DMC=dry matter content, SG=specific gravity,, **and*** indicate significant difference at probability level of 5 %, 1% and 0.1% respectively.*

5. SUMMARY AND CONCLUSION

Potato is one of the most widely cultivated vegetable crops in the highlands of Jimma. Farmers in the study area produce potato both as food and cash crop under irrigation and rain fed conditions. Yield and productivity of potato is far below the national average yield especially under irrigation potato production condition, owing to several factors; poor crop management practice and low soil fertility are the critical problems observed in most farmers' field. To improve the production and productivity of the crop, soil fertility management has to be the primary role of the producers. Fertility status of the soil is one of the most important factors for profitable and sustainable crop production. To this effect, a study was conducted to investigate the effect of nitrogen and phosphorus application on the yield and yield components of potato. The study was carried out in Jimma zone, Dedo district, which lies at an elevation of 2400 meters above sea level. The experiment was laid out in a Randomized Complete Block design in factorial combinations with three replications. The treatment consists of the combinations of four levels of N (0, 55, 110 and 165 kg/ha) and four levels of P (0, 45, 90, and 135 kg/ha) under irrigation. The results of the study showed that the interaction effects of N and P as well as their main effect had considerable influence on growth, yield component and quality parameters of potato.

The treatment at the rate of 165 kg N/0 kg P ha^{-1} and the control delayed days to flowering. The shortest days to attain 50% flowering (49.90 and 50.10 days) were recorded at 0/90 and 55/90 kg N and P ha^{-1}. Increasing phosphorus application from 0 to 135 kg ha^{-1}significantly increased main stem number per hill from 3.63 to 5.19 and increased main stem number by 42.97%. The highest mean main stem number per hill (5.19) was obtained at the highest level of phosphorus (135 kg P ha^{-1}), while the lowest value (3.63) was obtained from the control.

The largest plant height (71.6cm) was measured at the combination of 165 kg N and 135 kg Pha^{-1}, while the lowest plant height (44 cm) was recorded from the control. Plant height was statistically similar in treatment combinations of 55/0, 110/0 and 165/0 kg N and P ha^{-1}. Increasing the rates of both N and P from zero to the maximum also increased plant height by 63% over the control. The maximum days to attain 70% physiological maturity (114.05 days)

was recorded at lowest level of N (0 kg ha^{-1}) and minimum days to attain physiological maturity (106.34 days) was recorded at 55 kg N ha^{-1}. Increasing phosphorus applications from 0 to 135 kg ha^{-1} shorten number of days to physiological maturity by 9-10 days from the control.

Yield and yield components of potato were affected with application of N and P at different levels. Highest mean marketable tuber number (9.79) $hill^{-1}$ was obtained at 165 kg N and135 kg P ha^{-1}) while lowest marketable tuber number (5.03) $hill^{-1}$ was recorded at lowest nitrogen (0 kg N ha^{-1}) level. Increasing the level of applied nitrogen and phosphorus kg ha^{-1} increased marketable tuber number $hill^{-1}$ by 94.6% over the control. The interaction of nitrogen and phosphorus increased total tuber number by 60.6%. The maximum total tuber number was recorded at the combined application of 165 kg N with 135 kg P ha^{-1} (13.7 $hill^{-1}$), and the minimum total tuber number (8.53 $hill^{-1}$) was obtained from the control. The interaction effect of nitrogen and phosphorus was also highly significantly ($P<0.0001$) influenced the marketable tuber yield. Combined application of nitrogen and phosphorus at the rate 165 kg N and 195 kg P ha^{-1} gave the highest marketable tuber yield (36.13 t ha^{-1}) and the lowest marketable tuber yield (19.18 t ha^{-1}) was recorded from the control. Increasing the rate of nitrogen and phosphorus application was strongly increased total tuber yield from 12.91 to 42.27 t ha^{-1}. The highest total tuber yield was recorded for the combined application of 165 kg N and 135 kg P ha^{-1} (42.27 t ha^{-1}) and the lowest value (12.91 t ha^{-1}) was obtained from the control.

The maximum mean average tuber weight (78.97g) was observed at 165 kg N ha^{-1} while the lowest (52.45g) was at the control. Increasing level of nitrogen from 0 to 165 kg ha^{-1} increased average tuber weight by 50.56%. The highest average tuber weight (78.97g) was observed at 165 kg N ha^{-1} while the lowest (52.45g) was at the control. Average tuber weight progressively increased with increasing nitrogen rate up to 165 kg ha^{-1}. Similarly applied phosphorus highly significantly increased average tuber weight. Increasing application of phosphorus from 0 to 135 kg ha^{-1} increased average tuber weight by 27.24%.The maximum average tuber weight (76.45 g) was recorded at the highest level of phosphorus application in the treatment (135 kg p ha^{-1}). The minimum (60.08g) was obtained at the control treatment.

The interaction effect of nitrogen and phosphorus significantly ($P < 0.05$) influenced dry matter content of potato tuber. The highest dry matter (27.27%) percentage of potato tuber was recorded from plots that received the combination of nitrogen 105 kg ha^{-1} and phosphorus 135 kg ha^{-1}, while the lowest (22.17%) tuber dry matter percentage was obtained at the combination of highest (165 kg ha^{-1}) level of nitrogen and zero level of phosphorus. Tuber dry matter was significantly decreased at the combination of highest level of nitrogen fertilizer and lowest level of phosphorus or zero level of P.

In conclusion the result of this study show that different nitrogen and phosphorus rates and their interaction have a sound and promising impact on growth and yield of potato. Therefore, on the basis of the results of the present study farmers can tentatively use 110 kg $ha^{-1}$of nitrogen in combination with 135 kg phosphorus. However, further verification of the results on multi sites and years is suggested along with economic threshold considerations.

6. FUTURE LINE OF WORK

Optimization of fertilizers for the different varieties under different agro-ecological condition to understand their yield performance is suggested. Further, combined experiments with other fertilizers in different location and soil types may reflect the sustainability of this practice and investigation of economic threshold points.

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7. APPENDIX

Appendix 1. Analysis of variance probability values for growth parameters of Potato: variety Belete in Dedo south west Ethiopia

Source of variance	DF	Flowering day (50%)	Main stem number	Plant height	Dayto70% of maturity
Nitrogen(N)	3	<0.0001	0.0405	<.0001	<0.0001
Phosphorus(P)	3	<0.0001	<0.0001	<.0001	<0.0001
N*P	9	<0.0001	0.0875	0.0166	0.0392
Replication	2	0.9696	0.5290	0.8855	0.1210
CV (%)		3.48	14.03	2.51	1.136

DF =degree of freedom, N*P=Interaction between nitrogen and Phosphorus, FLD=flowering day, MST=main stem number, PH=plant height and DOM=days to maturity.

Appendix 2. Analysis of variance probability values for yield and yield components of Belete potato variety in Dedo South West Ethiopia

Source of variance	DF	MTN	UMTN	TTN	MY	UMY	TY	ATW
Nitrogen(N)	3	0.0001	0.0057	<0.0001	<0.0001	0.6550	<0.0001	<0.0001
Phosphorus(P)	3	<0.0001	<0.0001	<0.0001	<0.0001	0.4053	<0.0001	<0.0001
N*P	9	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0213
Replication	2	0.5072	0.6921	0.9941	0.7094	0.2561	0.9780	0.0314
CV (%)		4.72	9.81	5.22	6.86	23.43	5.85	4.29

DF=degree of freedom N*P=interaction between nitrogen and phosphorus, MTN=marketable tuber number, UMTN =un-marketable tuber number, TTN= total tuber number, MTY= marketable tuber yield, UMTY=unmarketable tuber yield TTY=total tuber yield, and ATW=average tuber weight.

Appendix 3. Analysis of variance probability values for Physical quality parameters

Source of variance	DF	Specific gravity	Dry matter content
Nitrogen(N)	3	<0.0001	0.3715
Phosphorus(P)	3	0.0005	0.0760
N*P	9	<0.0001	0.0015
Repelication	2	0.0693	0.2229
CV (%)		1.67	6.43

DF=degree of freedom N*P=interaction between nitrogen and phosphorus, SG=specific gravity and DMC=dry matter content.