EFFECT OF PLANTING DENSITY AND NPS FERTILIZER RATE ON GROWTH, YIELD AND YIELD COMPONENETS OF POTATO (*Solanum tubersum* L.) AT JIMMA, SOUTH WEST ETHIOPIA

M.Sc. Thesis

By

JEMAL KASSAW

JUNE 2020

Jimma, Ethiopia

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Submitted to the Department of Horticulture and Plant Sciences, School of Graduate Studies, College of Agriculture and Veterinary Medicine, Jimma University, in partial fulfillment of the requirements for the Degree of Master of Science in HORTICULTURE

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June 2020

Jimma, Ethiopia

SCHOOL OF GRADUATE STUDIES

JIMMA UNIVERSITY

COLLEGE OF AGRICULTURE AND VETERINARY MEDICINE

MSc THESIS APPROVAL SHEET

We, the undersigned, member of the Board of Examiners of the final open defense by **Jemal Kassaw** have read and evaluated his/her thesis entitled **"Effect of Planting Density and Nps Fertilizer on Growth, Yield and Yield Component of Potato (Solanum Tubersum L.) At Jimma, South West Ethiopia"** and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Master of Science in **Horticulture**

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DEDICATION

I dedicate this thesis to my parents.

STATEMENT OF AUTHOR

First, I declare that this thesis is a result of my genuine work and that I have duly acknowledged all sources of materials used for writing it. This thesis has been submitted in partial fulfillment of the requirements of M.Sc. degree at Jimma University, College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to users under rules of the Library. I declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is for scholarly interest. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

The author, Jemal Kassaw Abebe, was born in Abamela Kebele, Tenta Woreda, South Wollo Zone of Amhara Regional State in Ethiopia in 1995 GC. He attended Elementary and Secondary school education at Kologenet and Adjibar Secondary Schools, respectively. In 2012, he joined Mizan Tepi University and graduated with BSc degree in Horticulture in June 2014 GC. After graduation, he was employed by Mizan Tepi University as assistant lecturer in September 2015 GC. Then, he joined the School of Graduate Studies of Jimma University in September 2019 G.C to pursue a study leading to the Degree of Master of Science in Horticulture.

ACKNOWLEDGMENTS

First and foremost, I would like to praise and glorify the supreme Almighty Allah for providing me with the strength and patience that I acquired to complete the study. I would also like to express my deepest and heartfelt thanks as well as my most sincere appreciation and gratitude to my major advisor Dr. Amsalu Nebiyu and my co-adviser Dr. Weyessa Garedew for their keen interest, dedicated and meticulous supervision, for amicably motivating and scientifically supporting me during the whole period of the study. I also thank them for genuinely and constructively criticizing my work from the time of inception of the research work up to its completion and thesis write-up. The visits they made to my research field on a number of occasions and the scientific discussions I held with them in the research undertaking were exemplary and worthy of deepest gratitude.

Moreover, I am indebted to my best friends Yimamu for his encouragement and sharing experience and skills during data collection periods and all stage of research. I would like to express my sincere gratitude to my mother Mulu Mergiyaw, my father Kassaw Abebe, my best wife Medina Sissay and my family for their dedication and strong support throughout my study.

I would also like to thank Jimma University College of Agriculture and Veterinary Medicine for financial support, providing the experimental field and other valuable materials during the study. My special gratitude is extended to the staff members of Jimma University College of Agriculture and Veterinary Medicine soil laboratory for their unreserved effort to cooperate with me in soil analysis.

LIST OF ABBREVIATIONS

ABA	Abscisic acid
ANOVA	Analysis of Variance
ATA	Agricultural Transformation Agency
CEC	Cation Exchange Capacity
CSA	Central Statistical Agency
DAP	Di-ammonium phosphate
EARO	Ethiopian Agricultural Research Organization
FAO	Food and Agriculture Organization
IAA	Indole-3-acetic acid
LSD	Least Significant Difference
MOA	Ministry of Agriculture
RCBD	Randomized block design methods

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ABSTRACT

Potato (*Solanum tuberosum* L.) *is an important leading tuber crop for food and nutrition security as well as cash crop for smallholder farmers in Ethiopia. However, the yield of the crop is low at national as well as regional level which is constrained mainly by in appropriate planting density and low soil fertility. There is a need to optimize planting density and fertilizer to enhance crop growth and tuber yield. Therefore, a field experiment was conducted to investigate the effect of planting density and NPS fertilizer on growth, yield and yield components of potato at Jimma, south- western Ethiopia during the rainy season of 2019/2020. Four levels of intra-row spacing (20, 25, 30 and 35 cm) and four levels of NPS fertilizer (0, 75, 150 and 225kg ha*$^{-1}$ *NPS) were arranged in a randomized complete block design with 3 replicates as a 4 x 4 factorial combination. Results of the experiment indicated that the main effects of intra-row spacing and NPS fertilizer as well as the interaction effects highly significantly affected days to 50% flowering, plant height, main stem number, days to 75% physiological maturity, total tuber number per hill, weight of tubers, marketable tuber number per hill, unmarketable tuber number per hill, total tuber yield (t ha*$^{-1}$*), marketable tuber yield (t ha*$^{-1}$*) and unmarketable tuber yield (t ha*$^{-1}$*).Total tuber yield increased with the increased plant population and NPS fertilizer. The highest total tuber yield (40.36 ton ha-1) was obtained from the treatment combination of 20 cm intra-row spacing and 225kg ha*$^{-1}$ *NPS. On the other hand, the lowest total tuber yield (13.4 tons ha*$^{-1}$*) was recorded for the treatment combination of 35cm intra-row spacing and zero NPS fertilizer application. Based on the partial budget analysis, the treatment combination of 30 intra-row spacing and 225kg ha+ NPS fertilizer gave the maximum net return of Birr 404255.3 ha*$^{-1}$*.*

Key Words: Fertilizer, Marketable Yield, Plant Spacing

1. INTRODUCTION

Potato (*Solanum tubersum* L.) is the world's 4th most important food crop next to wheat, maize and rice, third most important food crop in terms of consumption (FAOSTATE, 2019) and first in production from root and tuber crops (Getachew *et al*., 2018). Its production in the developing world was increased, due to its important contribution to food security (Ernest *et al.,* 2018).

It contributes to world food security and has a critical role to play in developing nations facing hunger (Gebru *et al*., 2017). According to Liu *et al*. (2014), potato produces more nutritious food quickly on less land than any other crops. It Produces high yields, nutritionally valuable in the form of tubers that improves the household's income and food security (Arega *et al*., 2018), due to its plasticity to environmental conditions, short life span and high yielding (Milla, 2006; Gebru *et al.,* 2017).

Potato tubers are rich in calcium, potassium and vitamin C and good amino acid balance as a source of diet (Jaren *et al.*, 2016). It is used as raw material for industry were value added products for the French fry, chipping, starch processing and Better Potato for Better Life production (Douches, 2015; Miethbauer *et al*., 2015; Bekel and Hailu, 2019).According to Tony (2006), potato used for production of alcohol and feed for animals.

Average national potato yield was 13.137 from 75234.14 ha^{-1} of cultivated land during 2018/19 Maher cropping seasons and the Oromia regional actual yield was 16.57t ha^{-1} from 17,927.72ha^{-1} of land (CSA, 2019), But in Jimma zone (south west Ethiopia) yield of potato was only 11.75 t ha^{-1} respectively (Seid Mohammed, Personal communication,2020).

Average national and regional potato production potentials are low compared to world average production potential. The constraints that cause low productivity of potato are insufficient quality seed tubers for planting, low soil fertility, lack of maintain appropriate planting density, poor fertilizer management practices and scarcity of information on good fertilizer managements (Mohammed *et al*., 2018). On the other hand, diseases, drought, insects problems, lack of sufficient irrigation water, limited access to supply of agricultural inputs hinder potato production (Kemaw *et al*., 2017).According to Mazengia (2016); Gebru *et al.* (2017); Arega *et al*. (2018), the major factors for decreasing the yields of potato under smallholder growers in Ethiopia are lack of awareness on uses of improved varieties, misuse of inorganic fertilizers and poor agronomic practices.

To improve the gap in productivity between national and world wide, modern agricultural practices depends on widespread use of fertilizer. This approach has certainly increased tuber yields in many countries in the last three decades (Koushal *et al.,* 2011). According to kumer *et al.* (2019) report the use chemical fertilizers are the major cause of sufficient crop production for the world population.

The soil in the south western part of Ethiopia is low in soil organic matter, cation exchange capacity (Westermann, 2005). Low level of soil organic matter combined with poor land coverage have resulted in many production problems accounted for the low yield of potato in south western part of Ethiopia. On top of this, information on soil fertility studies for potato production in this region limited (Wakene, 2009) and hence, there is inadequate site specific fertilizer recommendation. Due to this reason fertilizer application practices in Jimma zone has been based on the experiences of other regions and this could be one of the reasons for low yield of potato in the area. To substitute nutrient deficit in the study area, farmers often use inorganic fertilizers like Urea as a source of nitrogen and Di-ammonium phosphate (DAP) as a source phosphorous for increasing potato yields, since these were the only fertilizers commercially available in the local market. Farmers usually follow a blanket recommendation of 100kg urea and150 kg of DAP per hectare.

The optimization of plant density is one of the most important subjects of potato production management, because it affects seed cost, plant development, yield and quality of the crop (Bussan *et al.,* 2007).The yield of seed potato can be maximized at higher plant population (closer spacing) or by regulating the number of stems per unit area and to certain extent by removing the haulm earlier during the maturity (Obrien and Allen, 2009). Moreover, inadequate application of proper agronomic management practices particularly time and rates of fertilizer application, and inter and intra row spacing used by potato growers determine the potato productivity (Girma, 2001; Daniel, 2006). Farmers in south western part of Ethiopia are using similar spacing for seed and ware potato production (25-30cm between plants) system which finally results in poor quality and different sized tuber seeds(Gebremedhin *et al.,* 2008).

It was reported that, the sub-optimal agronomic management practiced were the major contributing factors for low yield of potato cultivars (Gebremedhin *et al.*, 2008). Still many potato producer farmers in the area (Jimma zone) frequently give less attention to optimal plant population due to lack of sufficient land and high planting density supposedly yields more tuber number without considering size of tuber. In general, the poor crop management practices observed in most farmers' fields include the use of too low or too high plant density, inter and intra row spacing, poor quality seed material, inappropriate land preparation, time of planting, depth of planting, ridging, harvesting techniques and crop rotation.

However, information on maintaining appropriate plant population per unit area along with mineral NPS fertilizers is not available and understood by smallholder farmers to increase the growth and yield of potato in Jimma zone, Southwestern Ethiopia. Hence it is imperative to develop a verified research result on the use of planting Density with NPS fertilizers for the optimum production of potato. Therefore, this study was initiated with the following general and specific objectives.

1.1 General objective

- To examine effect of NPS fertilizer and planting density on growth, yield and yield components of potato under Jimma condition

1.2 Specific objectives

- To assess growth and yield responses of potato to NPS fertilizer rate under Jimma condition
- To determine the effect of intra row spacing on growth and yield of potato
- To assess the combined effect of plant population and NPS fertilizer on yield and yield component of potato
- To determine the best economic return of inter and intra row spacing for potato production

2. LITERATURE REVIEW

2.1. Botanical Description of potato

Potato is an annual and herbaceous plant that produces edible underground tubers that are used as vegetable (Struik and Wiersema, 2001). Potato belongs to Solanaceae family, with a basic set of 12 chromosomes (x = 12). It belongs to the genus *Solanum*. *Solanum tuberosum* L., which is tetraploid (4n=48), is the most commonly cultivated species (Rosa *et al*., 2010). According to the latest classification there are only four cultivated species namely *S. tuberosum*, *S. ajanhuiri*, *S. juzepczukii* and *S. curtilobum* (Spooner *et al*., 2007).

S.tuberosum is most predominant and widely grown species. The roots are fibrous and the tubers are enlarged portion of underground stem called stolon. The stem is angular, branched and bears pinnately compound, alternate leaves up to 30 cm long with small interjected leaflets between the main pinnae. The inflorescence is cyme and flowers are of varying colours like yellow, white, red, blue, pink or purple with yellow stamens inserted on short corolla tube but are rarely produced under conditions in which day lengths are short and temperatures are high. Potato is autogamous, but some amount of cross pollination occurs mostly by insects (Bumblebees). The fruits are small inedible berries and contain poisonous alkaloids (Solanine) (Rice *et al*., 2013). Generally white flowered varieties produce white skinned tubers and pinkish skinned tubers are produced by varieties with colored flowers (Winch, 2010). Potatoes are propagated through tubers, cut pieces of tubers with at least one or two eyes and "true seeds".

2.2. Potato production in the world

Potato (Solanum tuberosum L.) belongs to the family of Solanaceae and genus Solanum (Haward, 1969). It is the world's 4th most important food crop next to wheat, maize and rice, third most important food crop in terms of consumption (FAOSTATE, 2019) and first in production from root and tuber crops (Getachew *et al*., 2018). Potato has it is origin in the Andes of South America and was first cultivated in the Andes in the vicinity of Lake Titicaca near the present border of Peru and Bolivia (Haan and Rodriguez, 2016). It has dispersed from their origin to many countries around the world. Currently is produced in over 150 countries in areas from sea level to 4,000 meter in the tropical highlands and throughout the temperate zone (Liu *et al.*, 2014).

Potato (*Solanum tuberosum* L.) is one of the most important agricultural crops in the world. The global production of potato was 388191000t from 19302600 ha^{-1} of land in average yielding of 20.12t ha^{-1}, which feeds more than billion people around worldwide. The leading potato producing countries in the world are China, India and Russian federations (FAOSTATE, 2019). Africa potato production is reached over 30 million tons in the year 2013 (FAOSTATE, 2015). In volume of production, it ranks fourth most important food crop next to wheat, maize and rice, third most important food crop in terms of consumption (FAOSTATE, 2019) and first in production from root and tuber crops (Getachew *et al*., 2018). Its production in the developing world was increased, due to its important contribution to food security (Ernest *et al.*, 2018). Potato production and utilization has been established well than other root and tuber crops. Potato yields on average of more food energy and protein per unit of lands than cereals. The lysine content of potato complement cereal based diets that are deficient in this ammonium acid.

2.3. Potato production in Ethiopia

Potato crop was first introduced in Ethiopia around 1858 by Schimper, a German botanist (Pankhurst, 1964; Teshome, 2016). Ethiopia was endowed with great potential and suitable edaphic and climates for potato production and productivity (Diro, 2016). In Ethiopia, potato is mostly grown in four major areas, Central, Eastern, Northwestern and southern parts of Ethiopia (Hirpa *et al.*, 2015) and are major food crops that are consumed across the country (CSA, 2019).Since then, Potato has become an important garden crop in many parts of Ethiopia and it ranks first among root and tuber crops in volume produced and consumed followed by Cassava, Sweet potato and Yam (CSA, 2017). It is a high potential food security crop in Ethiopia due to its high yield potential, nutritional quality, short growing period and wider adaptability (Tewodros *et al*., 2014).

It is a crop with high potential to contribute to poverty reduction and becoming an important food crop in Ethiopia. The potato crop can contribute to improving food and nutritional security. It is regarded as a high potential food security crop for densely populated highland regions because of its ability to provide a high yield per unit input with a short crop cycle than major cereal crops (Hirpa *et al*., 2010), hence the Ethiopian government has identified it as one of the priority crops for agricultural growth program (Tesfaye *et al*., 2012).

Especially in rain fed systems this is of essence, as it makes potato one of the first crops that can be harvested after the onset of the rainy season. In conditions of food shortage this makes potato an essential 'hunger is breaking' crop to assure staple food before grains can be harvested. Recently, the government of Ethiopia declared that potato to be a national strategic food security crop (Abebe, 2017). The growing importance of potato as a food crop is prefaced on rising food insecurity in the country. Increasing potato production on a sustainable basis will enable the crop to assert as a national strategic food security crop and help ease the food security challenges of the country.

2.4. Ecological Requirement

Potato (*Solanum tuberosum* L.) is a weather sensitive crop with a wide variation among cultivars. It is a crop of temperate climate and it is moderately tolerant to frost (Rezaul *et al*., 2011). Potato grows well and produces yields at an altitude of over 1000 meters above sea level, although recently produced cultivars perform well at low elevations ranging from 400 to 2000 meters above sea level in tropical highlands (Levy and Veilleux, 2007). Elevations range between 1800 to 2500 meters above sea level is regarded as suitable for potato growth (Woldegiorgis and Chindi, 2016)..A rainfall ranging between 500 and 750 mm uniformly distributed during the growing period is required for optimum growth (Stol *et al*., 1991). Irrigation is required where rainfall is unreliable (Makani *et al*., 2013)

2.5. Production of potato under irrigated condition

An adequate water supply is required from tuber initiation up until near maturity for high yield and good quality. Applying water in excess of plant needs compromises the environment, may harm the crop, and is expensive for growers. Excessive irrigation of potatoes results in water loss and significantly increases of runoff and soil erosion from production fields to rivers, streams, and reservoirs. Leaching can lead to contamination of the groundwater due to lixiviation of fertilizers and other chemical products (Al-Jamal *et al*., 2001). Irrigation in excess of crop needs increases production costs, can reduce yield by affecting soil aeration and root system respiration, and favors the occurrence and severity of diseases and pests. Deficient irrigation promotes a reduction of tuber quality and lower yield due to reduced leaf area and/or reduced photosynthesis per unit leaf area (Van Loon, 2012).

Because of its shallow root system, potato is sensitive to water stress (Opena and Porter, 1999; Thornton, 2003; Unlu *et al.,* 2006), and even a short period of drought is likely to substantially reduce tuber yield (Jovanović *et al*., 2012). Experience gained to date shows that tuber yield increases considerably with irrigation (Milić *et al*., 2010). Potatoes are most often irrigated by furrow, sprinkler and drip methods. Worldwide, drip irrigation is preferred because of higher yields and better tuber quality (Yuan *et al.,* 2003; Onder *et al*., 2005; Kaur *et al*., 2005) and because it uses less water than other methods. In context of scarcity, more water used for irrigation means less water for other areas of the economy (Sidibe *et al*., 2012). With regard to the drip method, the effect of subsurface irrigation has recently become a focus of research. This method has major advantages in terms of efficient use of water resources including reduced evaporation and water losses through deep percolation, as well as the elimination of surface runoff (Camp, 2012).

2.6. Mineral Nutrients Affecting Growth and Yield of Potato

In the past years, mineral fertilizer was advocated for crop production to ameliorate low inherent fertility of soils in the tropics (Stoorvogel and Smaling, 1990). However, currently it is well recognized that the use of mineral fertilizer has not been helpful in intensive agriculture because it is often associated with reduced crop yield, soil acidity, and nutrient imbalance (Kumar *et al*., 2013).However, appropriate mineral fertilizer application, especially nitrogen and phosphorus are required to correct the nutrient imbalance in infertile soils (Peter *et al*., 2015).

2.6.1. Effect of Nitrogen fertilizer on growth and yield components of potato

Potatoes can generally grow on organic and mineral soils with pH of 5.0 - 6.5, light soils with good aeration to produce high tuber yield (Gebre *et al*., 2005). Nitrogen (N) is very important nutrient in potato production that the value of the other inputs cannot be fully realized unless Nitrogen is applied to the crop in an optimum amount ((Grewal *et al*., 1992; Baniuniene and Zekaite, 2008; Ruža *et al*., 2013). Several N fertilization rates have been advised as optimum for potato production in some European countries and the USA (Ruža *et al*., 2013).Potatoes require high amount of nutrients in order to produce high quantity of tubers per unit area (Dechassa *et al*.,2003;White *et al*., 2007). Plant tissues usually contain more Nitrogen than any other nutrient normally applied as a fertilizer.

Nitrogen is an integral component of many essential plant compounds. It is a major part of all amino acids and many other molecules essential for plant growth. Nitrogen is also essential for carbohydrate use within plants. All vegetative growth parameters were gradually and significantly increased by increasing the level of N fertilizer application up to optimum level (Asmaa *et al.,* 2010). However, an excess of this nutrient in relation to other nutrients (P, K and S) leads to low dry matter yield in other parts of the plant than the tubers, promoting excessive stolon and leaf growth (Marti and Mills, 1991).Both leaf maturation and tuber differentiation are delayed and the length of tuber bulking period, yield and tuber dry matter are reduced (Goffart *et al*., 2008).

Conversely, a shortage of Nitrogen restricts the growth of all plant organs, roots, stems, leaves, flowers, fruits including seeds and plants become stunted and yellow in appearance (Barker and Bryson, 2007). Shortage of Nitrogen also restricts tuber size due to reduced leaf area and early defoliation (Goffart *et al*., 2008).Nitrogen supply also play an essential role in the balance between vegetative and reproductive growth for potato (White *et al*., 2007).Nitrogen fertilization has been reported to increase the average fresh tuber, plant height, leaf number and tuber weight per plant (Kandil, 2011).

2.6.2. Effect of phosphorus fertilizer on growth and yield components of potato

The potato crop is phosphorus (P) inefficient (Nigussie, 2001). Fontes (1997) further stated that plant growth is delayed with low-P levels already at initial stages; besides tuber yield, number and length of roots and stolon are reduced. Phosphorus is known to be involved in several physiological and biochemical processes of plants being components of membranes, chloroplasts, mitochondria (Sanchez, 2007) and constituent of sugar phosphate, such as adenosine diphosphate (ADP), adenosine triphosphate (ATP), nucleic acid, phospholipids and phosphate (Hue, 1995).In many soils plant-available phosphorus is deficient and has to be supplemented with fertilizer (Mikhailova *et al*., 2003; Dechassa *et al*., 2003; Osono and

Takeda, 2005). Potato is highly responsive to soil-applied nutrients, especially to phosphorus (P), due to its short cycle and high yield potential (Fernandes and Soratto, 2012).

Tubers accounted for over 70% of the nutrient removed (Getu, 1998). phosphorus is abundantly available in soils (Khan *et al*., 2006) but availability for plants is generally low, because at least 70 to 90% of the P that enters the soil is fixed by Fe, Al and Mn in soils (Mcbeath *et al.,* 2006). Phosphorus is a nutrient that should therefore be available in adequate quantities from the early growth stages to maintain a high photosynthetic rate during tuber bulking (Hu *et al*., 2010). However, the application of high phosphorus doses may cause environmental and economic problems as well as a nutritional imbalance in potato plants (Hopkins *et al*., 2008). Assefa (2005) reported that stem number per hill was not significantly affected by the application of N and P. Potato tuber yield increased with increasing phosphorus fertilizer (Jenkins and Ali, 1999).Phosphorus deficiencies conversely significantly reduced tuber size and yield and specific gravity (Bryan *et al.,* 2005).

Potato tuber yield is influenced by phosphorus fertilizers through its effect on the number of tubers produced, the size of the tubers and the time at which maximum yields are obtained (Sharma and Arora, 1987). A report by Mohr and Tomasiewicz (2008), total tuber yield increased linearly with increasing phosphorus fertilizer rate leveled at 0,34, 67 and 100 kg P2O5 ha-1 with 34 kg P2O5 ha-1 gave numerically lower yield than any other treatments. Similarly, Wijewardena (1996) reported high tuber yield by applying 100 kg P ha-1 followed by 50 and 25 kg P ha-1, respectively. Increasing the rate of P from 0 to 138 kg P significantly increased tuber number plant-1 from 6.4 to 7.9 (Gebremariam, 2014). Israel *et al*. (2012) and Zelalem *et al.* (2009) reported that increasing the rates of P increased the number of tubers set plant-1.

2.6.3. Effect of Sulfur fertilizer on growth and yield components of potato

Sulfur (S) is one of the essential nutrients for plant growth and it accumulates 0.2 to 0.5% in plant tissue on dry matter basis and is required in similar amount as that of P (Ali *et al.,* 2008). Sulfur deficiency has become widespread over the past several decades in most of the agricultural areas of the world, becoming a limiting factor to higher yields and fertilizer efficiency (SRDI, 1999). Crop responses to applied Sulfur have been reported in a wide range of soils in many parts of the world (Brady and Weil, 2002). It is a building block of protein and a key ingredient in the formation of chlorophyll (Duke and Reisenaue, 1986). Without adequate Sulfur crops cannot reach their full potential in terms of yield or protein content (Zhao *et al.,* 1999). It is required for the synthesis of Sulfur containing amino acids such as cystine, and methionine.

The symptoms of Sulfur deficit are observed not only in plant species of high Sulfur requirements (Sahota, 2006), but also in plant species of relatively low Sulfur requirements, including potato (Klikocka *et al*., 2003). Their deficiency results in stunted growth, reduced plant height, tillers and delayed maturity also less resistance under stress conditions (Doberman and Fairhurst, 2000). Application of Sulfur fertilizer is a feasible technique to suppress the uptake of undesired toxic elements (Na and Cl) because of the antagonistic relationship, thus its application is useful not only for increasing crop production and quality of the produce but also improves soil conditions for healthy crop growth (Zhang *et al*., 1999). Sulfur improves K and Na selectivity and increases the capability of calcium ion to decrease the injurious effects of sodium ions in plants (Wilson *et al*., 2000).

Sulfur is also reported to enhance the photosynthetic assimilation of Nitrogen in crop plants (Anderson, 1990; Ahmad and Abdin, 2000). Hence, the application of Nitrogen and Sulfur fertilizers increases the net photosynthetic rate in crop plants, which in turn increases their dry matter and grain yield, as 90% of the plant's dry weight is considered to be derived from products formed during photosynthesis (Peoples *et al*., 1980).The requirement of Nitrogen by plants increases when N is fertilized with S, as their metabolism is coupled in the synthesis of S containing amino acids, membrane lipids, enzymes and coenzymes (Anderson, 1990).

According to (Diriba *et al.,*2015) the growth, yield and yield attributes of garlic bulbs increased significantly with the application of NPS fertilizers and with further increased growth stages of the plant, especially after 60 days of growth. Many previous 10 studies have shown that N fertilizer applications can increase dry matter content, protein content of potato tubers, total and/or marketable tuber yield (Zelalem *et al*., 2009).Poor use efficiency of N by the plant is caused by insufficient S availability to convert N into biomass production, which in turn may increase N losses from cultivated soils (Ceccotti, 1996). Response of crop growth and yield to the application of Sulfur has been reported for many crops (Singh, 2006), where an insufficient Sulfur supply can affect yield and quality of crops, caused by the requirement Sulfur for protein and enzyme synthesis (Zhao *et al*., 1999).

According to Sud (1996) significant responses of potato tuber yield to P and S application was obtained at individual application rates of 22 kg ha-1. Sud *et al*. (1992) indicated that increasing levels of N fertilizer recorded a significant increase in quality attributes in potato. The yield promotion by S on potato was already observed by Klikocka and Sachajko (2007), who found that the highest tuber yields were recorded when applying 25 kg S ha-1 in the ionic form or 50 kg S·ha-1 in the elemental form, as well as by Mondal *et al.* (1993), Pavlista (2008) and Sharma *et al.* (2011).

2.7. Effects of intra row spacing on phenology and growth of potato

2.7.1. Days to 50% emergence

Days to 50% emergence was the time taken place starting from planting to bearing or emerging. Varieties were different in days to 50% emergency, in which variety desire was emerged 2.5 days earlier than variety cardinal because of genetically difference between the two varieties (Ahmed *et al*., 2000).

Potato seed tubers emerged relatively faster at a wider intra row spacing(30 and 40 cm) than in closer intra row spacing(Bikila *et al.*,2014).seed size influence the length of times from planting to emergence; the larger seed size emerged earlier than small seed size(Mwansa,2002).Large seed tubes were associated with large embryo axis, leaf primordial and cotyledon area, and had slightly longer and thicker sprouts at planting time and this contributed to earlier germination and to establish faster since the tubers were not yet photosynthesizing but were relying solely on the supply of metabolites from the mother tubers(Masarirambi *et al*.,2012).According to Patel *et al*.(2008), who reported the bigger seed tuber(51-70g) showed earlier days to 50% emergence compared to the smaller seed tuber(31-50 g).the smaller seed tuber size required longest time to complete days to emergence, which indicates the larger seed tubers gave earlier emergence, and gave maximum crop coverage and growth(Sultana *et al.*,2001).

2.7.2. Plant height

Large tuber were proved in relation to better plant height foliage coverage and maximum vegetative growth (Hossain *et al*., 2011).plant heights in different environmental condition ranged from 45.96 to 63.63 and 40.12 to 62.81cm, respectively (Mahmud *et al.*, 2014). Patel *et al*. (2008) indicated that large size seed tubers (51-70g) resulted in higher plant height and growth than small tuber seeds.

Densely populated plants (closer inter and intra row spacing) shows intensive competition which leads to decrease in plant heights (Bikila *et al.*, 2014).In contrary, Tesfaye *et al*. (2012) reported the highest plant height (66.1cm) at the closer intra row spacing of 10cm and 20cm however, the shortest plant height (62 cm) was observed at 30 cm and 40 cm intra row spacing foliage coverage and maximum vegetative growth. This is due to the presence of higher competition for sun light among plants grown at the closer intra row spacing. Sharma and Singeh (2010) indicated that the increase in plant height was significantly more with double plant density. The use of 20 cm intra row spacing gave the tallest but less robust plants, because there was competition between plants, for solar radiation, which leads to etiolating; plants grow narrower with less branching than 40 cm intra row spacing (Daure *et al*., 2014).This may be due to better availability of nutrients, water and sun light since plants in wider spacing have less competition and grow more shoot; however, densely populated plants show intensive competition which leads to decrease in plant height.

Wider intra row spacing resulted in reduction in plant height and in closer inter row spacing the highest plant height was observed. This is due to the presence of higher competition for sunlight among plants grown at closer intra row spacing (Tesfaye *et al.*, 2013). Similar results obtain by Ashwani *et al.* (*2013*) showed that planting at wider intra row spacing resulted in reduction in plant height. In general, the plant height of the potato crop increases when plants are planted in closer intra row spacing due to competition for sunlight. In other words, when plants are planted in wider intra row spacing the same result may be obtained due to the plant getting enough mineral, water and sunlight.

2.7.3. Number of main stems per hill

Potato tubers show a wider range of variation and possess a variable number of growing buds arranged in groups over their surface (Mulubrhan, 2004).The number of eyes per tuber was reported to be dependent on the size of tubers(Allen,1978).varietal difference was also reported influenced eye number per tuber (lynch and Tai,1989).although variety, tuber size or other factors exert their influence on the number of eyes on tuber surface, there seems to be only one eye on a tuber that develops into stems and also no difference exists between eye types(apical or lateral) in their yield potential (Allen,1978).The same author also confirmed the performance of different eyes within tubers of the same size and total eye number by dissecting out the eyes to produce single eye tubers, therefore, revealed that differences between eye positions caused small differences in numbers of stems and tubers and tuber yield.

Allen (1978) reported the importance of increasing stem number per plant for increased graded and total tuber yield. Similarly, Gray and Hughes (1978) observed close relationship between the number of main stems or above ground stems and total yields and graded tuber yields. These investigators claimed that high stem number per plant favored high tuber yield through effect of haulm growth and tuber number per plant. Rajadurai (1994) found that the number of stems produced per tuber increased with increasing tuber size and intra row spacing, and verifies that the medium size seed tubers significantly increased stem numbers over small size seed tubers.

2.7.4. Influences of intra row spacing on potato tuber yield

Increasing the planting density from 4.44 to 8.00 plants m-2 significantly increased total tuber number/ha. The highest tuber yield per hectare was obtained at closer spacing of 10 cm whereas the lowest was obtained at wider intra row spacing of 40 cm. The wider intra row spacing yield per hectare was reduced due to the insufficient number of plant grown per hectare compared to plant grown at closer intra row spacing per hectare. The maximum yield was obtained at closer plant spacing than wider plant spacing. This might be attributed to efficient use of available soil nutrients and other growth factors in plants grown at closer plant spacing than wider plant spacing.

The increased yield at higher densities might be due to the ground being covered with green leaves earlier (earlier in the season, light is intercepted and used for assimilation), fewer lateral branches being formed and tuber growth starting earlier (Zebenay, 2015). Narrow spacing increases the hectare yield and decreases the yield per plant. The highest yield was obtained with large size seed tuber (45-55 cm) planted in narrow spacing (60 x 20cm). However, the combination of large size seed tuber and narrow spacing produce many small side size tubers of low market value (Rajadurai, 1994). The highest yield was obtained from 65 cm inter row spacing; whereas the lowest yield was recorded at 80 cm inter row spacing.

Regarding the intra row spacing the higher total yield per hectare was obtained from 20 cm intra row spacing. As intra row spacing increased from 20-35 cm, total tuber yield decreased from 37.54 to 29.38 t/ha. Intra -row spacing of 35 cm showed lower total tuber yield. It was clearly evident from the result that the yield of seed tuber per hectare increased with decreasing plant spacing. The increased yield was attributed to more tubers produced at the higher plant population per hectare although average tuber size decreased because of increasing inter plant competition at closely spaced plants leading to more unmarketable tuber yield. At closer spacing, there is high number of plant per unit area which brings about an increased ground cover that enables more light interception, consequently influencing photosynthesis (Harnet *et al*., 2014). Yield performance (kg/ha) was greatest at the medium density level (90 by 30 cm), followed by plants established at 90 by 45 cm. Reducing the intra-row spacing from 45 to 30 cm significantly ($p<0.05$) increased plant population and subsequently increased the yield (kg/ha) performance. Tuber yield was significantly ($p< 0.05$) affected by plant density as plants planted at 90 by 30 cm exhibited highest yield performance compared to those planted at 90 by 15 cm and 90 by 45 cm (Michael *et al*., 2012).

Roy *et al*. (2015) conducted on intra row spacing of 10, 15 and 20 cm and observed there was a significant difference among yield variables. The inappropriate intra row spacing can affect the tuber quality and marketable tuber size of potato since it is correlated with plant populations (Harnet *et al.,* 2014).The absence of optimal intra row spacing practices could significantly reduce the total tuber yield up to 50%, therefore optimization of intra row spacing is one of the most agronomic practices of potato production (Endale and Woldegiorgis, 2001).

The number of eyes per tuber increases with tuber weight though does the number of sprouts or stem per seed size decreased from very large tubers to small tubers (Masarirambi *et al.*, 2012). The increased yield by high plant population results in reduced large tuber size yield. The large size tubers increased with spacing increase(Khalafalla, 2001).Higher plant densities lead to early canopy closure .nevertheless ,while this increase yield ,some of other factors may reduce quality because high plant densities increase tuber numbers per square meter and reduced tuber size(Masarirambli *et al.*, 2012).

Kumar *et al*. (2012) reported that the total tuber yields in potato increase with closer spacing. The same authors also identified that the variation in intra row spacing can also affect tuber size distribution. For any given potato variety, information on intra row spacing is required to optimize yields of marketable size tubers (Kumar *et al.*, 2012). According to Bohl *et al*. (2011) total tuber yield increased as seed tuber size increased from 42g(34.1t/ha) to 85 g(37.4t/ha) planted at 20 cm intra row spacing. The authors reported that the total tuber yield decreased as intra row spacing increased from 20 cm to 40 cm; at the 40 cm intra row spacing,42g seed tuber yielded 26.3t/ha compared with 32.7 t/ha for 85g seed tuber, an increase of 6.4t/ha. Intra row spacing alters the yield of vegetable crops, the majority of potato tuber quality variables were preferable at 30 cm intra row spacing (Tesfaye *et al*., 2013).

2.7.5. Effect of plant population on marketable tuber yield t/ha

Effect of row spacing on yield found that those plants produced higher marketable yield at the widest spacing (Robert *et al*., 2015). The highest marketable tuber yield was obtained in response to planting the tubers at the spacing of 60 x 30 cm whereas the lowest marketable tuber yield was recorded at the spacing of 50 x 30 cm plant spacing. Plant spacing of 60 x 30 cm produced higher marketable yield than 50 x 30 cm and 75 x 30 cm plant spacing by about 12.04 and 9.53%, respectively. Similarly, marketable tuber yield produced at 60 x 20 cm and 50 x20 cm exceeded that of 50 x 30 cm plant spacing by about 8.65 and 8.72%, respectively. Plant spacing of 60 x 30 cm, 60 x 20 cm and 50 x 20 cm produced marketable tuber yield per hectare without significant difference (Zebenay, 2015).

The highest marketable yield was obtained at the wider intra row spacing of 30 cm whereas the lowest was obtained at closer spacing of 10 cm. At wider intra row spacing due to presence of minimum competition, plants absorbed the sufficient available resource and intercepted more light. This increased their photosynthesis efficiency for higher photo assimilation production and ultimately resulted in increased more marketable tuber yield (Tesfaye *et al.,* 2013). According to Alemayew *et al.* (2015) increasing the planting density from 4.44 to 6.67 plants m-2 significantly increased total and marketable tuber yield by 5.21 and 4.67 t/ha.

2.7.6. Effect of plant population and tuber size on unmarketable tuber yield t/ha

The highest unmarketable yield was obtained at the closer intra row spacing of 10 cm whereas the lowest was obtained at closer spacing of 40 cm. This is due to presence of higher competition between plants in closer intra row space (Tesfaye *et al*., 2013). The highest unmarketable tuber yield was obtained at closer plant spacing (50 x 20 cm) whereas the lowest unmarketable tuber yield was recorded at wider plant spacing (75 x 30 cm). the closer spacing of 60 x 20 cm and 50 x 30 cm would need more seed tubers than the spacing of 60 x 30 cm, the latter spacing (60 x 30 cm) would be more profitable. The highest unmarketable tuber yield was produced at the highest planting density of 8.00 plants m^{-2} , and exceeded the unmarketable tuber yield obtained at the lowest planting density of 4.17 plants m^{-2} by 0.863 t/ha (Alemayew *et al*., 2015). Generally, plants grown at closer spacing produced high unmarketable tuber yield than plants grown at wider plant spacing. Increasing plant density also increased the yield of unmarketable tuber yield. Closer plant spacing increased competition of plants for growth factors due to high number plant per unit area than wider plant spacing which led to producing high number of under size tubers which was high unmarketable tuber yield (Zebenay, 2015).

2.7.7. Effect of plant population on tuber number per plant

The highest number of tuber per plant (10.93) was recorded at the wider intra row spacing 40 cm whereas the lowest number of tuber per plant (6.7) was obtained at closer spacing 10 cm. This is because in wider intra row spacing there is minimum competition among plants for space and resource and better exposure for light; this results in increased number of tuber per plant (Tesfaye *et al.,* 2013).Number of tuber per plant increases with increasing seed tuber size and planting space. Plants grown at closer plant spacing of 50 x 20 cm produced highest total tuber number per hill higher than plants spaced at 60 x 20 and 75 x 30 cm by about 11.27 and 12.18 %, respectively.

However, total tuber number per hill produced at 50 x 20 cm plant spacing has no statistically significant difference with 60 x 30 cm and 50 x 30 cm plant spacing. The production of total number of tubers per hill increased as plants grown at narrow plant spacing and decreased at wider plant spacing. This might be due to the higher number of plants produced at closer plant spacing than plants at wider spacing which led to the production of highest number of total tubers per hill (Zebenay, 2015). Tuber numbers were significantly affected by plant population density, with the highest density plants having a lower number of tubers per plant (Michael *et al.,* 2011).

Intra row spacing has a large influence on the number of tubers per hectare. As seed tubers are spaced closer together, tuber numbers per plant typically reduced. However, because the seed tubers are spaced closer together, the resulting total plant population per ha increase, and the overall tuber itself is of marginal importance in optimizing economic return in potato production (Thornton *et al*., 2007).Narrow spacing increased the hectare yield and decreased the yield per plant. The large size tubers planted at narrow intra row spacing (20cm results highest yield (Rajadurai, 1994).

2.7.8. Effect of plant population on average tuber weight

Average tuber weight was the third most important yield component contributing to the total tuber yield(Morena *et al.,*1994; Mulubrhan, 2004).The growth of tuber tissue was occurring both by cell division as well as by expansion in which cell division is more important than cell expansion of tuber growth(Reeve *et al*., 1973).

When plant density increased the weight of tubers decreased in all seed tuber sizes except in plants grown at plant spacing of 50 x 20 cm and from small seed tuber size (25 to 34 mm). The production of tubers with higher weight when medium seed tuber size (35 to 45 mm) was used as planting material with wider space (75 x 30 cm) might be due to the production of optimum number of stems with lesser competition for resource between plants compared to small and large seed tuber sizes planted at closer plant spacing (Zebenay, 2015).

In general, as intra row spacing increase (plant population decreased) the average tuber size increased and tubers per hectare decreased. Plant population is important due to the increased opportunity to manipulate plant population to target a specific tuber size market. Higher plant population results in lowering average tuber size (Tarkalson *et al.,* 2011).The increased yields at higher plant density were attributed to the ground covered with green leaves earlier; fewer lateral branches being formed and tuber growth starting earlier (Mwansa, 2002).According to Roy *et al.* (2015) the largest average tuber weight was observed in intra row spacing of 25 cm (48.70) followed intra row spacing of 20 cm (44.75g and lowest from 15 cm (41.24g).

2.7.9. Effect of Plant Density and NPS fertilizer on Some Potato Tuber Quality

2.7.9.1. Dry matter

High dry matter potatoes are desirable for processing and such potatoes return more processed product per unit of row product, have a better texture or meatiness after cooking, absorb less fat during frying and accumulate less reducing sugars in storage than low dry matter potato tubers (Iritani and Weller, 1973). For most forms of potato processing, the higher the dry matter content of the row product, the higher is the yield of finished product (Wein, 1997). Therefore, processors typically set a minimum dry content below which they will refuse to purchase the potatoes. Generally, high dry matter content has been reported by many people to be desirable because of less sugar accumulation during storage (Iritani and Weller, 1976). Higher stem densities produce tubers with higher dry matter contents than similar sized tubers from low densities (Eskin, 1989).

Tesfaye *et al*. (2012) reported that the dry matter content of potato variety is highly influenced by the variety, cultural and environmental conditions during the growing season. The total dry matter yield of crops depends on the size of leaf canopy, the rate at which the leaf functions and the length of time the canopy persists. A study of dry matter production and distribution of the various plant parts is the course of development is important for evaluation of the growth rate, productivity and yield level of potato (Tsegaw, 2005).

Similarly, Ifenkwe *et al.* (1974) observed significant differences between planting densities, row widths and varieties. At small tuber sizes treatments with high stem densities produced tubers with a higher dry matter content than tubers from low stem densities. Wurr (1974c) observed that at closer spacing gave the highest dry matter percentage of tubers and at wider spacing the lowest at all harvest. Bleasdale and Thompson (1969) also pointed out that close plant spacing gave tuber which for a given size had higher dry matter percentage than tubers from wider plant spacing and suggested that this effect might be explained by accepting that high plant densities deplete the moisture status of the ridges far more than low densities.

The percent dry matter of tubers is related to the level of nitrogen applied and the No3 N concentration in the petiole tissue (Rowberry *et al.,* 1963).Increased nitrogen rates results in decreased of dry matter of tubers and increased the total amino-nitrogen content of the tubers (Painter and Augustin, 1976). In agreement with this idea Beukema and Van der zaag, 1990) also stated that excessive nitrogen may cause low dry matter content and high protein and nitrate content, especially if it leads to harvesting the crop before it reaches its natural maturity.

Similarly, Rowberry *et al.* (1963) found lowest dry matter percentage in tubers at harvest from plants receiving highest nitrogen applications. This is attributed to prolonged vegetative growth and delayed maturation. Therefore, high levels of nitrogen, while resulting in higher tuber yields, lowered the percent dry matter in tubers. But, in contrast to this idea, Millard and Marshall (1986) found that the dry matter content of the tubers at harvest were unaffected by nitrogen supply. Dry matter production rates of tubers also vary with variety and season (Soltanpour, 1969). Higher stem densities produce tubers with higher dry matter contents than similar sized tubers from low densities (Eskin, 1989).

2.7.9.2. Specific gravity

Specific gravity is determined by the weight in air in water methods is an accepted procedure for estimating solids content of potatoes. This procedure is reasonably accurate and relatively easy to make. Therefore estimates of dry matter content from specific gravity measurements are used as a tuber quality measurement of harvested tubers (Kleinkopf *et al.,* 1987). Tubers of higher specific gravity tended to have less moisture and less turgor than tubers of lower specific gravity (Sawyer and Collins, 1960).

It had been reported that excessive rates of nitrogen may result in reduced specific gravity (Sommerfeldt and Knutson, 1965). Sanderson and White (1987) approved that as nitrogen rate increase tuber specific gravity declines and the average reduction was 0.0015, 0.0013, 0.0047 units for 67, 135 and 202 kg N ha-1 and this is due to prolonged vegetative growth and delay in maturity (Sanderson and White, 1987).

Rowberry *et al*. (1963) also found without exception that increasing the level of nitrogen resulted in lower specific gravity of tubers. The lowest reading occurred with the highest level of nitrogen. However, Joern and Vitosh (1995) indicated that tuber specific gravity was not affected by nitrogen rate. Specific gravity tended to decrease with increased spacing (Rex *et al.*, 1987; Sanderson and White, 1987). Trails show the lowest specific gravity was obtained 30 cm spacing and the highest at the 22 cm spacing and with the 38 and 46 cm spacing resulting in tubers of intermediate specific gravity (Sanderson and White, 1987). But in contrary, Rowberry *et al*. (1963) and Halderson *et al.* (1992) observed seed spacing treatment had no apparent or significant effect on specific gravity of tubers.

3. MATERIALS AND METHODS

3.1. Description of the study area

The experiment was conducted at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), experimental Station, Eladalle which is located at 7 km away from Jimma town. Jimma is geographically located at 346 km Southwest of Addis Abeba at an elevation of 1763 meters above sea level situated at latitude of 7^0 S 44’N and longitude 36^0 54’ E in Ethiopia(from GPS reading, 2019). The experimental site receives an annual rainfall of 1928.5 mm with maximum and minimum temperatures of 31.8^{0}C and 8.5^{0}C, respectively; and the average maximum and minimum relative humidity of the area are 91.4 and 39.92%, respectively (Bpedors, 2000).

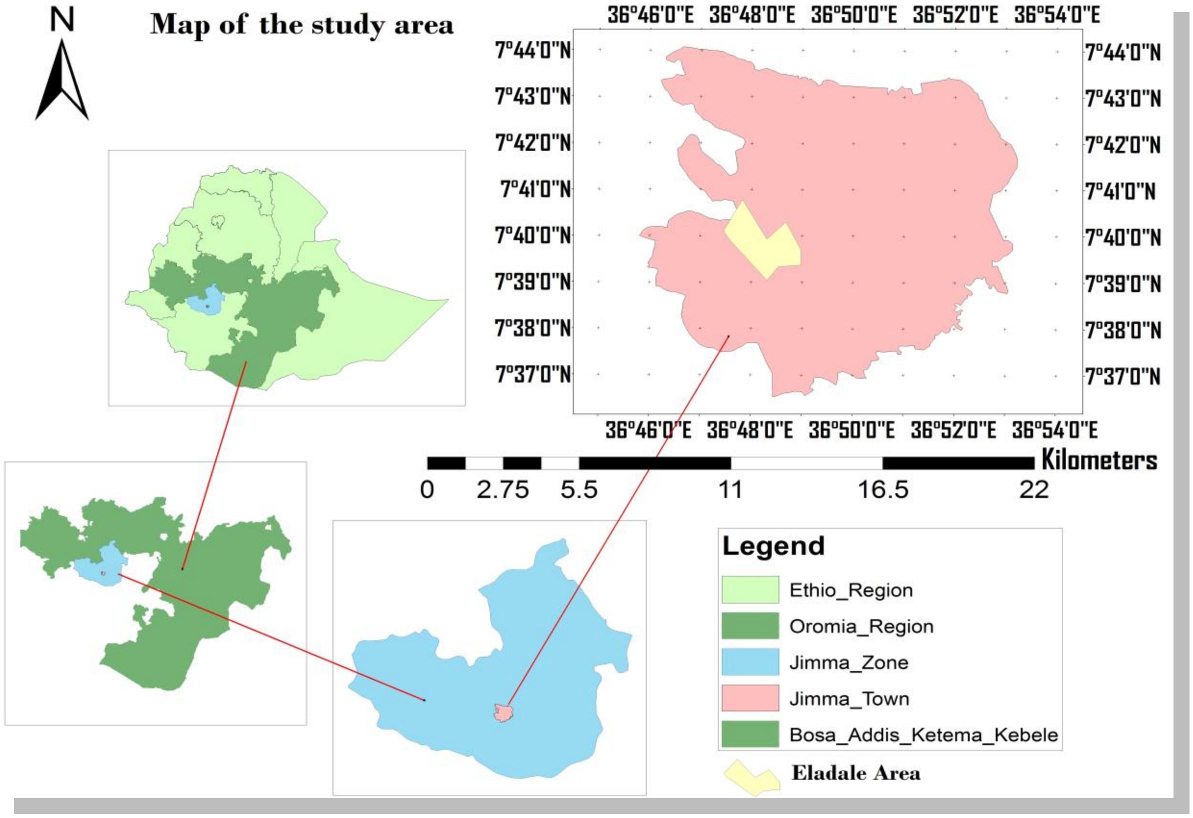

Figure 1. Map of study area

3.2. Experimental materials

Potato cultivar "Belete" was used as experimental material. It was obtained from Holetta Agricultural Research Center. “Belete” was released by the Holetta Agriculture Research center in 2009. Belete is adapted to areas situated between 1600-2800 meters above sea level and receiving an annual rainfall of 750 to 1000 mm. It is comparatively resistant to potato late blight disease (John, 2017). Day to attain maturity of “Belete” cultivar ranges between 90 and 120 days. Productivity in research center and farmers field was 47.2 t ha^{-1} and 28-33.8t ha^{-1} respectively (Arega *et al.*, 2018).

3.3. Treatments and experimental design

The experiment consisted of two factors, four levels of (NPS) fertilizer application rates (0, 75, 150 and 225kg/ ha^{-1}) and four levels of intra row spacing (20, 25, 30 and 35cm). These NPS fertilizer rates were determined based on recommendation given by Agricultural Transformation Agency for the study area which is 150 kg ha^{-1} NPS fertilizer (ATA, 2016). The inter row spacing was maintained at 75 cm. The experiment was laid out as 4×4 factorial arranged in RCBD and replicated three times. There were sixteen treatment combinations (4×4), which were assigned to each plot randomly. The list of treatments combinations is shown in Table 1 below.

Table 1. Description of treatments combinations

Treatment number	Description
T1	20cm intra row and 75 cm inter row with 0 kg ha^{-1} NPS
T2	20cm intra row and 75 cm inter row with 75kg ha^{-1} NPS
T3	20cm intra row and 75 cm inter row with 150kg ha^{-1} NPS
T4	20cm intra row and 75cm inter row with 225kg ha^{1} NPS
T5	25cm intra row and 75 cm inter row with 0kg ha^{-1} NPS
T6	25cm intra row and 75 cm inter row with 75kg ha^{-1} NPS
T7	25cm intra row and 75 cm inter row with 150kg ha^{-1} NPS
T8	25cm intra row and 75 cm inter row with 225kg ha^{-1} NPS
T9	30cm intra row and 75 cm inter row with 0kg ha^{-1} NPS
T10	30cm intra row and 75 cm intra row with 75kg ha^{-1} NPS
T11	30cm intra row and 75 cm inter row with 150kg ha^{-1} NPS
T12	30cm intra row and 75 cm inter row with 225kg ha^{-1} NPS
T13	35cm intra row and 75 cm inter row with 0kg ha^{-1} NPS
T14	35cm intra row and 75 cm inter row with 75kg ha^{-1} NPS
T15	35cm intra row and 75 cm inter row with 150kg ha^{-1} NPS
T16	35cm intra row and 75 cm inter row with 225kg ha^{-1} NPS

3.4. Experimental procedure and crop management

The total experimental plot was measuring 56.5m in length and 13 m in width with total area of 734.5m^2. The selected area was cleared, ploughed, harrowed to a depth of 25 - 30 cm and leveled using oxen and human power. There were 48 plots, each plot measuring 3m x 3m (9m^2) and was separated by a buffer of 0.5 m and 1 m between plots and blocks, respectively. Well sprouted Potato seed tubers were planted on August, 2019 at Eladalle. The fertilizer treatments were applied at about 8cm deep and covered by 3-5 cm by soil to avoid direct contact of fertilizers and potato tubers.

Urea fertilizer was applied by splitting the recommended fertilizers into two and one part applied at the time of planting by mixing with NPS fertilizers to initiate sprouting and the rest one part was applied at 40 days of planting by side placing methods to increase vegetative growth. Uniform, 42-85 grams well sprouted, two and more than two eye potato tubers were planted at 5-7cm depths. After planting, a ridge was done to cover the potato tubers by excavating the soil from both sides. 37.5cm from row.

The experiment was carried out during the main rain season. Agronomic practices such as weeding, earthing up, pest and disease management were kept uniform for all treatments adopted for the area. Due to high rainfall condition to prevent the incidence of late blight mancozeb 50% was applied on the field at 30 days interval from planting up to harvesting.

Table 2. Description of inter-intra row spacing and total number of tuber per plot

Between row and between plant spacing (cm)	**Number of rows/plot**	**Number of plants per row**	**Total number of plants per plot**
75x20	4	15	60
75x25	4	12	48
75x30	4	10	40
75x35	4	9	36

3.5. Soil sampling and analysis

Before planting, physical and chemical properties of the experimental field soil was examined. Therefore, representative soil samples were collected from the experimental field randomly in a zigzag pattern at a depth of 0-30 cm during land preparation time using an auger. The soil samples were composited and a one kg sample was taken as a working sample. Crumbs of soil were broken into pieces and sieved. The collection composite samples were submitted to JUCAVM soil laboratory and air-dried on paper trays, ground, and sieved to pass through a 2 mm sieve for chemical analysis.

Physical properties of soil textural (sand, silt and clay) before planting soil analysis was carried out by hydrometer method as described by (Okalebo *et al*., 2002). Total nitrogen was determined using the Kjeldhal method (Dewis and Freites 1970). pH of the soil was measured in water at soil to water ratio of 1:2.5 potentiometric pH meters with glass electrode (Hazelton and Murphy, 2007), and determination of cation exchange capacity (CEC) was done using 1N ammonium acetate (NH4-AOC) method as described by Cottenie (1965). The available phosphorus content of the soil was determined by Bray II method (Olsen *et al*., 1954).

Table 3. Physical and chemical properties of the experimental soil before planting

Parameter	**Value**	**Rating**	**Reference**
pH	6.23	Slightly acid	Hazelton & Murphy,2007
%TN	0.22	Medium	Bruce & Rayment (1982)
Av.P(ppm)	11.34	Medium	Bray II (1954)
%OC	2.5	Medium	Hazelton &Murphy(2007)
CEC(cmol)	19.26	Medium	Landon J.R.(1991)
Texture			
%Clay ,Silt ,and Sand	42,45.33,12.6 respectively		

Where Cmol = Cent mole, pH = hydrogen power, % OC = percent of organic carbon, %TN = Percent of total nitrogen, Av.p.ppm = available phosphorus in parts per million, CEC = Cation exchange capacity.

3.6. Data collection

Twelve plants were picked at random from the middle two ridges and dug out. Data on different components of growth, yield and yield components were recorded. The detailed methodology adopted for collection of different data is shown below.

3.6.1. Phenological data

Days to 50% flowering

Days to 50% flowering of potato was recorded when 50% of planted potato developed flowering from each plot. The data were taken by observing each plot and counting the days back from planting to 50% flowering.

Days to maturity

Number of days from emergence to physiological maturity was registered when 75 % of the plants per plot were ready for harvest as observed by the senescence of the haulms or plants leaves turned yellowish.

3.6.2. Growth parameters

Plant height (cm)

It was recorded by measuring the plant height from the soil surface to the tip of the main stem of twelve randomly taken middle row plants using meter at 75% of physiological maturity of the crop and the mean values in centimeter was recorded from the plot.

Main stems number per hill

The actual number of main stems per hill was recorded as the average stem count of twelve hills per plot at 50% flowering. Only stems that emerged independently above the soil as single stems were considered as main stems (Stems arising from the mother tuber were considered as main stems). Stems branching from other stems above the soil were not considered as main stems.

3.6.3. Yield and yield components data

Average number of tuber per plant

Tuber number per plant was recorded from twelve plants from each plot by digging and all tubers were counted separately in each plot and average tubers were taken by dividing total tuber number harvested from 12 plants from each plot to the number of harvested twelve plants from each plot.

Average tuber weight (kg)

It was recorded by weighting total tubers harvested from twelve plants from each of the plot by dividing to the number of tubers obtained from the sampling of twelve plants.

Marketable number of tubers per plant

Number of tubers harvested from randomly sampled twelve plants per plot which were counted as marketable after sorting tubers which had greater or equal to 25 g weight free from disease and insect attack. The average number of marketable tubers was recorded (Lung'aho *et al.*, 2007).

Unmarketable number of tubers per plant

The tubers that are sorted as diseased, insect attacked and small-sized (< 25 g) from randomly selected twelve plants per plot as indicated above was recorded as unmarketable tuber number. The average number of unmarketable tubers was counted and registered from the plot (Lung'aho *et al.*, 2007).

Marketable Tuber Yield (t ha^{-1})

Tubers that harvested from each net plot area, free from mechanical damage, disease and insect pest damages and medium to large in size which ($\geq$25g) were considered as marketable tuber yield (Tilahun *et al*.,2018).Then the yield was converted by calculation to total marketable tuber yield ton per hectares.

Unmarketable Tuber Yield (t ha^{-1})

Tubers diseased, damaged, small in size (potato tuber <25g) were grouped as unmarketable tuber yield per plot (Tilahun *et al*., 2018). Then the yield measured by kg of unmarketable tuber per plot. Then it was converted to unmarketable tuber yield tone hectare.

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

The total tuber yield per plot was recorded by adding up the weights of marketable and unmarketable tuber and later extrapolated to per hectare (Zelalem *et al.,* 2009).Total tuber yield t ha^{-1} = Marketable tuber yield t ha^{-1} + Unmarketable tuber yield t ha^{-1}

Economic Analysis

The economic analysis was done using the partial budget analysis described by CIMMYT (1988).Net return (Birr ha–1) and cost benefit ratio were calculated by considering the sale prices of potato and cost of fertilizers and labour for all field activities done. Thus, the economic gains of the different treatments were calculated to estimate the net returns and the cost of cultivation, after considering the cost of fertilizer NPS, labour and the income from total potato tubers for economic analysis. Hence, following the CIMMYT partial budget analysis methodology, total variable costs (TC), gross benefits(GB) and net benefits (NB) were calculated (CIMMYT, 1988). For each pair of treatments, marginal rate of return [MRR (%)] was calculated as the ratio of the difference in higher net benefit to lower benefit over the difference in higher total costs that vary to lower costs and expressed in percent. Thus, the treatment which was non-dominated and having a MRR of greater or equal to 50% with the highest net benefit was taken to be economically profitable.

Cost benefit analysis was done to determine the relative economic returns on the applied treatments using the prevailing market prices. The yields were adjusted by 10% downwards due to management level variability between a researcher and a farmer (CIMMYT, 1988). The economic indicators used were: Gross benefit is the product of the adjusted yield (t ha^{-1}) and the sale prices (birr kg^{-1}) and calculated by multiplying the yield in t ha^{-1} by the market price and also net Benefit was calculated by subtracting the total cost of production from the gross benefit. Marginal analysis compares the net benefits with the total variable cost. The total variable cost was determined for each treatment and was compared with the net benefit. Here also dominant treatments were analyzed and arranged in terms of increasing variable costs. The corresponding net benefits were also indicated. A treatment is dominant when it has a higher cost but a lower net benefit than any preceding treatment. Finally, marginal rate of returns were calculated (MRR), where by percentage change in benefit over change in total variable cost in moving from a lower cost treatment to a higher one. All the treatments were arranged from the highest to the lowest in terms of profitability. This was achieved by dividing the total variable cost by the net benefit multiplied by 100.

$$\mathbf{MRR}=\frac{\text{Change in net benefits}}{\text{Change in cost}} * 100$$

3.6 .4. Data analysis

Before analyst the data was normality checked. All data was subjected to analyses of variance (ANOVA), using SAS (statistical software) version 9.3. Whenever the ANOVA shows significant difference between treatments, mean comparison and separation was done by using least significant difference (LSD) at 5% level of significant. Correlation analysis among growth and yield variables of potato were done by using Pearson's correlation analysis.

4. RESULTS AND DISCUSSION

4.1. Effect of planting density and NPS Fertilizer on phenological variables of Potato

4.1.1. Days to 50% flowering

The analysis of variance revealed that the main effects of planting density and NPS fertilizer (P=0.049) and their interaction effects (P=0.0001) Showed significant difference on days to 50% flowering of potato (Appendix Table1).

The earliest days to 50% flowering (46.3days) were recorded with a treatment combination of spacing 20cm and 0 kg/ha NPS. The longest days to 50% flowering (73.33 days) of potato plant was observed with treatment combination of spacing 35cm and 225kg/ha of NPS fertilizer application rate. Increasing combined application from spacing 20 cm and 0 kg/ha NPS to spacing 35 and 225 kg NPS fertilizer delayed days to 50% flowering by 27 days compared to control(Table 4).

The possible reason for the delayed days to attain 50% flowering of potato plants recorded from treatment combination of spacing 35cm and 225kg/ha of NPS fertilizer was due to high level of nitrogen, phosphorous, and other nutrients obtained from inorganic fertilizer sources. These nutrients promote good leaf development, increase sun light interception, excessive vegetative growth, high photosynthesis and production of sufficient carbohydrates. As result prolongs the day required to attain 50% of flowering.

The result of this study is in agreement with the finding of Yourtchi *et al.* (2013) who reported the earliness in flowering due to combinations of lower rates of inorganic NP and narrow intra row spacing as well as the control treatments could be attributed to the enhancement of vegetative growth and storing of sufficient reserved food materials for differentiation into flower buds. On the other hand, the delayed flowering in response to the interaction effect of maximum amount of mineral and wide intra row spacing could be due to extended vegetative phase of the plant (Najm *et al.*, 2010) and could also be due to enhanced soil moisture holding capacity as a result of mineral fertilizer application and wide intra row spacing (Srivastava *et al.,* 2012).The number of days required to flowering is one of the important parameter for potato farmers due to the fact that it enables the grower to forecast its harvesting scheme as well as the marketing plan (Khalafalla, 2001).

4.1.2. Days to physiological maturity

The analysis of variance revealed that the main effects of planting density and NPS fertilizer (P=0.036) and their interaction showed highly significant (P=0.0001) difference on days to physiological maturity (Appendix Table2).

Early days to physiological maturity (66) were recorded from the treatment combination of intra row spacing 20cm and zero NPS fertilizer, which are statically at par to day to the treatment combination of intra row spacing 25cm and zero NPS fertilizer. The prolonged days to physiological maturity (95.3) were observed from treatment combination of intra row spacing of 35cm and 225 kg/ha NPS fertilizer (Table 4).

This is due to the fact that days to plant maturity increased with wide intra row spacing (low plant density) and increasing NPS fertilizer as a result of increased nitrogen, and phosphorus, in the soil in the form of inorganic source, which increases vegetative growth and leaf area of plants, that increase the amount of solar radiation interception, physiological processes and carbohydrate production because of suitable soil and nutrients contents increases, the day of physiological maturity delayed.

The results of the present study are generally in agreement with the findings of various researchers where increasing fertilizer rates, including NPS and wide intra row spacing prolonged days to maturity of different vegetables including potato (Ayichew *et al*., 2009; Gebremeskel, 2016; Mekashaw, 2016; Yosef, 2016). Belete variety matured after 100 days of planting, when potato plants were applied with 272 kg ha^{-1} of NPS fertilizer (Jemberie, 2017) which is in conformity with the results of the present study. Also the present result was in line with the report of Berga *et al*. (1994) who reported that excessive applications of NPS fertilizer delay maturity and reduces the partitioning of dry matter to the tubers. Beukema and Van der Zaag (1990) noted that a high planting density stimulates early tuber growth and earlier maturing crop. Similarly, Rowberry *et al.* (1963) found that increased level of nitrogen prolonged active vegetative growth (Beukema and Van der Zaag, 1990)

Table 4. Interaction effect of intra row spacing and NPS Fertilizer on Phenological variables of potato production

Spacing(cm)	NPS(kg/ha)	50% flowering	Day of maturity
20	0	46.33^{h}	66.00^{j}
	75	53.66^{ef}	78.00^{gh}
	150	60.00^{b}	84.33^{ef}
	225	68.33^{a}	89.33^{cd}
25	0	50.33^{g}	71.66^{i}
	75	54.66^{de}	81.00^{fg}
	150	60.33^{b}	85.66^{e}
	225	68.33^{a}	91.33^{bc}
30	0	51.66^{fg}	75.66^{h}
	75	56.33^{cd}	81.66^{f}
	150	61.00^{b}	86.33^{de}
	225	69.33^{a}	94.33^{ab}
35	0	52.00^{fg}	77.66^{gh}
	75	57.33^{c}	81.66^{f}
	150	61.00^{b}	87.33^{de}
	225	70.33^{a}	95.33^{a}
$LSD_{(0.05)}$		**2.0051**	**1.00**
CV (%)		**2.04**	**2.44**

4.2. Effect of planting density and NPS Fertilizer on growth variables of Potato

4.2.1. Plant height

The analysis of variance revealed that the main effects of planting density and NPS fertilizer (P=0.025) and their interaction showed highly significant (P=0.0001) difference on plant height (Appendix Table3).

The treatment combination of intra row spacing of 20 cm and 225 kg/ha NPS fertilizer showed the highest plant height of potato (93.6cm) which was also statistically in parity with the plant height (92.30cm and 91.00cm) obtained with intra row spacing 25cm and 225 kg

NPS ha^{-1}, and intra row spacing of 30cm and 225 kg NPS ha^{-1} respectively (Table 5). Increasing the different rates of NPS fertilizer from zero to 150kg ha^{-1} increased mean plant height. While the shortest plant height was observed on plants at treatment combination of intra row spacing 20 cm and 0 kg/ha NPS fertilizer rate (62.6cm) as indicated in Table 5. This might be due to population density and competition effect for resource like sun light, nutrient and water.

The possible reason for the increments of potato plant heights via increasing NPS fertilizer was due to the increased amount of macro nutrients like nitrogen, phosphorous, and sulfur, which increases cell division and vegetative growth of plants, promotes the formation of chlorophyll resulted in higher photosynthetic activity, vigorous vegetative growth and taller plants.

The finding is in agreement with Suh *et al.* (2015) who demonstrated that the highest values of plant height were high for plots narrow intra row spacing(10cm and 20 cm) with NPS fertilizer(150 kg/ha,200 kg/ha) at the rate compared with wide intra row spacing(35cm,40cm) and sole application of NPK mineral fertilizer. Similar to our result, Bwembya and Yerokun (2001) reported that plants applied with N and P fertilizer were significantly taller than those in the control plots.

4.2.2. Main stem number

The analysis of variance revealed that the main effects of planting density and NPS blended fertilizer (P=0.02) and their interaction (P=0.001) showed highly significant difference on main stem (Appendix Table4).

The highest main stem number (6.2) obtained from treatment combination of intra row spacing of 35cm and 225 kg/ha NPS fertilizer, which is statistically in parity with intra row spacing of 30cm and 225kg ha^{-1} NPS fertilizer (5.94).This might be due to the fact that fertilization application encouraged more number of independent stems. On the other hand, the lowest main stem number (4.1) was obtained from the treatment combination of intra row spacing of 20cm and zero kg ha^{-1} NPS fertilizer (Table 5).

In line with this study, Beukema *et al*. (1990) reported that the widest spacing and high N fertilization results in maximum number of stem per hill than closer spacing and unfertilized treatment. According to Jamaati *et al*. (2009) increasing NPS fertilizer level increased the stem number; however further increases NPS fertilizer level did not affect it any more. Singh *et al.* (2016) and Melkamu and Minwyelet (2018) reported that nitrogen with sulfur fertilizer resulted in a significant and maximum number of stem per plant.

In a separate study Lynch and Rowberry (1977) observed increased branch development at higher fertility levels and wider spacing, and the authors concluded that this may be a form of compensatory growth and the relationship between auxiliary branch development and plant density ensured a similar leaf area index over a range of plant densities. Therefore, variation in the number of stems per plant may be associated with variation in their seed size and performance.

Table 5. Interaction effect of intra row spacing and NPS Fertilizer on Growth variables of potato production

Spacing(cm)	**NPS (kg/ha)**	**Plant height**	**Main stem number**
20	0	62.60^{h}	4.10^{i}
	75	81.40^{d}	5.16^{defg}
	150	86.23^{bc}	5.41^{def}
	225	93.60^{a}	5.75^{bc}
25	0	69.33^{fg}	4.61^{h}
	75	81.36^{d}	5.13^{fg}
	150	85.50^{cd}	5.45^{cde}
	225	92.30^{a}	5.86^{b}
30	0	69.16^{fg}	5.00^{g}
	75	75.70^{e}	5.38^{def}
	150	83.43^{cd}	5.47^{cd}
	225	91.00^{ab}	5.94^{ab}
35	0	66.86^{gh}	5.15^{efg}
	75	73.66^{ef}	5.43^{def}
	150	81.70^{cd}	5.84^{b}
	225	86.46^{bc}	6.20^{a}
LSD$_{(0.05)}$		**1.67**	**0.3149**
CV (%)		**3.61**	**3.51**

Means sharing the same letter are not significantly different at P ≤ 0.05 CV= Coefficient of variance, LSD= Least significant difference.

4.3. Effect of planting density and NPS Fertilizer on Yield Variables

4.3.1. Average number of tuber per plant

The analysis of variance revealed that the main effects of planting density and NPS fertilizer (P=0.035) and their interaction (P=0.0001) showed highly significant effect on average number of tuber per plant (Appendix Table 2).

The highest number of tuber per plant (11.63) was recorded at the wider spacing of 35cm with 225kg ha^{-1} NPS fertilizer treatment combination whereas the lowest number of tubers per plant (3.20) was obtained at the closest spacing of 20 cm with zero NPS fertilizer (Table 6).

Stem density increased by planting more tubers and number of tubers per plant decreased due to a decrease in number of tubers per stem decreased. In the closest spacing there could be maximum competition among plants for spacing and resources and also low plant exposure for high radiation interception that increase the photosynthetic efficiency of the plant and finally resulting in decreased number of tubers per plant. The reason for highest number of tuber per plant obtained from wider intra row spacing and inorganic fertilizer was due to increases in vegetative growth, tuber bearing stolons, photosynthesis process, and physiological activity of the plants by improving soil environments and soil aeration for better root penetration that results in increased potato yield

The result of this study is in conformity with finding of Annad and Krishinapp(1989), who stated that the increase in total tuber number per plant is in response to the increased application of the NP fertilizers and wide spacing. This might be due to the increased photosynthetic activity and translocation of carbohydrate to the root, which is probably helped in the initiation of more stolon in potato. Taheri *et al*. (2010) also found the highest ratio (13.07%) of number of large tubers as a result of wide spacing combined with 225 kg P ha^{-1}.Tuber number increases with increase in planting density may be attributed to the increased number of main stems per unit area, each of which behave as an independent plant and produce larger numbers of tubers per unit area as suggested by Zabihiba *et al.*, (2011).

In contrary of our result, tuber number is also determined by the number of stems produced which in turn depends up on the tuber size and variety as reported by Ebwongu *et al*. (2001).

4.3.2. Average tuber weight

Average tuber weight was highly significantly (P = 0.0001) affected due to the main effects of intra row spacing and NPS fertilizer as well as their interaction (Appendix Table 2).

Maximum average tuber weight (38kg/plot) was obtained from a treatment combinations of 35 cm spacing and 225 kg ha^{-1} NPS fertilizer. Low average tuber weight (13 kg/plot) was recorded at 20 cm intra row spacing with no NPS application (Table 6).

The possible reason for maximum average tuber weight (38kg/plot) was recorded from treatment combination of 35 cm spacing and 225 kgha^{-1} NPS which could be, due to the nutrient utilization efficiency of the potato plants, and the applied fertilizer might have promoted better nutrient availability, which in turn increased leaf area, vegetative growth, water use efficiency and physiological process of the plants resulted in increased in size and weight of tubers.

The present result agreed with the finding of Zabihiba *et al*. (2010) who reported that increase in density probably causes the increase in competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight. The production of higher average tuber weight at wider plant spacing as compared to closer plant spacing was also reported by other authors (Bussan *et al*., 2007, Gulluoglu and Arroglu, 2009, Harnet *et al*., 2014).

Similarly, Karafyllidis *et al*. (1997) reported that increase of density probably causes increase competition between and within plants and hence, leads to decrease in availability of nutrients to each plant and consequently, results in decline of mean tuber weight .Yield increases are attributable to more tubers being produced at the closer intra row spacing per unit area and average tuber weight is decreased due to increased inter-plant competition with closer intra row spacing.

4.3.3. Marketable tuber number per plant

The main effects of intra row spacing and NPS fertilizer and their interaction revealed highly significant difference (P=0.01) on marketable tuber number per plant (Appendix Table 2).

Higher marketable tuber number per plant(10.11) was recorded from intra row spacing of 30 cm+ 225kg ha^{-1} NPS, followed by intra row spacing of 35cm+225 kg ha^{-1} NPS and intra row spacing 25cm+225 kg ha^{-1} NPS with marketable tuber number of 9.81 and 8.85 respectively (Table 4). While the lowest marketable tubers number per plant (2.88) obtained with the treatment combination of intra row spacing 20cm and zero NPS fertilizer (Table 6).

The possible reasons for the maximum marketable number of tuber per hill observed from the wider intra row spacing and high rate of combined application of NPS fertilizer could be due to the presence of adequate amount of nitrogen which resulted in better vegetative growth, greater photo assimilate for the production of marketable tuber number. Other reason for high marketable potato tuber number per hill was due to the availably of essential macro nutrients at the time of growing periods. Availability of N, P, and S increases vegetative growth, leaf area, mature slowly after fully developments, interception of high solar radiation, which increase carbohydrate accumulation in leaf area and gradually moves from source to sink area. Those nutrient sources create favorable environment and soil condition for growth and developments of potato at the time of vegetative growth result in production of medium to large sized tubers per hill.

Current finding corroborates with Zewide *et al*. (2018),who reported that increasing the application of NP inorganic fertilizers increases marketable tuber per hill from 50.2% to 56.7% compared with unfertilized fields indifferent seasons due to high integration of nutrients trigger vegetative growth and development. Similarly, number of marketable tuber increased significantly as the rate of sulfur increased, probably due to Sulfur’s role in synthesis of sulfur containing amino acids, proteins, energy transformation, activation of enzymes which in turn enhances carbohydrate metabolism and photosynthetic activity of plant with increased chlorophyll synthesis (Juszczuk and Ostaszewska, 2011).This was important for 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).

4.3.4. Unmarketable tuber number per plant

The main effects of intra row spacing and NPS fertilizer and their interaction revealed highly significant difference (P=0.001) on unmarketable tuber number per plant (Appendix Table 2).

Maximum unmarketable tuber number (3.02) was counted at intra row spacing (20 cm) and zero NPS fertilizer. The lowest unmarketable tuber number (0.72) was observed at 30 cm intra row spacing and 225 kg ha^{-1} NPS fertilizer treatment combination (Table 6).

The possible consequence for observation of highest number of unmarketable potato tuber (3.02) per hill from control might be due to deficiency of N, P, and S nutrients. Those deficiency causes the nutrients contents in the soil does not meet nutrient requirements of potato for vegetative growth, physiological processes, cell division, and stolon developments.

Current study was in line with Zewide *et al*. (2012), who reported that, the deficiency of nitrogen and phosphorous increases unmarketable tuber number per hill by affecting vegetative growth of potato. Shubhadip *et al*. (2017), reported that the size of potato tuber per hill was deteriorated due to insufficient (no) application of inorganic fertilizers. Also this result is consistent with that of Dwelle and Love (1993) who concluded that in closer intra row spacing bulking rate of individual tubers decreased and this resulted in smaller tubers and lower marketable tuber yield.

4.3.5. Marketable tuber yield

The main effects of intra row spacing and NPS fertilizer and their interaction revealed that highly significant difference (P=0.001) on marketable tuber yield (t ha-1) of potato (Appendix Table 2).

Low planting density and increased application of NPS fertilizer increased yield of marketable tuber. Thus, the highest yield of marketable tuber yield (39.21 t ha^{-1}) was recorded with treatment combination of intra row spacing of 30cm and 225 kg NPS ha^{-1} fertilizer, which however was not statistically different from that obtained at followed by intra row spacing 35cm and 225 kg ha^{-1}NPS fertilizer (38.6 t ha^{-1}) and intra row spacing of 25 cm and 225 kg ha^{-1} NPS fertilizer (38.2 t ha^{-1}) (Table 6). At wider spacing due to presence of minimum competition, plants absorbed the sufficiently available resources and intercepted more light. This increased their photosynthetic efficiency for higher photo assimilate production and ultimately result in marketable tuber yield. The lowest marketable tuber yield (12.9 t ha^{-1}) was recorded with intra row spacing 20 cm and zero NPS fertilizer (Table 6).

The higher marketable tuber yield at low planting density is attributed to the effect of low competition between plants for the available soil nutrient. Similarly, the yield increment in marketable tuber yield due to increased NPS fertilizer application implies that this mineral nutrient can contribute to produce more and healthy marketable size tubers due to its effect in delaying tuber growth associated with greater partitioning of dry matter to the above ground portion that ultimately contributed to the increased marketable tuber yield.

Current finding is in line with Masrie *et al.* (2015), who reported that application of inorganic soil nutrients increase large and medium sized marketable tuber yield resulted from balanced micro and macro nutrients helps to enhance metabolic activity of the plants. Positive effects of inorganic fertilizers on soil texture, aeration, water holding capacity and Cation exchange capacity of the soils helps to increase marketable tuber yields of potato (Asfaw, 2016). Also Getachew *et al*. (2018), reported that increasing application rate inorganic fertilizer, marketable tuber increases due to the increase in the soil nutrients that resulted in better vegetative growth which in turn enables the crops to produce greater photo assimilate.

The possible reason for the lowest marketable tuber recorded from 20 cm and zero NPS fertilizer might be shortage of available nutrients for growth and developments of plants that results to small leaf size, short growing period's and developments of small sized, disease tubers numbers which results increase unmarketable tubers. Current finding is in line with Daniel (2007) and Asfaw (2016),who reported reports that decreased marketable tuber yield was records from control treatments due to deficiency of growth promoting nutrients.

This resulted also consistent with that of Dwelle and Love (1993) who concluded that in closer intra row spacing bulking rate of individual tubers decrease and this resulted in smaller tubers and lower marketable tuber yield .In contrast at narrower intra row spacing there is high competition among plants for resources and leads to small size tuber which is less preferred in market. In terms of marketable yield the result showed that increasing plant population decreases marketable yield that is attributed to smaller tuber size. This indicates that at wider intra row spacing the presence of minimum competition, plants might have absorbed the available recourses and intercepted more light. Hence, this might have increased their photosynthetic efficiency for higher photo assimilate production and ultimately resulted in increased more marketable tuber yield (Tesfaye *et al.*, 2010).

4.3.6. Unmarketable tuber yield

The analysis of variance revealed that both main effects of planting density and NPS fertilizer and their interaction showed highly significant (P=0.001) difference on unmarketable tuber yield (Appendix Table 2).

The highest unmarketable tuber yield (2.2 t ha^{-1}) was obtained from the treatment combination of narrower intra row spacing (20cm) and 225 kg ha^{-1} NPS fertilizer. Conversely, the lowest yield of unmarketable tuber (0.28 t ha^{-1}) was recorded for wider intra row spacing of 30cm and 225kg ha^{-1}NPS fertilizer treatment combination (Table 6).

Possible reason for the highest unmarketable tuber yield (2.2t ha^{-1}) recorded from the treatment combination of narrower intra row spacing of 20cm and 225 kg ha^{-1} NPS fertilizer could be due to increase in closer plant spacing with increased NPS fertilizer rate. The closest spacing might have resulted in significantly higher yield of small tubers.

This result is consistent with that of Tesfaye *et al*. (2013) who reported that the highest unmarketable yield was obtained at the closer intra row spacing of 10 cm whereas the lowest was obtained at wide spacing of 40 cm. This is due to presence of higher competition between plants in closer intra row space. Similarly Alemayew *et al*. (2015) reported that The highest unmarketable tuber yield was produced at the highest planting density of eight plants m^{-2} , and exceeded the unmarketable tuber yield obtained at the lowest planting density of 4.17 plants m^{-2} by 0.863 tha^{-1}).

4.3.7. Total tuber yield

The main effects of intra row spacing and NPS fertilizer and their interaction revealed highly significant difference (P=0.001) on total tuber yield (t ha^{-1}) of potato (Appendix Table 2).

The total tuber yield tha^{-1} increased with wide intra row spacing and application of NPS fertilizer compared to narrow spacing and zero application of NPS fertilizer. The highest total tuber yield (40.36 t ha^{-1}) obtained from intra row spacing of 20cm and application of 225 kg NPS ha^{-1} fertilizer followed by intra row spacing of 25cm and 225 kg ha^{-1} NPS fertilizer (39.80t ha^{-1}) which however, was not significantly different from that recorded at intra row spacing of 30cm and 225 kg ha^{-1} NPS fertilizer 39.5 t ha^{-1} respectively (Table 6). On the other hand the lowest total tuber yield (13.4 t ha^{-1}) was obtained from treatment combination of intra row spacing of 35cm and zero NPS fertilizer.

The possible reasons for the highest total tuber yield observed from intra row spacing of 20cm and application of 225 kg NPS ha^{-1} fertilizer could be related with increasing Nitrogen, Phosphorous and Sulfur contents in the soil and modification of soil environments like aeration, nutrient availability, soil structures and Cation exchange capacity. These conditions enable the crops increase nutrient uptakes, water absorption, better vegetative growth, and absorption of high solar radiation. As result the crops are able to make functional metabolic activities that increase photosynthesis and carbohydrate production which helps for high yield production.

This result is consistent with that of Mohammadi *et al*. (2013) who reported that the presence of balanced supplement of nitrogen and phosphorus through mineral fertilizers might have contributed to increased cell division, expansion of cell wall, meristematic activity, photosynthetic efficiency and regulation of water intake into the cells, resulting in the enhancement of yield parameters. The increased yield at higher densities may be due to: the ground being covered with green leaves earlier (earlier in the season, light is intercepted and used for assimilation), fewer lateral branches are being formed and tuber growth starting earlier. To produce smaller tubers, higher plant densities are needed than for the production of big tubers. Similarly total potato yield increased due to increased application of sulfur fulfilling the requirement of Sulfur from subsurface zone of the soil that improves uptake of other macro and micronutrients resulting in enlarged potato tubers and increase total yields (Mohammede *et al.*, 2017).

In other words, increased plant population increased yield due to more tubers being harvested per unit area of land (Beukema and Van der zaag, 2010). However, decreases in total yields as a result of wider spacing were compensated in part by an increase in large-size tubers and a decrease in small tuber yields. This is apparently a result of reduced interplant competition which resulted in an increase in the total number of tubers per plant and average tuber size with wider seed piece spacing (Rex *et al,* 2012

Table 6. Interaction effect of intra row spacing and NPS Fertilizer on yield variables of potato production

Spacing (cm)	**NPS (kg/ha)**	**Av. No. Of tuber p-^{1}**	**Weight of tuber kg plot^{-1}**	**Marketable tuber plant^{-1}**	**Unmarketable tuber plant^{-1}**	**marketable tuber yield t ha-1**	**Unmarketable tuber yield t ha-1**	**Total yield t/h**
20	0	3.2^{i}	13.23^{n}	2.88^{j}	3.02^{a}	12.92^{h}	1.133^{e}	14.05^{j}
	75	6.1^{fg}	19.40^{j}	4.31^{g}	1.70^{de}	20.16^{d}	1.37^{c}	21.53^{g}
	150	7.8^{d}	21.33^{i}	6.59^{de}	1.16^{fgi}	23.24^{b}	1.53^{b}	25.10^{d}
	225	8.96^{c}	32.43^{c}	7.81^{c}	0.95^{hij}	38.17^{a}	2.20^{a}	41.47^{a}
25	0	5.00^{h}	15.46^{m}	3.46^{gh}	2.44^{b}	15.89^{g}	0.95^{f}	16.84^{i}
	75	6.63^{ef}	19.40^{j}	5.61^{f}	1.61^{de}	20.47^{d}	1.23^{de}	21.70^{g}
	150	7.91^{d}	24.83^{g}	6.66^{d}	1.14^{fgh}	23.20^{b}	1.30^{cd}	24.47^{de}
	225	10.120^{b}	28.50^{d}	8.85^{b}	0.78^{ij}	38.23^{a}	1.57^{b}	39.80^{b}
30	0	5.26^{gh}	16.17^{l}	3.86^{g}	2.087^{c}	17.93^{ef}	0.50^{hi}	18.43^{h}
	75	6.74^{ef}	23.77^{h}	5.71^{ef}	1.43^{ef}	18.07^{e}	0.60^{hg}	18.67^{hi}
	150	8.03^{d}	26.37^{f}	7.05^{cd}	1.08^{ghi}	23.07^{b}	0.37^{ij}	23.44^{ef}
	225	10.40^{b}	36.23^{b}	10.11^{a}	0.73^{j}	39.21^{a}	0.28^{j}	39.40^{bc}
35	0	5.93^{fg}	17.67^{k}	4.10^{g}	1.84^{cd}	12.92^{fg}	0.48^{hi}	13.40^{k}
	75	7.23^{de}	24.63^{g}	6.21^{def}	1.28^{fg}	17.65^{ef}	0.71^{g}	18.37^{hi}
	150	8.89^{c}	27.87^{e}	7.77^{c}	0.97^{ghij}	21.77^{c}	0.48^{hi}	22.23^{fg}
	225	11.63^{a}	38.00^{a}	9.81^{a}	0.72^{j}	38.63^{a}	0.39^{ij}	38.97^{c}
LSD(5%)		**0.40**	**0.30**	**0.44**	**0.16**	**1.24**	**0.13**	**0.59**
CV (%)		**6.52**	**1.54**	**8.37**	**13.38**	**3.09**	**5.67**	**3.13**

4.4. Correlation Coefficient Analysis

The correlation values showed the magnitudes and direction of the association and relationships among the parameters. Correlation analysis among major response variable are indicated in Table 7

Results of correlation indicates that total tuber yield of potato showed highly significant (P=0.0001) and positive correlation with mean plant height (r=0.71**), days to 50% flowering(r=0.89**), main stem number(r=0.82**),days to maturity(r=0.89), average number of tuber per plant(r=0.89**), weigh of tuber(r=0.93**), marketable tuber yield (r=0.91**) and marketable tuber per plant (r=0.86**). The possible reason for the observed association between total tuber yield and those parameters could be as Nitrogen, Phosphorus, Sulfur and other important nutrients increased in the soil due to NPS fertilizers. The soil would be more fertile and plants get sufficient nutrients, produce more leaf numbers and more vigorous growth as well as produce more photosynthesis, produce sufficient carbohydrates to increase the yield of potato.

On the other hand unmarketable tuber per hill (r= -0.79**), unmarketable tuber t ha^{-1} (r= -0.86**) had highly significant (P=0.0001) difference and negatively correlated with total yield of potato tuber. The reason for negative association of total tuber yield with unmarketable tuber yield could be due to improvement of soil fertility status, increased soil aeration, nutrients uptakes which enhanced the size of potato tubers and in turn reduced unmarketable potato tuber yields.

Current study is in line with Mohammed *et al.* (2018) who reported that total yield and marketable tuber yield of potato was positively and significantly correlated with all growth parameters and negatively correlated with unmarketable tuber yield of the crop due to application of inorganic nutrients by improving crop productivity and profitability. Mustefa(2018); Getachew(2019), reports increasing the application of fertilizers increase the soil fertility which results increase plants growth, photosystems and carbohydrate as result total yield positively and significantly correlated with growth parameters and negatively with unmarketable yields of the crops.

Table 7. Simple Correlation coefficient among different parameters

	MS	**DFL**	**PH**	**DM**	**ANTP**	**WTK**	**MTP**	**UMTP**	**MTY(t ha^{-1})**	**UMTY(t ha^{-1})**	**TY(t ha^{-1})**
MS	1	0.87**	0.74**	0.90**	0.91**	0.87**	0.86**	-0.88**	0.84**	-0.88**	0.82**
DTF		1	0.87**	0.94**	0.94**	0.94**	0.94**	-0.91**	0.94**	-0.87**	0.89**
PH			1	0.82* *	0.80**	0.76**	0.85**	-0.84**	0.80**	-0.81**	0.71**
DM				1	0.94**	0.91**	0.93**	-0.93**	0.92**	-0.92**	0.89**
ANTP					1	0.93**	0.92**	-0.91**	0.93**	-0.89**	0.89**
WTK(kg)						1	0.93**	-0.89**	0.93**	-0.85**	0.93**
MTP							1	-0.96**	0.96**	-0.90**	0.87**
UMTP								1	-0.92**	0.93**	-0.86**
MTY (t ha^{-1})									1	-0.85**	0.91**
UMTY (t ha^{-1})										1	-0.79**

PH=plant height at 50% flowering, DTF=Days to 50% flowering, DTM= Days to 50% maturity, ANTP=Average number of tuber per plant, UMTP=Unmarketable tuber per plant, WTK=Weight of tuber in kilogram, MTY=Marketable tuber yield, MTP=Marketable tuber per plant, UMTY=Unmarketable tuber yield and TY=Total tuber yield

4.5. Economic benefit

The results of the partial budget analyses revealed that the highest net returns of Birr 404255.3was recorded in the treatment combination of intra row spacing of 30cm and 225 kg ha-1 NPS followed by treatment combination of intra row spacing of 30cm and 225kg ha-1 NPS .However, the lowest net returns of Birr 117376.8 was received from treatment combination of intra row spacing of 20 cm and zero NPS fertilizer).Dominance analysis is thus carried out by first listing the treatments in order of increasing costs that vary. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary was considered dominant (CIMMYT, 1988).High net return from the foregoing treatments could be attributed to high yield and the low net return was attributed to low yield. However, the highest marginal rate of return was recorded in the treatment combination of intra row spacing of 30cm and 225kg ha^{-1} NPS fertilizer receiving and the minimum marginal rate of return was recorded from the treatment combination of intra row spacing of 35cm and 75kg ha^{-1} NPS fertilizer.

Table 8. Interaction of intra row spacing and NPS fertilizer on economic analysis of marketable tuber yield

Spacing	**NPS (kg ha-1)**	**TVC**	**GAY**	**ADY**	**GFB**	**NB**	**MRR**
20cm	0kg ha-1	21943.2	12.90	11.61	139320	117376.8 D	
20cm	75kg ha-1	23124.7	20.10	18.09	217080	193955.3	6481.464
20cm	150kg ha-1	24316.2	23.20	20.88	250560	226243.8	2709.903
20cm	225kg ha-1	25485.7	38.10	34.29	411480	385994.3	13659.73
25 cm	0kg ha-1	18802.6	15.89	14.30	171612	152809.4	3489.173
25 cm	75kg ha-1	19984.1	20.46	18.41	220968	200983.9	4077.402
25 cm	150kg ha-1	21175.6	23.20	20.88	250560	229384.4	2383.592
25 cm	225kg ha-1	22345.1	38.23	34.41	412884	390538.9	13779.78
30cm	0kg ha-1	15670.2	17.90	16.11	193320	177649.8 D	
30cm	75kg ha-1	16851.7	18.06	16.25	195048	178196.3	46.25476
30cm	150kg ha-1	18043.2	23.07	20.76	249156	231112.8	4441.167
30cm	225kg ha-1	19212.7	39.21	35.29	423468	404255.3	14804.83
35cm	0kg ha-1	14104	16.74	15.07	180792	166688 D	
35cm	75kg ha-1	15304	17.65	15.89	190620	175316	719
35cm	150kg ha-1	16504	21.74	19.57	234792	218288	3581
35cm	225kg ha-1	17704	38.60	34.74	416880	399176	15074

Where: Purchasing costs for fertilizers NPS (Nitrogen, phosphorus, sulfur) were estimated at Birr 15 kg -1..The selling price of potato at the local market at the harvest time was estimated at Birr 535/quintal . Purchasing costs for potato seed Birr 9/kg.MC=marginal total cost, MRR = marginal rate of return TVC=total variable cost, GAY=growth average yield, *ADY= Adjusted yield, GR=gross return, NR= net return.*

5. SUMMARY AND CONCLUSION

Potato (*solanum tuberosum* L.) is commonly produced in an area up to 2500m above sea level in different parts of the country, as source of income and improves food security of the growers. Productivity of the crop however, is limited by lack of optimizing plant population, low soil fertility and poor nutrient management practices.

A field experiment was conducted to determine planting density and NPS fertilizer on growth, yield and yield components of potato at Jimma zone, Eladale site in 2019. A 4x4 factorial experiment consisting of Four levels of intra-row spacing (20 ,25 , 30 and 35 cm) and four levels of NPS fertilizer (0, 75, 150 and 225kg ha-1 NPS) was arranged in a randomized complete block design with 3 replicates. Data on growth, yield and yield attributes were collected and analyzed using SAS Version 9.3. The result indicated that combination of planting density with NPS fertilizer was found to be important for the growth, yield and yield components of potato in the study area and ensued in better performances for growth, and yield attributes variables.

Results indicated that the interaction effect of intra row spacing and NPS fertilizer significantly influenced plant height, days to 50% flowering, days to 75% of physiological maturity, main stem number, weight of tuber, total tuber yield, marketable tuber yield, unmarketable tuber yield, total tuber number per plant, marketable tuber number per plant and unmarketable tuber number per plant.

The highest mean number of plant height(93.3), early days to 50% flowering(46.3), early days to 75% of physiological maturity(66),main stem number(6.2), highest weight of tuber(38k.g), highest total tuber yield tha^{-1}(40.36), highest marketable tuber yield t ha-1(39.21), unmarketable tuber yield tha^{-1}(2.2), highest total tuber number per plant(11.63), highest marketable tuber number per plant(10.1) and highest unmarketable tuber number per plant(3.02) were observed from the treatment combination of intra row spacing of 20cm and225 NPS fertilizer, intra row spacing of 20cm and zero NPS fertilizer, intra row spacing of 20cm and zero NPS fertilizer, intra row spacing of 35cm and 225 NPS fertilizer, intra row spacing of 35cm and 225 NPS fertilizer, intra row spacing of 20cm and225 NPS fertilizer, intra row spacing of 30cm and225 NPS fertilizer, intra row spacing of 20cm and225 NPS fertilizer, were applied respectively. The highest net benefit of birr 404255.3 ha^{-1}, with an acceptable marginal rate of returns (14804.83%) were observed from treatment combination of intra row spacing of 30cm and 225kg ha^{-1} NPS fertilizer. Total tuber yield (t ha^{-1}) positively and highly significantly correlated with days to 50% flowering, days to 75% physiological maturity, weight of tuber, total number of tuber per plant, marketable tuber per plant, marketable tuber yield, total tuber yield, marketable and total tuber number, plant height, and main stem number and negatively correlated with unmarketable tuber per plant and unmarketable tuber yields.

In conclusion, the result of current study indicated that the treatment combination of intra row spacing and NPS fertilizer improved growth and yield of potato. Accordingly, the highest tuber yield was obtained from treatment combination of intra row spacing 20cm and 225k.g NPS fertilizer. In terms of economic point of view, treatment combination of intra row spacing 30cm and 225 kg ha^{-1} NPS fertilizer gave high net benefit with high marginal rate of return and economically feasible.

Therefore on the basis of present finding, potato can grow well in study area and benefits the farmers when they practice combined application of intra row spacing of 30cm with 225kg ha^{-1} NPS fertilizer which resulted in high marketable yield of potato. Since the study was conducted for only one season, using only one variety and at one location. It will be worth repeating the experiment to arrive at a conclusive result.

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APPENDICES

Appendix Table 1. Analysis variance showing mean squares for 50% of flowering days, 75% of maturity days, plant height at 60 days after emergence and main stem numbers at 50% of flowering days

Source of variation	DF	DFR	DM	PH	MS
Rep	2	1.312500	8.395833	16.602708	0.00471458
Intra	3	22.298611	86.694444	53.7	0.66709167
NPS	3	783.187500	844.972222	1233.619167	3.16364722
Intra*NPS	9	3.206019	9.805556	21.420648	0.09526389
ERROR	30	1.445833	4.129167	8.346931	0.03565903
CV		2.04	2.44	3.61	3.51

*DF = degrees of freedom, DFR = days to 50% flowering, DM= days to 75% maturity, PH=plant height, main stem number and NS, * and ** implies non-significant, significant and highly significance differences at 5% level of probability, respectively*

Appendix Table 2. Analysis of variance showing mean squares for average number of tuber per plant, weight of tuber, marketable tuber number per plant, unmarketable tuber number per plant, unmarketable tuber yield, marketable tuber yield, and total tuber yield of potato affected by the application of intra row spacing and NPS fertilizer

Source of variables	**DF**	**ANTP**	**WT**	**MTY**	**UNMTY**	**TTY**	**MTN**	**UNMTN**
Rep	2	0.318	0.1818	0.318	0.019	5.285	0.548	0.121
Intra	3	7.406	85.82	11.102	632.06	101.61	4.988	0.566
NPS	3	63.489	687.60	1214.48	242.41	476.14	66.931	5.460
Intra*NPS	9	0.569	8.278	0.569	266.58	14.361	0.631	0.126
ERROR	30	0.238	0.135	0.238	0.068	0.509	0.278	0.036
CV		6.523	1.54	3.098	5.673	3.16	8.37	13.38

*DF=Days of 50% flowering, MTY= marketable tuber yield, UNMTY= unmarketable tuber yield, WT=weight of tuberANTP= average number of tuber per plant, MTN= marketable tubers per plant and UNMTN= unmarketable tuber number per plant, NPS=Nitrogen, phosphorus and sulfur fertilizer and NS, * and ** implies non-significant, significant and highly significance differences at 5% level of probability, respectively*

Appendix Table 3. Average rainfall and temperature record of Jimma Zone in 2019

Month	Mean rainfall (mm)
January	0mm
February	65mm
March	61.4mm
April	215mm
May	196.2mm
June	389mm
July	239.7mm
August	383.1mm
September	221.4mm
October	93mm
November	162mm
December	12.7mm
Total	1928.5

Source: Jimma zone Metrology Station (2019)

Appendix Figure 1. Different pictures captured during the research process