EFFECTS OF BLENDED NPS FERTILIZER AND FARMYARD MANURE ON GROWTH, YIELD AND QUALITY OF POTATO (*Solanum tuberosum* L.) IN DEBRE BERHAN, NORTH SHEWA, ETHIOPIA

MSC. THESIS

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In Partial Fulfillment of the Requirements for the Degree of Master of Science in Agronomy

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Debre Berhan, Ethiopia

COLLEGE OF GRADUATE STUDIES, COLLEGE OF AGRICULTURE AND NATURAL RESOURCE SCIENCES DEBRE BERHAN UNIVERSITY

APPROVAL SHEET – I

This is to certify that the thesis entitled: **EFFECTS OF BLENDED NPS FERTILIZER AND FARMYARD MANURE ON GROWTH, YIELD AND QUALITY OF POTATO (*SOLANUM TUBEROSUM L.*) IN DEBRE BERHAN, NORTH SHEWA, ETHIOPIA** submitted in partial fulfillment of the requirements for the degree of Master of Science with specialization in Agronomy of the Graduate Program of the Department of Plant Science, College of Agriculture and Natural Resource Sciences, DebreBerhan University and is a record of original research carried out by Getacher Demissew Id. No PGR/198/11, under my supervision, and no part of the thesis has been submitted for any other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it to be accepted as fulfilling the thesis requirements.

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APPROVAL SHEET – II

We, the undersigned members of the board of the examiners of the final open defense by Getacher Demissew have read and evaluated his thesis entitled **EFFECTS OF BLENDED NPS FERTILIZER AND FARMYARD MANURE ON GROWTH, YIELD AND QUALITY OF POTATO (*SOLANUM TUBEROSUM* L.) IN DEBRE BERHAN, NORTH SHEWA, 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 of Master of Science in Agronomy.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the department graduate committee (DGC) of the candidate’s major department.

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DEDICATION

This thesis work is dedicated to my wife Kalekidan Gebeyehu and my son Kidane Mareyam Getacher for their fondness and consistent care in the success of my existence

STATEMENT OF THE AUTHOR

I declare that this thesis is my genuine work, and that all sources of materials used in this thesis have been profoundly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the Master of Science (MSc) at Debre Berhan University and it is deposited in the University Library to be made available for users under the rule of the library. I intensely 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 allowed without special permission, provided that accurate acknowledgment of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the College of Graduate Studies when in his judgment the proposed use of the material is in the interest of scholarship. In all other instances, however, permission must be obtained from the author and advisors of this thesis.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASW	Available Soil Water
CEC	Cation Exchange Capacity
CIP	International Potato Center
CW	Container Weight
CSA	Central Statistical Agency
DAP	Di-ammonium Phosphate
DBARC	Debre Berhan Agriculture Research Center
DMRT	Duncan’s Multiple Range Tests
DW	Dry Weight
ETB	Ethiopian’s Birr
FYM	Farmyard Manure
FW	Fresh Weight
GFB	Gross Field Benefit
LAI	Leaf Area Index
MOA	Ministry of Agriculture
MOANR	Ministry of Agriculture and Natural Resource
MRR	Marginal Rate of Return
NPS	Nitrogen, Phosphorus, Sulfur
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
TSS	Total Soluble Solid

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EFFECTS OF BLENDED NPS FERTILIZER AND FARMYARD MANURE ON GROWTH, YIELD AND QUALITY OF POTATO (*Solanum tuberosum L.*) IN DEBRE BERHAN, NORTH SHEWA, ETHIOPIA.

Getacher Demissew

ABSTRACT

Potato (Solanum tuberosum L.*) is one of the most important food security and cash crops in Ethiopia due to its high production potential, nutritional quality, short growing period and wider adaptability. However, Low soil fertility and crop nutrient imbalances management practices are major constraints preventing Ethiopian farmers from realizing high agricultural productivity. So far, the emphasis has not been given to assessing the influence of the combined application of inorganic and organic fertilizer on the yield and quality of potato. Thus, a field experiment was carried out during the main cropping season at Debre Berhan University College of agriculture and natural resource science research site. The field experiment was conducted with the objective of evaluating the effects of NPS fertilizer and farmyard manure on the growth, yield and quality of potato. The treatments consisted of four levels of NPS (0, 60, 120 and180 kg ha^{-1}) fertilizer and four levels of farmyard manure (0, 10, 20 and 30tha^{-1}) and an improved potato variety called 'Gera' (KP-90134.2) was used as a test crop. The experiment was set out as a Randomized Complete Block Design (RCBD) in a 4x4 factorial arrangement and replicated three times. The results indicated that days to 50% flowering, days to75% physiological maturity, total leaf area per plant (cm^2) and unmarketable tuber yield (tha^{-1}) were significantly affected ($P \leq 0.05$) by application of the main effect of 180kgha^{-1} NPS and 30tha^{-1} FYM fertilizer. The combined application of 180 kg ha^{-1}NPS fertilizer and30tha^{-1} farmyard manure resulted in the tallest plant height(73.26cm),the highest main stem number(4.73),the highest number of branch(16.93),the highest leaf number(378.86), the highest leaf area index (6.82), the highest marketable tuber number per plant (25.53),the highest average tuber weight(88.26g tuber^{-1}), the highest total tuber yield (32.68tha^{-1}) while the application of 30tha^{-1}FYM and 180kgha^{-1}resulted in a non-significant change in tuber quality of potato. The combined application of 180 kg ha^{-1} NPS and 30tha^{-1} FYM fertilizer level gave the maximum economic benefit (Birr 119,758 ha^{-1}) with an acceptable marginal rate of returns (1,636.1%). Hence, plots received 180 kg NPS ha^{-1}and 30t FYM ha^{-1} fertilizer level recommended for the production of potato in the study area and similar agro- ecologies with acceptable economic benefit.*

Keywords: *Blended fertilizer, FYM, leaf area index, Marketable tuber yield, Tuber quality*

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important tuber crops in the world. It is native to South America (Eskin *et al.,* 1989). It is the most important vegetable crop, constituting the fourth most significant food crop in the world following wheat, maize and rice and first among root and tuber crops (Douches, 2013). It is one of the widely grown roots and tuber crops being a rich source of nutrients for human nutrition. It contains approximately 79% water, 18% starch as a safe source of energy, 2% protein and 1% vitamins, including vitamin C, minerals including calcium and magnesium and many trace elements (Ahmad *et al.,* 2011). The potato has better a ability to furnish a high output of high-quality product per unit input with a shorter crop cycle (generally less than 120 days) as compared to major food grain crops like maize (Hirpa *et al.*, 2010). As a result, the crop is appreciated as a respectable source of nutrient food and cash by a large number of food insecure smallholder farmers and pastoralists in Ethiopia (Haverkort *et al.*, 2012).

The potato has been introduced to Ethiopia in 1859 by a German Botanist, Schimper (Berga *et al.*, 1994b). In Ethiopia, potato ranks first among root and tuber crops both in the volume of production and consumption followed by cassava, sweet potato and yam where smallholder farmers are the major producers as food, and cash crop (CSA, 2017). The average national tuber yield has increased mainly in the highlands as well as in the mid altitudes in the range of (1700-2800 m.a.s.l.) with an annual rainfall of not less than 900 mm of rain-fed production (Bekele and Hailu, 2001). In Ethiopia, its production area has reached about 66,926ha and total production of 968,969.6 tons cultivated by over 1.2 million households (CSA, 2018). Hence, the productivity of this crop in the country is 13.8 t ha^{-1} which is lower as compared to the world's average yield of 19 t ha^{-1} (CSA, 2017). Amhara Region is the major potato growing area in Ethiopia followed by Oromia and Southern Nations, Nationalities and Peoples Republic (SNNPR). The Region contributes about 40% of the national potato production where South Gonder, North Gonder, East Gojam, West Gojam and Awi are major potato producing zones (CSA, 2018).The gap between the potential yield and actual average national yield per unit area of land could be due to unavailability and high price of quality seed tubers, lack of improved varieties, low use of organic manures and unbalanced fertilizations, and the low market price at the time of harvesting, diseases and post-harvest losses (Fuglie, 2007;Abay and Tesfaye, 2011).

The application of organic manure and inorganic fertilizers could substantially influence the production of potato (Biruk Masrie *et al*., 2015; Bekunda *et al.*, 2010 and Melkamu Alemayehu *et al.*, 2019). Organic fertilizers like farmyard manure (FYM) improve plant nutrient availability, physical, chemical, and biological properties of soils and thus enhance crop yields (Baia *et al.*, 2018; Tsegaye Girma *et al.*, 2017 and Gosling and Shepherd, 2005). Using FYM has positive, beneficial effects on vegetative growth, yield and tuber quality and it can decrease the demand for chemical fertilizer (Tesfaye Balemi *et al.*, 2012 and Najm *et al.*, 2013; Kolay, 2007). But the use of organic manure alone may not be enough to maintain the present level of crop production and enhancing soil fertility because of its limited availability, relatively low nutrient content and high labor requirements (Palm *et al.*, 1997; Getachew Zeleke *et al*., 2010).

In Debre Berhan district, the majority of potato growers depend on P in the form of Di-ammonium phosphate (DAP) and N in the form of urea (Ethio SIS, 2014).Recently, the ministry of agriculture (MoA) popularize the implementation of a soil test based fertilizer application system through the use of soil fertility information (MoANR, 2013) and thus introduced a new fertilizer (NPS) which contain Nitrogen, Phosphorous and Sulfur in the country's farming System to increase productivity since sulfur is the fourth essential nutrient next to N, P and K. Thus, a new brand of NPS blended fertilizer having a proportion of 19% N, 38% P_2o_5 and 7% S, are currently substituting DAP in Ethiopian crop production system as the primary source of phosphorous (MoANR, 2013).

The application of inorganic NPS blended fertilizers has the main advantages to the farmers from which nutrients are supplied in ratios to suit the demands of particular soils and crops (Roy *et al.*, 2006). Increasing the rates of NPS fertilizers increased plant height, stem number, leaf area index, days to flowering, days to maturity, average tuber number per hill, average tuber weight, marketable tuber yield and total tuber yield (Arega Amdie, 2018; Minwyelet Jemberie *et al.*, 2017 and Melkamu Alemayehu *et al.*, 2018). Many previous research outputs indicated that the combined application of organic and inorganic fertilizer resulted an increased in growth, yield and yield component and quality parameters of potato (Amin Ababiya,2018; Bewket Getachew,2019; Fessha Alemu,2019; Mousavi *et al.*, 2007; Gruhn *et al.*, 2000; Menon, 1992; Melkamu Alemayehu *et al.*, 2016 and Israel Zewide *et al.*, 2018). This implies that the integrated nutrient management paradigm recognizes the need for both organic (FYM) and inorganic mineral (NPS) inputs to sustain soil health and maximize mineral fertilizer and organic resource use efficiency and crop productivity due to positive interaction and complementarities between them (Woomer *et al.*, 1999; and Vanlauwe *et al.*, 2002).

Even though, FYM and NPS fertilizers are utilized as a means of increasing productivity of potato, the increasing cost of fertilizer, a few trends of farmers using FYM for increasing productivity, a little study about the combined use and recommended rate of NPS and FYM fertilizer are a bottleneck problem observed in the study area. By considering the above situation, conducting a research in this line is vital to increase the yield and quality of potato in DebreBerhan. Hence, the present study was conducted with the objectives: -

- **General objective**

  - ❖ To evaluate the effect of NPS fertilizer and farmyard manure on growth, yield and quality of potato (*solanum tuberosum* L.) in Debre Berhan, North Shewa, Ethiopia.

- **Specific objectives**

  - ❖ To determine the effect of integrated nutrient management on growth, yield, yield components and nutrient content of potato and

  - ❖ To investigate the role of integrated nutrient management on soil fertility

2. LITERATURE REVIEW

2.1. Botany of Potato

The cultivated potato belongs to the family Solanaceae, genus Solanum, and accommodated in series Tuberosa (van den Berg and Jacobs, 2007). The plant bears two kinds of stems, the above ground base that supports the leaves and flowers and the underground one whose terminal portion swells to form the tubers as it accumulates starch and carbohydrates from photosynthesis in leaves (Anonymous, 2013; Margaret *et al.*, 2007).

Branching may occur at any node, but branching is most common at the stem of the plant. Some branches arise from underground nodes on the main stem. Without disturbing the soil, it is difficult to tell these from stems that have originated from separate eyes of the seed tuber. Other auxiliary branches arise from nodes just above the soil. The extent of axillary branching, both sympodial and basal, is of essential importance in determining yield potential (Ewing, 1997). Leaves are pinnate with a single terminal leaflet and three or four pairs of large, ovoid leaflets with smaller ones in between (Struik, 2007).

Flower initiation generally occurs before tuber initiation and takes place a few weeks after emergence. In this sense, potato is a determinate plant. The clusters bear white, pink, crimson, blueish, or purple blooms with yellow stamens. Flower bud abortion may take place at a very early phase of development, but in any event, the apical growth of the main stem ceases with the shaping of the flower buds. The cessation of development of the main shoot axis may not be obvious because sympodial growth of one or more auxiliary branch just under the apex permits further extension above the flower cluster (Alemkinders and Struik, 1994). The fruits are small inedible berries and contain poisonous alkaloids (Rice *et al.*, 1990). The fruits are spherical to ovoid berries, about 1-4 cm in diameter. They are green or green tinged with white or purple spots or bands when ripe (Spooner and Salas, 2006).

The potato has a relatively shallow, fibrous root system with the majority of the roots in the surface 30 cm depth (Onder *et al.*, 2005). The root system grows rapidly during early development and achieves maximum development by mid-season. Thereafter, root length, density and root mass decrease as the plant grows. Rooting depths of 1.2 m or more have been reported for potato under favorable soil conditions (Tanner *et al.*, 1982).

2.2. Ecological Requirements of Potato

Potato is grown in many different environments, but it is best adapted to cool weather and temperature between 16 to $25^{o}{}_{C}$ that favors foliage growths, net photosynthesis, and tuberization (Levy, 1992). The rate of sprout development from seed pieces depends on soil temperature. Very little sprout elongation occurs at $6°_{C}$. Elongation is slow at $9°_{C}$ and is maximized at about $18°_{C}$. The optimum soil temperature for initiating tubers is $16\text{-}19°_{C}$. Tuber development declines as soil temperatures rises above $20°_{C}$ and tuber growth practically stops at soil temperatures above $30°_{C}$. The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favors the development of large tubers (Western Potato Council, 2003).

Potato cultivated at the elevations above 1500 m.a.s.l is cooler and therefore congenial for seed and ware tuber production due to low aphid population (Kadian *et al.,* 2010; Wudineh Getahun *et al.,* 2016). Increases in either daylight or night temperature above optimal levels ($18^{O}{}_{C}$ to 20 ${}^{O}{}_{C}$) reduce tuber yields and cool night temperatures are important because they affect the accumulation of carbohydrates and dry matter in the tubers. At lower night temperatures, respiration is slowed, which enhances the storage of starch in the tubers (Western Potato Council, 2003; Levy and Veilleux, 2007; Pereira *et al.,* 2008). High temperature inhibits tuberization in both short and long photoperiods, however, its effect is much greater under long photoperiods. High temperature affects the partitioning of assimilates by decreasing the amount going to the tubers and increasing the amounts to other parts of the plant; similar effects are also observed in long photoperiods. Exposing the shoot to high temperatures ($30\text{-}35^{o}$c) had the greatest inhibitory effect on induction to tuberize as determined by tuberization of cuttings taken from the plants after the treatment (Ewing and Struik, 1992). It is not frost tolerant and will be killed at temperatures of $-3^{0}{}_{C}$ or lower (Li, 1977).

A uniformly distributed rainfall ranging between 500 to 750 mm during the growing period is required for optimum growth (Stol *et al.,* 1991). The root system of the potato plant is not extensive and ample soil water is necessary whether from rain or supplemental irrigation. Potatoes require a continuous supply of soil water along with adequate soil aeration. Yields are greatest when soil moisture is maintained above 65% of the available soil water (ASW) capacity. Potatoes respond to an ample soil moisture supply to increase the yield and quality of the tuber (Dolores *et al*., 2009; Lutaladio *et al.,* 2009). There are generally fewer tubers set when available soil moisture is maintained below 65% of the ASW capacity. The amount of water needed by potatoes varies with the soil type, temperature, humidity, air movement, plant and stem populations, variety and cultural practices (Western Potato Council, 2003).

Potato plants require a well-drained soil so that the roots have adequate oxygen. The most attractive tuber shape and skin appearance are achieved with light, sandy soils or with muck soils. Soils with a pH of 5.5 - 6.5 are suitable for tuber production (Tantowijoyo and Vande flirt, 2006). Potatoes grow well at a higher soil pH, but scab can be a problem. If it is not practical to maintain a low, scab- resistant cultivars must be grown (Ewing, 1997). The growth and quality of potatoes are influenced by several factors, including temperature, moisture, light, soil type, nutrients, variety, size of seed tubers, plant stand, stems population, pest management, planting date and harvest date. It is only when all factors that influence growth of the crop are at optimum levels can the most profitable yields of quality seed potatoes be attained (Lung'aho *et al.*, 2007).

2.3. Importance of Potato

The importance of potato as one of the world's major staple crops is increasingly being recognized, because it produces more dry matter and protein per hectare than the major cereal crops. The nutritional value of potato tubers is a key factor for its progressive production, along with the economic benefits that potato cultivation can bring to developing countries (Van Gijessel, 2005; McGregor, 2007). Potato is an important food crop after cereals, in human diet in developed as well as in developing countries (Wheeler, 2009; Kushwaha *et al.*, 2014).

Among root and tuber crops in Ethiopia, potato ranks first in volume production and consumption followed by cassava, sweet potato and yam (CSA, 2016). Similarly, it also goes beyond wheat, rice and maize in terms of dry matter and protein production of per unit of area (Romero-Lima *et al.*, 2000). It has substantial amounts of vitamins, minerals such a crop is undoubtedly very important for countries like Ethiopia, where inadequate protein and supplies of calories are the apparent nutritional problems (Berga *et al.*, 1994b; Lutaladio and Castaldi, 2009). Potato is consumed in different forms such as boiled or fried and many different processed products, like chips, French fries, flakes, powder etc., which are enjoyed across the generations and continents (Pandey *et al*., 2009). Traditionally, consumers select potatoes by visual characteristics, such as tuber size, shape, and color and skin brightness in the fresh market.

The nutritional value of potato tubers is a key factor for its progressive production, along with the economic benefits that potato cultivation can bring to developing countries (Canali et al., 2010). Each potato cultivar has the unique tuber appearance and nutritional composition (Storey and Davies, 1992). The tuber is known to supply carbohydrate, high quality protein, and a substantial amount of essential vitamins, minerals, and trace elements (Horton and Sawyer, 1985). It provides considerable source of carbohydrates (22.6 g/100g), dry matter (20 g/100g), starch (16.3 g/100 g), 70-80% water, protein 2.1%, fat 0.3%, crude fibre 1.1% and ash 0.9% (Banjare *et al.,* 2014). Potatoes are also rich source of vitamins, especially C and B. A single, medium-sized potato tuber contains about half the daily adult requirement of vitamin c and significant amount of vitamin B, iron, potassium, and zinc (FAO, 2014)

Besides being an economical and nutritious food source, potatoes also have medicinal properties. A potato tuber is antispasmodic, mild anodyne, digestive remedy, diuretic, and emollient. Moreover, potato is a good medicine for stomach ulcer, duodenum ulcer and stomach acidity. Moreover, there has been an increasingly higher interest on the part of consumers for use of the nutrient rich potato, because population based epidemiological studies have stressed the important role of diet (especially mineral malnutrition) and lifestyle in the emergence of some degenerative chronic diseases, such as cancers and cardiovascular diseases, in both developed and developing countries (Andre *et al.,* 2007).

2.4. Production Status of Potato in Ethiopia

The cultivated potato belongs to the family Solanaceae, genus Solanum, and accommodated in series Tuberosa (van den Berg and Jacobs, 2007). Potato is the world's most important tuber crop. It is grown in more than 125 countries (FAO, 2009) of the world with a total production of 308 million tons (Kumar *et al.,* 2012). Potato cultivation is expanding strongly in the developing world, where the potato's ease of cultivation and nutritive content has made it a valuable food security and cash crop for millions of farmers. Developing countries are now the world's biggest producers and importers of potatoes and potato products (FAO, 2009).

In Ethiopia, root crops are also a good source of food, cash and foreign exchange for the growers and the country, respectively (Mesfin Admasu, 2009). According to Vita (2015) Ethiopia has possibly the highest potential for potato production of any country in Africa with 70% of the

13.5 million ha of arable land suitable for potato cultivation. It is grown in four major areas: the central, the eastern, the northwestern and the southern. From total potato farmers in Ethiopia about 10%, of the potato farmers are located in central, 3% in eastern, 40% in northwestern and more than 30 % in southern Ethiopia (Adane *et al.*, 2010). However, potato is widely regarded as a secondary non-cereal crop in part because it has never reached the potential that it has in supporting food security (Vita, 2015). In the major potato produced areas of the country, the average yield (less than 10 Mg ha^{-1}) is far below the potential, however, there are improved varieties that yield 19–38 Mg ha^{-1} on farmers' fields (Hirpa *et al.*,2010).

2.5. Challenges of Potato Production in Ethiopia

Potato has long been regarded as a lowly subsistence crop and is still an underexploited food crop. Potato has huge potential to improve food security, income and human nutrition and it is in Ethiopia where the potential of this crop is increasingly being realized and explored by farmers, private investors, and policy makers. While, national average yields are still far below attainable yields, ample opportunities exist to unleash this crop's potential for increased food security and income generation (Teklemariam, 2014).

The low acreage and productivity of potato in Ethiopia are attributed to many factors. The major ones are lack of well adapted and high-yielding cultivars, unavailability and high cost of seed tubers, inappropriate agronomic practices, and lack of marketing and suitable post-harvest management facilities, pests and disease (Berga *et al.*, 1994b; Tekalign Tsegaw, 2005 and Endale Gebre,2008) Also described that lack of varieties with stable and high yield potential, lack of good quality seeds, disease and pest problems, drought and seed dormancy to fit the local cropping calendar, lack of improved characterization and ex situ conservation of potato genetic resources are very important limitations to potato production by smallholder farmers in sub-Saharan-Africa. Several varieties of potato are grown by farmers some of which are local and others are improved varieties. According to Tekalign Tsegaw (2005) 98.7% of the seed tubers required in Ethiopia are supplied from the local varieties. The seed tubers supplied by this system have poor sanitary, physiological, physical and genetic qualities (Adane *et al.*, 2010; Berga *et al.*, 1994b; Tekalign Tsegaw, 2005).

The yield gap between attainable and potential yield of potato in Ethiopia is very high. In Ethiopia bacterial wilt disease are one of the most important factors that contributes to the high yield gap in the country. The contribution of diseases to the gap between the production potential and the current average national production takes a large part since potato crop is susceptible to a number of diseases including late blight, viruses and bacteria wilt (Aliy, 2008). Furthermore, the use of local varieties is one and the most important factors which contribute to the low yield of potato in Ethiopia. This is because; the local varieties are susceptible to late blight and of course low yield potential (Getachew *et al*., 2000).

2.6. Effect of Mineral Fertilizers on Potato Production

Application of mineral fertilizers in the tropics had stagnated, and this was explained by poor marketing and inadequate profitability from mineral fertilizer use (Hartemink, 2002). 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).

Potato demands a high level of soil nutrients due to relatively poor developed and shallow root system this is due to fast rapid early growth and tuber formation (Ghannad *et al.,* 2014; Perrenoud, 1993). The main reason contributing to low yields of potato in most parts of the world is low soil fertility. This is attributed to continuous cultivation without adequate replenishment of the mined nutrients (Naz *et al.,* 2011). Optimum potato growth and profitable production depend on many management factors, one of which is ensuring a sufficient supply of nutrients. Hence, a comprehensive nutrient management program is essential for maintaining a healthy potato crop, optimizing tuber yield and quality, and minimizing undesirable impacts on the environment. The fertility status of soil type, amount and time of fertilizer application has a big influence on yield and quality of potato production (Westermann, 2005). Mineral fertilizers have the merit of being readily soluble in soil solution, less bulky and easier to manipulate, but their constitution in most cases does not include the much-needed essential minor elements as compared to farmyard manures to increase the productivity of potato (Bekunda *et al.,* 2010).

The nutrient uptake rates of potato are often slow early in the season, increased rapidly during the tuber bulking stage, and then decelerate as the plant matures (Hopkins *et al.,* 2008). As compared with cereal crops, the potato produces a lot more dry matter in a shorter cycle (Singh and Trehan, 1998). Potato absorbs huge quantities of nutrients from the soil per season (Trehan *et al.,* 2005) but, it often unable to exploit nutrients and soil moisture fully within a soil profile and this result in their relatively high demand for many nutrients. The dry matter content and starch content of potato tubers can increase or decrease depending on the mineral fertilizers forms and rates and their correlation (Makaraviciutte, 2003).

2.6.1. Effect of Nitrogen Fertilizer on Potato production

Among the macro-nutrient's nitrogen has been distinguished as being the most limiting nutrient in plant development. Nitrogen is an inbuilt part of many compounds such as chlorophyll, nucleotides, alkaloids, enzymes, hormones and vitamins and these are essential for plant growth processes (Brady and Weil, 2008). It acts as a significant role in the balance between vegetative and reproductive growth of potatoes (Alva, 2004). Plant uptake nitrogen both in the cationic ($NH4^{+}$) and/or the anionic ($NO3^{-}$) form. Nitrogen fertilizer increases the nitrogen intake and this increase causes a positive effect on chlorophyll concentration, photosynthetic rate, plant height, the entire number of leaves and dry matter accumulation (Israel Zewide *et al.*, 2012). Nitrogen in the presence of adequate phosphorus stimulates canopy growth, leaves and branches. This is through the production of excess leaves and branches, an extension of leaf area duration and expansion of leaf area (Muthoni and Kabira, 2011).

A good supply of nitrogen stimulates root growth and development as well as the uptake of other nutrients (Brady and Weil, 2008). A crop with more nitrogen will mature later in the season than a crop with less nitrogen because extended vegetative growth is related to excessive haulm development, whereas early tuber growth to less abundant haulm growth (Israel Zewide *et al.*, 2012 and Barbara, 2007). On the other hand, shortages of nitrogen restrict the increase of all plant organs such as bases, stems, leaves, flowers, fruits and finally give stunted plant architecture with yellow leaf appearance (Barker and Bryson, 2007). A shortage of nitrogen also restricts tuber size due to the reduced leaf area and early defoliation (Goffart *et al.*, 2008).

Increasing the application rate of nitrogen significantly increased the total tuber number per hill (Yibekal Alemayehu, 1998; Lakachew Emiru, 2007 and Zelalem Aychew *et al.*, 2009). The growth in total tuber number per hill, with the supply of fertilizer nutrients could be due to more comfortable growth, more foliage and leaf area and a higher supply of photosynthesis that helped in producing bigger tubers resulting in higher yields (Sharma and Arora, 1987). The total tuber yield found to be strongly connected with average tuber weight and total tuber number signifying both the increase in tuber number as well as size have substantially contributed to tuber yield increase in response to the fertilization of nitrogen treatments (Sanderson *et al.*, 1987; Zelalem Aychew *et al*., 2009; Miller and Rosen, 2005).

The N fertilizer application has significant effects on the quality of potatoes. Increasing degrees of N fertilizer recorded a substantial reduction in quality attributes in potatoes (Sud *et al.*, 1992). The specific gravity of tubers decreased with increasing rates of N fertilizer (Kleinkopf *et al.*, 1981). This seems to be a contemplation of the delay in maturity due to high nitrogen treatment. Excessive nitrogen may cause low dry matter content and high protein and nitrate content, particularly if it leads to harvesting the crop before it reaches its natural maturity (Nebret Tadesse, 2012; Zelalem Aychew *et al.*, 2009; Beukema and Van der Zaag., 1990).

2.6.2. Effect of Phosphorus Fertilizer on Potato Production

Phosphorus is the second most important macro-nutrient after nitrogen that plays a significant role in physiological and biochemical reactions such as photosynthesis and transfer characteristics (Grant *et al.*, 2001; Mehrvarz *et al.*, 2008 and Brady and Weil, 2008). Plant uptake phosphorus in the form of $H_2PO_4^-$ and HPO_4^- (Tisdale *et al.*, 1995). It is a nutrient that should be available in adequate quantities from the early growth stages to maintain a high photosynthetic rate during tuber bulking (Hue *et al.*, 2010; McCollum, 1978b and Grant *et al.*, 2001). Phosphorus nutrition also enhances many aspects of plant physiology, including the fundamental processes of photosynthesis, root growth, particularly the development of lateral roots and fibrous rootlets (Brady and Weil, 2008).

The potato tuber yield is known to be influenced by phosphorous fertilizers through its effect on the number of tubers produced, the size of the tubers and the time at which maximum production is obtained (Sommerfeld and Knutson, 1965; Sharma and Arora, 1987). The application of an appropriate rate of phosphorus fertilizer increases the tuber yield of potatoes however, the response will be negative if applied beyond the optimum rate (Sharma and Arora, 1987). Phosphorus has various effects on tuber quality, since its functions in the cell division and synthesis and storage of starch in the tubers (Hough land, 1960). Thus, phosphorous can increase the size and percentage of dry matter of the tubers (Rosen *et al.*, 2014). However, under the high availability of soil phosphorous, its supply can decrease the production of larger tubers without changing the tuber specific gravity (Rosen & Bier man, 2008).

2.6.3 Effect of Sulfur Fertilizer on Potato Production

Sulfur (S) is the fourth major nutrients after N, P and K with essential nutrient for plant growth and it contain 0.2 to 0.5% in plant tissue on dry matter basis and is required in related amounts as that of P (Ali *et al.,* 2008). Sulfur is required by plants for proper growth and yield as it is known to convey constituent in many reactions in all existing cells (Sud and Sharma, 2002). The content of sulfur in potato tubers is on average between 0.7-2.0 g kg^{-1} and its uptake ranges from 18 to 40 kg ha^{-1} (Klikocka, 2004). It is required by plants for proper growth and yield, which holds a good effect on soil properties as it may reduce soil pH, which improves the availability of microelements such as Fe, Zn, Mn and Cu and it is known to take part in many reactions in all living cells and associated characteristics (Sud and Sharma, 2002; Tantawy *et al.,* 2009).

Application of S fertilizer can significantly increase tuber yield and starch content of potato, while contributing to a reduction in tuber N concentration due to an increase in dry matter production (Sud and Sharma, 2002). In addition, the application of 20 kg ha^{-1} sulfur increased stem and tuber number (Singh and Srivastava, 1995). Moreover, the yield-promotion by Sulfur results in the highest tuber yields were recorded when applying 25 kg S ha^{-1}in the ionic form or 50kg S·ha^{-1} in the elemental form (Sharma *et al.,* 2011).

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). Intensive cropping and use of high-grade fertilizers have caused to reduce the number of sulfurs in soils. Sulfur deficient plants had lower utilization of nitrogen, phosphorous and potash and a significant reduction of catalase activities at all growth stages (Nasreen *et al.,* 2003). Its deficit decreases crop yield and often leads to a deterioration of the yield and quality, which is defined by the content of minerals and their ratios (McGrath and Blake-Kalff, 2003).

Sulfur is being known in view of its function in improving crop quality and balance of anions in agricultural crops including potatoes (Tandon, 1991). Sulfur fertilization has positively changed the tuber yield of potato while decreased the content of dry mass (Cultus, 2013). It also enhances starch synthesis in tubers and it is a constituent of proteins and many enzymes (Lalitha *et al.*, 2002). It increases the resistance of potatoes to environmental stress and acts as an important part in protecting the plants from pests and diseases (Klikocka, 2005).

2.6.4. Effect of Blended NPS Fertilizer Rates on Growth, Yield and Quality of Potato

Various researchers reported the beneficial effects of the application of sulfur-containing fertilizers like NPS on growth, yield and yield parameters as well as the quality of potato (Chettri *et al*., 2002; Choudhary *et al*., 2013). It is critical for optimizing potato growth, yield and quality (Miller and Rosen, 2005; Singh, 2006). Increasing the rates of NPS fertilizers increased plant height, leaf number, branch number, stem number, leaf area index(Simon Koroto and Selemawit Dula, 2019;Arega Amdie, 2018; Minwyelet Jemberie *et al.*, 2017 and Melkamu Alemayehu *et al.,* 2018).The NPS fertilizer prolonged days to flowering and maturity of potato plants which could be associated with the supply of additional nutrients, that may promote the vegetative growth of the plants that in turn prolonged flowering and maturity of the potato plant and other vegetable crops(Arega Amdie, 2018;Melkamu Alemayehu *et al*.,2018).The increasing rate of NPS fertilizer application produced the highest average tuber number per hill, average tuber weight, marketable tuber number, marketable tuber yield and total tuber yield (Minwyelet Jemberie *et al*., 2017; Amin Ababiya, 2018; Arega Amdie, 2018 and Melkamu Alemayehu *et al*., 2018, Minwyelet Jemberie *et al.,* 2017).Even if, NPS fertilizer has positively changed the tuber yield of potato, the specific gravity, dry matter content and starch content of tubers were decreased with increasing rates of NPS fertilizer (Arega Amdie,2018; Getachew Kahsay., 2016; Minwyelet Jemberie *et al*., 2017 and Melkamu *et al*., 2018).

2.7. Effect of Organic Fertilizers on Potato Production

Organic fertilizers are all forms of organic soil amendments that originate from both livestock waste and crop residues, with the nutrients in them being mineralized by soil microbes and slowly making them available to plants over a long period of time (Lampkin, 2000). farmyard manure, green manures and compost applications might provide a valid alternative to the conventional mineral N fertilizers mitigating potential environmental risks due to N leaching and sustained potato yield (Canali *et al.*,2012).

Soil fertility aspects enhanced by the maintenance of the organic matter include the direct contribution of nutrients, influence on cation exchange capacity and binding of heavy metals and pesticides. In plant nutrition, organic matter level of the soil is the key property that determined the availability status of essential nutrients (Katyal, 2000). This tie up rises from the fact that organic matter is the basic resource of several nutrient elements. organic resources are key resources owing to ameliorative effect on nutrient supply, detoxification of harmful soil constituents, moisture and nutrient retention, and their role in soil structure improvement (Ahenkorah *et al.*,1995). The application of organic manure can contribute to agricultural sustainability (Wells *et al.*, 2000) as continuous and adequate use of manure with proper management has been shown to have many advantages, which include providing a whole array of nutrients to soils, increasing soil organic matter (SOM) (Verma *et al.*, 2005), improving water holding capacity and other physical properties of soil like bulk density, penetration resistance and soil aggregation (Chang *et al*., 1990; Wells *et al.*, 2000).

Organic manures and their extracts have been described to improve soil fertility, soil structure and furthermore help plants in combating pests and diseases (Khadem *et al*., 2010). The organic material is utilized to prevent or ameliorate the negative stress effects in plants and yield reductions. Regular application of organic amendments can sustain soil N fertility and increase marketable potato yields to 16.4 t ha^{-1}as compared to the unamended and unfertilized soil (Dayegamiye *et al.*, 2013). Using of FYM has positive, beneficial effects on vegetative growth, yield and quality of the tuber (Tesfaye Balemi *et al.*, 2012; Najm *et al.*, 2013). High ware potato production was obtained with 20 t FYM ha^{-1}(Pawon *et al.*, 2006). Increasing the quantity of FYM from zero to 20 and 30 t/ha increased yields by 30% and 47% respectively (Hasandokht, 1997). The effect of 5 t/ha FYM on potato announced an increased in tuber yield (Sharma, 1991).

The importance of organic manure is being realized again because of the high cost of commercial fertilizers and its long-term adverse effect on soil chemical properties. On all field crops, the potato has the best response to farmyard manure. By applying farmyard manure, the effect of N as a mineral fertilizer may be increased by 20% (Vander Zaag and Beukema, 1990). Besides supplying macronutrients and micronutrients to the soil (Negassa *et al*., 2001; Tirol-Padre *et al*., 2007), farmyard manure also improves the physico-chemical properties of the soil (Tirol-Padre *et al.*, 2007). However, unless it is integrated with inorganic fertilizers, the use of farmyard manure alone may not fully satisfy crop nutrient demand (Patel *et al;* 2009).

Animal manures are also useful in improving the efficiency of fertilizer recovery thereby resulting in higher crop yield (Gedam *et al*., 2008). Application of organic manure is frequently recommended for improving soil properties and obtaining clean products (Gomaa *et al*., 2005). A positive effect of manure application on crop yield was observed in numerous studies which revealed that stable yields could be obtained from potatoes fertilized with the application of organic manure (Cerny *et al*., 2010).

Application of composts have also been found to cause a direct anti-disease effect by stimulating competing microorganisms and also by inducing immunity to plant diseases (Brinton *et al*., 1996 and Ghorbani *et al*., 2006). Frequently, the regular use of organic material (compost) is essential for the sustainable cropping of upland soils with inherent low natural fertility (Schoningh and Wichmann, 1990). In addition, compost greatly increases the cation (or base) exchange capacity of the soil and can significantly improve the uptake by plants of nutrients from mineral fertilizers. As compost breaks down liberating carbon dioxide and moisture, it increases the concentration of carbon dioxide in the soil and just above the surface. This aids the photosynthesis of plant material and is believed to account for much of the increased yield when crops are heavily manure (Dalzell *et al.,* 1987). The use of composted organic wastes as a fertilizer and soil amendment not only brings economic benefits to small scale farmers, but also reduces pollution because of reduced nutrient run-off, and nitrogen leaching (Nyamangara, 2003).

2.8. Integrated Use of Organic and Inorganic Fertilizers on Potato Production

Combined uses of organic and chemical fertilizers are required to supply and maintain better soil fertility for sustainable crop production on a given soil and the use of organic manure is more beneficial when combined with inorganic fertilizers (Bekunda *et al.,* 2010; Mugwira and Murwira,1998). Application of organic manures, like FYM and cattle manure along with mineral fertilizers makes soil loose and increase the root length density which resulted in high nitrogen and phosphorus uptake (Minhas and Sood, 1994; Maftoun *et al.*, 2004; Mkhabela and Warman, 2005). The increased uptake of nutrients due to mineral fertilization along with organic manure application could be due to added supply of nutrients and proliferous root system developed under balanced nutrient application resulting in better absorption of water and nutrients along with improved physical environment (Pathak *et al.*, 2005; Laxminarayana, 2006).

Application of inorganics and organics help to improve the physico-chemical properties as well as biological properties of soils. Potatoes are plants with along vegetation period; therefore, they assimilate nutrients from organic and mineral fertilizers rather intensively (Makaraviciute, 2003). Supplementing the inorganic fertilizers with Farmyard manure substantially increased both quantity and quality of potato (Tolessa and Friensen, 2001). Phosphorus fertilizers and manure into the soil, increased phosphorus uptake by plants, through favoring production of carbonic acid, the acid that increases solubility of phosphate compounds in calcareous soils (Chen, 2003). Compost with inorganic fertilizers were more effective in supplying these interactions which can be explained by improvements in soil structure caused by the compost leading to better moisture retention characteristics and improve the efficiency of use of mineral fertilizers (Muriwira *et al.,* 1995).

2.9. Effect of Integrated Nutrient Management (INM) For Potato Production

Integrated nutrient management implies the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity on one hand (Islam *et al.,* 2013) and to minimize nutrient losses to the environment on the other hand (Singh *et al.,* 2002). It is achieved through efficient management of all nutrient sources (Singh *et al.,* 2008). Integrated plant nutrient management has now assumed great importance, firstly because of the negative nutrient balance, and secondly, neither the chemical fertilizers alone nor the organic sources exclusively can achieve the production sustainability of soils, as well as, crops yield under highly intensive cropping system (Udadhyay, 1999). Hence the use of integrated nutrient management is really important and the best approach to conserve and better soil fertility (Lander *et al.,* 1998 and Gruhn *et al.,* 2000) thereby increasing crop productivity in an effective and environmentally friendly fashion without sacrificing the soil productivity of future generations.

2.9.1. Integrated Use of FYM and NPS Fertilizer on Potato Production

To ensure soil productivity, plants must have an adequate and balanced supply of nutrients that can be realized through integrated nutrient management where both natural and man-made sources of plant nutrients are used (Gruhn *et al.,* 2000). Combining inorganic and organic fertilizers result in greater benefits than either input alone through positive interactions on soil biological, chemical and physical properties (Bekunda *et al.,* 2010). The use of inorganic fertilizers and manure to enhance soil fertility and hence crop yield improvement is a traditional method that has been in use for a very long time. Phosphorus fertilizers and manure into the soil, increased phosphorus uptake by plants, by favoring the production of carbonic acid, the acid that increases the solubility of phosphate compounds in calcareous soils (Chen, 2003).

The combined application 150kgha^{-1}NPS fertilizer and 30tha^{-1}cattle manure significantly influenced plant height, total tuber yield and specific gravity of potato (Amin Ababiya, 2018). This could be due to balanced C/N ratio; more organic matter builds up, enhanced microbial activity, improvement in soil properties, better root proliferation, sustainable availability and accelerated transport and higher concentration of plant nutrients. All these might have accelerated metabolic activities, contributing to better photosynthesis and efficient translocation of photosynthesis from sink to sources (Ouda and Mohadeen, 2008). The application of 245.1 kg ha^{-1} NPS combined with 13.5 t ha^{-1} FYM recorded the highest tuber weight, marketable and total tuber yields (Melkamu Alemayehu *et al.,* 2016). Similarly, yields of potato increased due to the combined application of farmyard manure (FYM) and inorganic mineral nitrogen (Tesfaye Balemi, 2012). Dry matter, total carbohydrates and specific gravity, and TSS reducing the content during the application of cattle manure with chicken manures (Abou-Hussein *et al.*, 2003).

2.10. Effect of Integrated Nutrient Management (INM) for Soil Fertility

The basic concept underlying the integrated nutrient management system (INMS), nevertheless, remains the maintenance and possible improvement of soil fertility for sustained crop productivity on long term-basis and also to reduce inorganic (fertilizer) input cost (Basavaneppa and Biradar ,2002) .Thus, integrated nutrient supply/management (INS) aims at maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity through optimization of benefit from all possible sources of plant nutrients in an integrated manner (Kalhapure and Dhonde,2013). Agriculture remains a soil-based industry, there is no way that required yield increases of the major crops can be attained without ensuring that plants have an adequate and balanced supply of nutrients (Antil and Singh ,2007). The appropriate environment must exist for nutrients to be available to a particular crop in the right form, in the correct absolute and relative amounts, and at the right time for high yields to be realized in the short and long term (Kumar and Chopra ,2016).

Highest productivity of crops in sustainable manner without deteriorating the soil and other natural resources could be achieved only by applying appropriate combination of different organic manures and inorganic fertilizers (Sable *et al.*,2007). It is important to identify the best type of available organic resources which can be used as fertilizers and their best combination with appropriate proportion of inorganic fertilizers (Patil *et al.*,2003). Sufficient and balanced application of organic and inorganic fertilizers is a major component of INM (Srivastava *et.al.*,2015). Successful INM extension will also require greater monitoring and testing of plants and soils (Mollah *etal*.,2011). Monitoring will help ensure that an environment conducive for optimal plant growth and crop yield can be established through nutrient application and soil reclamation (Nehra and Hooda ,2002). There is a lack of prioritized and strategic problemsolving agricultural research that is related to plant nutrition management and the incorporation of mineral and organic sources of plant nutrients into the soil (Javaria and Khan 2010). Therefore, the application of targeted, sufficient, and balanced quantities of inorganic fertilizers will be necessary to make nutrients available for high yields without polluting the environment (Islam and Nahar 2012; Kannan *et al.*,2013).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

DebreBerhan town was situated 130 km from Addis Ababa on the main road of Addis Ababa to Dessie. The study was conducted in DebreBerhan University, college of agriculture and natural resource science research site during 2019 main cropping season with *vertisols* soil type. Geographically the experimental site is situated at 9°39’24.18’’N latitude and 39°31’16.78’’ E longitudes. It lies at an altitude of 2782 m.a.s.l. (Fig.1). Major crops grown in the study area are wheat, barely, pea, haricot bean, potato, carrot and garlic. In the mixed crop livestock, the farming practices in the area is dominated by sole cropping.

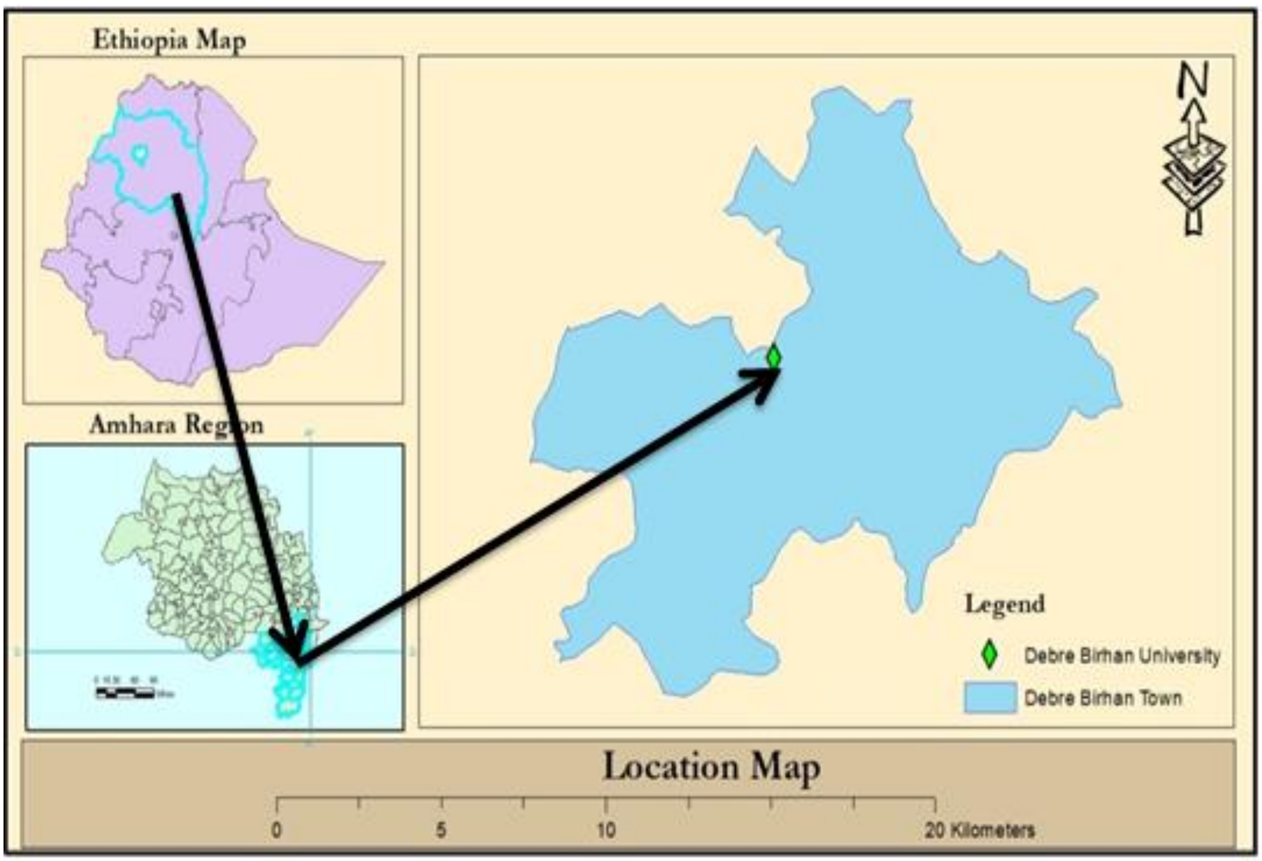

Figure 1. Map of the study area

Meteorological data were taken from Debre Berhan agricultural research center. According to long term climate data (2010-2019) recorded in the last decade, the area receives total annual rainfall of 1485.5mm (Fig. 2) (Appendix Table 4). The main rainy season of the study areas extended from June to September. Rainfall distribution of the study area is characterized by a unimodal pattern. The monthly minimum and maximum temperature of the study areas during cropping season was 9.8^{0}c and 28.5^{0}c respectively (Fig.3) (Appendix Table 4). According to the modern climatic zone classifications of Ethiopia (Alemneh Demissie, 2003) which was based on altitude, rainfall, average annual temperature and length of growing season, the study areas belong to cool sub-humid agro-climatic zone.

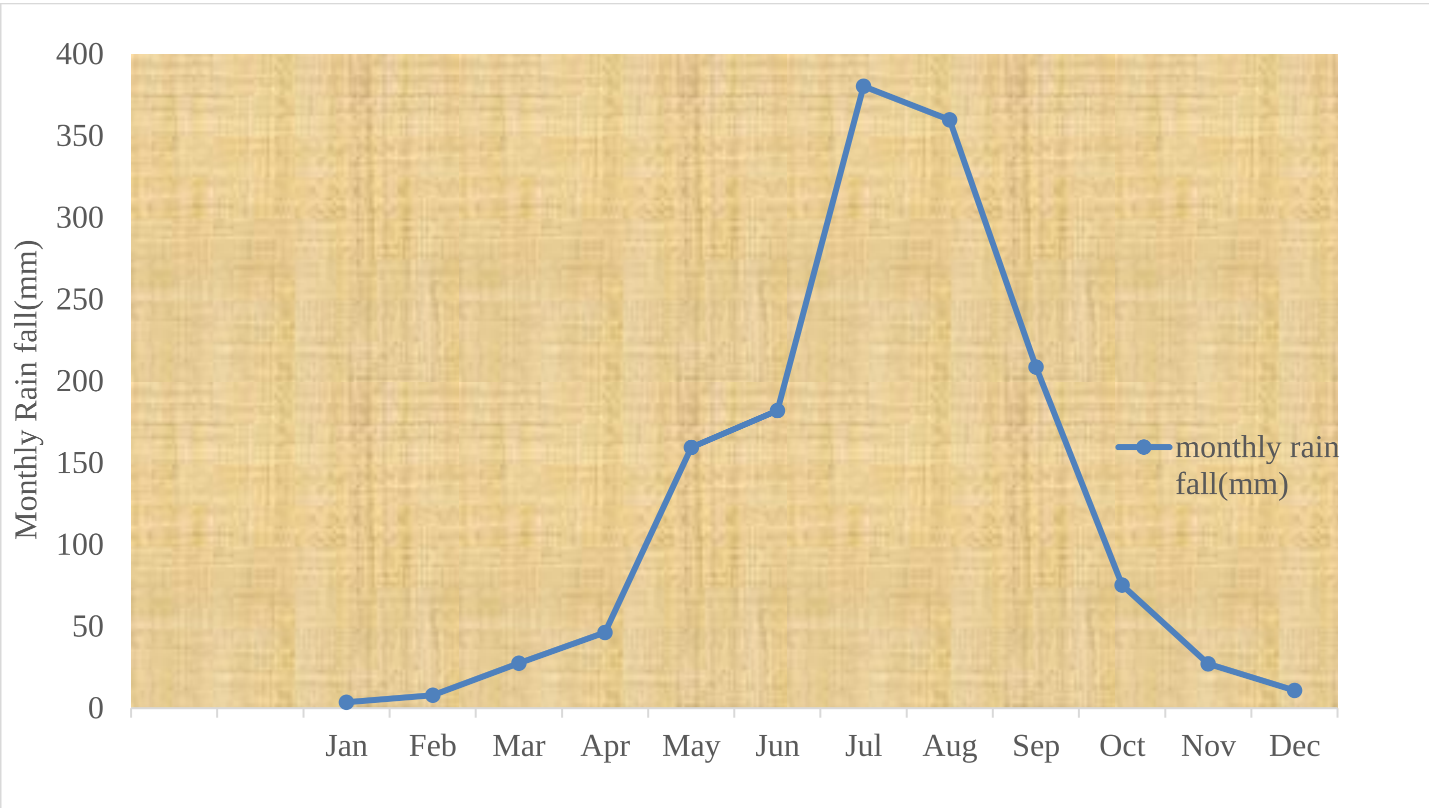

Figure 2. Monthly rain fall distribution during crop growing season

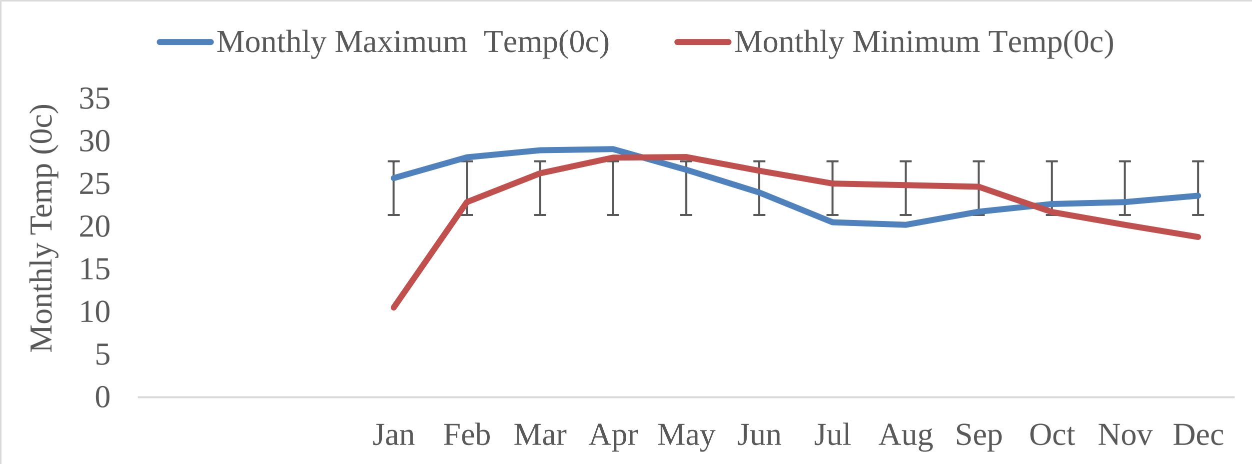

Figure 3. Maximum and minimum temperature (^{O} c) recorded during cropping season in the study area

3.2. Experimental Material

The improved potato variety Gera (KP-90134.2) was used as experimental material in the study area. The variety was released by the Debre Berhan Agricultural research center in the year 2003. FYM and NPS fertilizer were used as experimental material and FYM was brought from DebreBerhan sheep production farming system and it was well decomposed sheep manure.

Table 1. Some characteristics of Gera potato (KP-90134.2) variety.

No	Description		Agronomic characteristics
1	Altitude (m.a.s.l)		2200-3200
2	RF (mm)		800-950
3	Starch content		15.86%
4	Skin color		White
5	Flower color		White
6	Average dry matter content		21.95%
7	Yield (ton. ha^{-1})	Farmer field	27.2
		Research field	31.2
8	Maturity date		120-157

Source: Crop varieties register (MoANR, 2014, Anonymous,2012).

Table 2. Organic carbon (OC), Nitrogen(N), phosphorus (P), and sulfur(S) composition of the FYM used in the experiment

Organic carbon (OC)	13.79%
Available phosphorus (P)	18.5%
Available nitrogen (N)	2.615%
Available sulfur (S)	2.85%

Table 3. Organic carbon (OC), Nitrogen(N), phosphorus (P), and sulfur(S) additions to the soil from the FYM

Types of nutrient	Amount of nutrient added to the soil from FYM (kg/ton)		
added	10ton	20ton	30ton
Available phosphorus(P)	1848.14	3700	5548.1
Available nitrogen (N)	259.25	518.5	781.5
Available sulfur(S)	281.48	566.6	848.1
Organic carbon (OC)	1377.7	2755.5	4133.3

3.3. Treatments and Experimental Design

The treatments consisted of four levels of NPS blended fertilizers (0, 60, 120 and 180 kg ha^{-1}) and four levels of farmyard manure (0, 10, 20 and 30t ha^{-1}). The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times. There were sixteen treatment combinations that were assigned to each plot randomly. The area of the experimental field was 103.5m*15.5m. Ridges and plots were levelled manually and a single plot size with an area of 6mx4. 5m (27m^2) was prepared. The distance between plots and blocks were 0.5 and 1m apart, respectively. The tubers were planted at the spacing of 75 cm between rows and 30 cm between seed tubers. Each plot contained six rows of potato plants, with each row accommodating 20 plants with a total population of 120 plants per plot.

3.4. Experimental Procedure and field managements

In order to have a better seedbed for proper root development, the experimental field was plowed by using tractor to a fine soil tilth. A total of 48 experimental plots were laid out and the required numbers of ridges were marked and ridges were formed manually in each plot with the spacing of 75 cm between the ridges. Well decomposed farmyard manure was applied as organic sources of nutrients and each level of FYM was weighed and full doses which varied depending on treatments were homogeneously applied and distributed to the respective experimental plots and incorporated into the soil 4 weeks before planting. NPS was used as a source of mineral nutrients and which varied depending on treatments were utilized as a side dressing at planting time. Medium-sized and well-sprouted potato tubers were planted at the depth of 5 cm on ridges at the specified spacing by placing one tuber per hill. Weeds were managed by hoeing and hand weeding. Earthing-up was performed two times before flowering to initiate tuber bulking and one time after blooming to prevent exposure of tubers to direct sun. Ridomil Gold was sprayed two times at the rate of 2.5 kg ha^{-1} at the interval of 7 days using 400 litter of water ha^{-1} to control late blight disease. When the plants reached physiological maturity (when75% of the haulms dried up) tubers were harvested.

3.5. Soil and FYM Sampling and Analysis

Soil samples were taken one time before planting randomly using a zigzag pattern from ten spots of the experimental field at the depth of 0-20 cm using an auger and 1kg composite sample were prepared. Similarly, the sample of farmyard manure (1 kg) was prepared for chemical analysis. The collected soil samples and FYM were composited, air-dried at room temperature under shade and it was ground to pass through a 2 mm sieve for determination of soil texture, soil pH, cation exchangeable capacity (CEC), total N, exchangeable potassium, total OC, available P and available S for doing in standard laboratory procedures. Then the composite sample was put in a polythene bag and submitted to at Debre Berhan Agricultural research center soil and water laboratory for further analysis.

The pH of the soils was determined by diluting the soil with water in 1:2.5 ratios. Total nitrogen contents of the samples were determined by Tekalign *et al*., (1991) and to determine the Cation Exchange Capacity (Cmol kg^{-1} soil), the soil sample first was leached using 1 M ammonium acetate, washed with ethanol and the adsorbed ammonium was replaced by sodium. Then, the CEC was determined titrimetric ally by distillation of ammonia that was displaced by Na

(Sahlemedhin and Taye, 2000). Available phosphorus was also found using the Olsen method (Olsen *et al*., 1954). Available sulfur (meq/l $SO4^{-2}$) was determined by monocalcium phosphate extraction method or turbid metric estimation (Hoeft *et al*., 1973) and available Particle size (soil texture) was found by using a hydrometer method (Bouyoucos, 1965).

3.6. Data Collected

3.6.1 Phenological data

Days to 50% emergence: - It was recorded as the number of days from planting to 50% of the plants in each net plot emerged.

Days to 50%flowering: - It was recorded as number of days from planting to the time when 50 percent of the plant stands in each experimental plot yield flowers.

Days to75% maturity: - Number of days from planting to physiological maturity were registered when 75 % of the plants per plot were ready for harvest as observed by plant leaves turned yellowish.

3.6.2. Growth parameters

Plant height (cm): -The height of 10 randomly taken plants from the central rows were measured by the tape meter at physiological maturity stage from the ground surface to the tip of the main stem and averaged to get the mean plant height.

Main stems number per hill: - The actual numbers of main stems per hill were recorded as the average stem count of 10 plants per plot at 50% flowering. Only stems that emerge independently above the soil as single stems were considered as main stems (Stems arising from the mother tuber were considered as main stems).

Average number of branches per plant: - The numbers of branches were recorded from 10 randomly selected plants per plot at physiological maturity stage. Except for the main stem numbers of plants above the ground all other are considered as branch number.

Plant leaf area and leaf area index: - plant leaf area was measured from ten randomly taken plant per plot, then taking potato plant leaves from the bottom, middle and top of the plant leaves separately and using square paper method draw each leaf and count each square having the leaves picture, then average out the square count and multiply by 0.25(the area of one square) and this multiplied by the total number of leaves to get total leaf area and the average was recorded. Leaf area index was measured by calculating plant leaf area divided by plant land cover area. The ground cover areas were measured by using (πr^2). Leaf area index (LAI) was calculated using the formula described by Yoshida (1981) as shown below. The sample leaves were taken at the vegetation level, at the beginning of tuberisation.

$$\mathbf{LAI} = \frac{\textbf{Sum of the leaf area of all leaves } (\mathbf{cm^2})}{\textbf{Ground area}}$$

3.6.3. Yield and yield components

Average tuber weight (g/tuber): - The mean tuber weight in gram was computed by weighting 10 randomly selected tubers harvested from each net plot and the values were utilized for further analysis.

Marketable tuber number per plant: - The number of tubers harvested from 10 randomly selected plants per plot which were considered as marketable after sorting tubers which had larger or equal to 25 g weight, free from disease and insect attack. The average number of marketable tubers was counted and recorded accordingly (Lung'aho *et al.*, 2007).

Unmarketable tuber number per plant: - The tubers that were sorted as diseased, insect attacked and small-sized (< 25 g) from ten randomly selected plants per plot were recorded as an unmarketable tuber number. The average number of unmarketable tubers was counted and registered from the plot and this was done accordingly (Lung'aho *et al.,* 2007).

Marketable tuber yield ($\mathbf{tha^{-1}}$): - The tubers that were sorted and counted from ten randomly selected plants as marketable tuber were weighted and converted to marketable tuber yield in tons per hectare.

Unmarketable tuber yield ($\mathbf{tha^{-1}}$): - The mean weight of tubers which were unhealthy, injured by insect pests, with defects and less than 25g weight categories from net plots tubers were recorded and calculated to tha^{-1}.

Total tuber yield ($\mathbf{t\ ha^{-1}}$): - The total tuber yield per plot was recorded by adding up the weights of marketable and unmarketable tuber and later calculated per hectare.

3.6.4 Quality Parameters

Percent dry matter content (%): - Five fresh tubers free of disease, insects and undamaged were randomly selected from each plot and weighed. The tubers were then chopped into small pieces with the help of stainless-steel knife, mixed thoroughly, and the exact weight of each sample was determined and recorded as fresh weight. The samples were placed in paper bags and dried in an oven at 105^{o}C until a constant weight was obtained. Each sample was immediately weighed using digital sensitive balance and recorded as dry matter. Percent dry matter content for each sample was calculated by the following formula:

$$\textbf{Percent dry matter content}\ (\%) = \frac{[(\mathbf{DW} + \mathbf{CW}) - \mathbf{CW}](\mathbf{g})}{[(\mathbf{FW} + \mathbf{CW}) - \mathbf{CW}](\mathbf{g})} \times \mathbf{100}$$

Where: - DW=Dry weight, CW=Container weight, FW = Fresh weight

Specific gravity of tubers (g/cm^3): - It was determined by the ratio of the tuber weight in air and the tuber weight in the water method. Tubers of all shapes and size categories, which weighed about 5 kg, were randomly taken from each plot. The selected tubers were washed with water. The samples were then first weighed in air and then re-weighed is suspended in water. Specific gravity is then computed using the following formula (CIP, 2007).

$$\textbf{Specific gravity} = \frac{\textbf{weight in air}\ (\mathbf{kg})}{\textbf{weight in air}\ (\mathbf{kg}) - (\textbf{weight in water})} \times \mathbf{100}$$

Total starch content (g/100g): - The percentage of starch was calculated from the specific gravity using the following equation (Yildrim *et al*., 2005)

$$\textbf{Starch}(\%) = \mathbf{17.546} + \mathbf{199.07} \times (\textbf{specific gravity} - \mathbf{1.0988})$$

Determination of total soluble solids (TSS °brix) and pH

Before analysis of samples, 5 randomly taken tubers were selected from all sizes and washed it and peeled using a knife, then crushing the sample and extracting the juice using a manual juice extractor then taking each sample using a test tube for further analysis. The percentage of TSS in tubers was estimated by hand refractometer according to Cox and Pearson (1962). Total soluble solid (TSS) was measured by adding two droplets of juice to standing refractometer in the focusing of sunlight. Between the intervals of sampling, the prism of the refractometer was washed with distilled water and dried before use and the refractometer was standardized against distilled water (0% TSS).

The reading was taken when ½ dark, ½ lights at the cross-section point and the result was expressed in a three-digit fraction number and measured by Abbe refractometer.jpg (359×503pixels) temperature-controlled prism and the results expressed as ^{0}Brix. The pH of the tuber was determined using an extract of tuber juice, which was prepared according to Nunes and Emond (1999), the juice was first filtered with cheesecloth and the PH value of tuber juice was measured by adding the juice to the pH meter then directly measured by reading it at room temperature (25^{o}c). It was determined with PHS-25cw microprocessor or pH/MV meter.

3.7. Partial Budget Analysis

The economic analysis was carried out by using the methodology described in CIMMYT (1988) in which prevailing market prices for inputs at planting and for outputs at harvesting were used. All costs and benefits were computed on the hectare basis in Eth-Birr. The concepts used in the partial budget analysis were the mean marketable tuber yield of each treatment. The economic gains of the different treatments were calculated to approximate the net returns and the cost of NPS, farmyard manure, and the income from total potato tubers used for further economic analysis. Moreover, the market prices of NPS, FYM fertilizer, the marketable tuber and the cost of labor were getting from market assessment during the observational period.

Gross average marketable tuber yield (kg ha^{-1}) (AvY): AvY was an average yield of each treatment.

Adjusted yield (AjY): AjY was the average yield adjusted downward by a 10% to reflect the difference between experimental yields are often higher than the yields that farmers could expect using the same treatments; hence in economic calculations, yields of farmers are adjusted by 10% less than that of the research results (CIMMYT, 1988).

Adjustable marketable tuber yield = Average yield - (Average yield -0.1)

Gross field benefit (GFB): GFB was computed by multiplying field/farm gate price that farmers receive for the potato when they sale it as adjusted marketable tuber yield.

Gross field benefit (GFB) = Adjustable marketable tuber yield*field/farm gate price for potato.

Total variable cost (TVC): Total cost was the cost of fertilizers and application cost of fertilizers as differing dosages for the experiment. The costs of other inputs and production practices such as labor cost, land preparation, planting, earthing up, weeding, and harvesting were considered the same or are insignificant among treatments.

Net Income (NI) or Net Benefit (NB): - was calculated as the amount of money left when the total variable costs for inputs (TVC) are deducted from the total revenue (TR).

NB = TR – TVC

Marginal rate return (MRR): was the measure of increasing in return by increasing input.

$$\mathbf{MRR} = \frac{\textbf{Change of Net Benefit } (\boldsymbol{\Delta NB})}{\textbf{Change of Total Variable Cost}(\boldsymbol{\Delta TVC})}$$

Marginal rate of return (MRR %): was calculated by dividing the change in net benefit by the change in total variable cost.

$$\boldsymbol{MRR}(\%) = \frac{\textbf{Change of Net Benefit } (\boldsymbol{\Delta NB})}{\textbf{Change of Total Variable Cost } (\boldsymbol{\Delta TVC})} * \mathbf{100}$$

Dominance analysis (identification and elimination of inferior treatments): is also used to eliminate those treatments which involve higher cost but do not generate higher benefits. Any treatment that has higher TVC but net benefits that are less than or equal to the preceding treatment (with lower TVC but higher net benefits) is dominated treatment (marked as **“D”**). Thus, the treatment which was non-dominated and having an MRR of greater or equal to 100% with the highest net benefit was taken to be economically profitable.

3.8. Correlation Analysis

The correlation analysis was done for the growth, yield and quality parameter of potato as affected by the application of FYM and NPS fertilizer and done according to Carey, (1998).

3.9. Data Analysis

Data were subjected to analysis of variance (ANOVA) using SAS version 9.1 (SAS Institute Inc., 2012). Duncan’s multiple range test (DMRT) was used to compare the differences among the means of the treatments as elucidated by Steel and Torrie (1984) at the 5 % probability level

4. RESULTS AND DISCUSSION

4.1. Soil physico-Chemical Properties of the Experimental Site before planting

The physico-chemical attributes of the soil sample taken before sowing suggested that sandy 16%, clay 66% and silt 18% and this could be categorized as clay soil based on USDA (1987) textural soil classification scheme (Table 1). The soil of the experimental field is slightly acidic (6.02) (Table 1). The optimum pH range for potato requirement is between 5.2-6.5(Fageria *et al.,* 2011). The CEC of the site was 23.7 meq /100g soil and it was medium content according to Landon (1991) (Table 3).

The total organic carbon of the experimental field was 3.25 (Table 1) which is grouped under low. Total OC (%) greater than 10 as higher, 4-10 as medium and less than 4 as low (Booker, 1991). The total nitrogen of the research site was 0.16% (Table 1). According to Tekalign Mamo *et al*., (1991) classification, soil N availability of < 0.05% as very low, 0.05-0.12% as poor, 0.12-0.25% as medium and > 0.25% as high.

The available P content of the experimental soil was 8.6 pp.m (Table1). According to Olsen and Chapman (1954), P classified soil P availability of <3pp m very low, 4-7pp m low, 8-11pp m medium, 12-20pp.m high, >20 pp.m very high. The analysis of available S was 0.12 ppm (Table 1). According to Alemu Lelago *et al*., (2016) classified soil S availability of < 10 ppm very low, 10 - 20 ppm low, 20 - 80 ppm medium, 80-100 ppm high, >100 ppm very high. From the values of soil analysis, the very low content of sulfur and total OC (%) as well as the medium contents of total nitrogen and available phosphorus indicate that application of these nutrients is important for optimum production and might be yield-limiting factor for potato production in the study area.

Table 4. Selected physico -chemical properties of the experimental soil before sowing.

Soil physicochemical properties	Values	Ratings	References
Texture			
Sand %	16		
Silt %	18		
Clay %	66		USDA (1987)
Textural Class	clay		
Available phosphorus (ppm)	8.6	medium	Olsen (1954)
CEC [Cmol (+) kg^{-1} soil]	23.7	medium	Landon (1991)
pH	6.02	Slightly acidic	Tekalign Tadesse *et al., (1991)*
Total nitrogen	0.16	medium	Tekalign Tadesse *et al*., (1991)
Organic carbon %	3.25	low	Booker (1991)
Available sulfur (ppm)	0.12	very Low	Alemu Lelago *et al*., (2016)

Table 5. Chemical characteristics of FYM used in the experiment.

Available phosphorus (ppm)	18.5	high
CEC (Cmol (+) kg^{-1}soil)	38.92	high
pH	7.03	neutral
Total nitrogen	2.615	high
Organic carbon %	13.79	high
Available sulfur (ppm)	2.85	very low

Where Cmol = Centi mole, pH= power of hydrogen, % OC = per cent of organic carbon, %TN = Per cent of total nitrogen, AV. P. Ppm = available phosphorus in parts per million, CEC = Cation exchange capacity.

4.2. Phenological Parameters

4.2.1. Days to emergence

The analysis of variance on days to 50% emergence revealed that the main effect FYM, NPS fertilizer and their interaction were not-significant ($P > 0.05$) (Appendix Table 1) (Table 6). The uniform emergence of the potato plants from all plots regardless of the variations in the applied doses of the fertilizers might be attributed to the fact that the sprouting process in potatoes is mainly controlled by the potential of the stored food in the seed tubers to drive and sustain emergence. This determination is in accord with that of Lynch and Tai (1989) and De La Morena et al., (1994) who reported that the emergence of potato tuber was affected by storage conditions and physiological age of the seed tubers rather than being disciplined by the fertility status of the land.

4.2.2. Days to flowering

The number of days to 50% flowering was significant ($p \leq 0.01$) influenced by NPS and FYM application and not-significantly affected by their interaction (Appendix Table1). The maximum period required to reach days to 50% flowering (66 days) was recorded from the application of 30 tha^{-1}FYM whereas the shortest duration to 50 % flowering (63.33 days) was recorded from the control treatment (Table 6). The delayed flowering in response to the application of organic fertilizer (FYM) could be due to the extended vegetative phase of the plant owing to the availability of nutrients in farmyard manure (Ramesh *et al.*, 2009; Najm *et al.*, 2010). The present finding was agreed with Melkamu Alemayehu *et al.* (2016) and Simon Koroto (2019) who reported that increasing the application rate of FYM delays days to 50% flowering.

The maximum period required to reach days to 50% flowering (70.33 days) was recorded from the application of 180$kgha^{-1}$ whereas the shortest duration to 50 % flowering (56.66 days) was recorded from the control treatment (Table 6). The maximum period recorded might be due to the increased rate of NPS contributed to have an excessive haulm development which brings about staying longer duration to attain 50% flowering. This result was in agreement with Israel Zewide *et al.* (2012) and Melkamu Alemayehu and Minwyelet Jemberie (2018) reported that the application of NPS fertilizer delayed the time of flowering.

Similarly, in conformity with this result, Arega Amdie (2018) reported that increasing the rate of NPS application delayed 50% flowering. But in contrast to this study, Minwyelet Jemberie *et al.* (2017) and Getachew Kahsay *et al.* (2016) reported that there were no significant differences in days to flowering in potato due to the application of different level of NPS fertilizer treatment.

Table 6. Phenological parameters of potato as affected by FYM and NPS fertilizer application rates at Debre Berhan during 2019 crop season

FYM rate (tha^{-1})	days to emergence	days to flowering	days to maturity
0	20.46	63.33^{c}	102.16^{b}
10	20.46	64.58^{b}	103.25^{b}
20	20.68	64.83^{b}	105.42^{a}
30	20.58	66.00^{a}	106.58^{a}
NPS rate (kg ha^{-1})			
0	20.5	56.66^{d}	100.75^{c}
60	20.42	63.83^{c}	101.08^{c}
120	20.63	67.91^{b}	105.66^{b}
180	20.63	70.33^{a}	109.92^{a}
DMRT (significance)	NS	**	**
CV (%)	2.79	1.19	1.88

Mean values sharing the same letter in each column are not significant difference at the 5 % probability level.

4.2.3. Days to maturity

The number of days to 75% physiological maturity was significantly ($p \leq 0.01$) influenced by the main effects of NPS and farmyard manure (FYM) application and not-significantly affected by their interaction (Appendix Table 1). The maximum period required to reach days to 75% physiological maturity (106.58 days) was recorded from the application of 30 tha^{-1}FYM but statistically similar days was recorded by the application of 20 tha^{-1}FYM whereas the shortest duration to75% physiological maturity (102.16 days) was recorded from the control treatment which is statistically similar with the application of 10 tha^{-1} FYM (Table 6). The prolonged maturity under higher rates of FYM application might be due to farmyard manure activates many species of living organisms which release phytohormone and may stimulate the plant growth and absorption of nutrients which extended days to physiological maturity (Arisha *et al.*, 2003). The present result was inconsistent with that of Melkamu Alemayehu *et al.* (2016) and Abdulaziz Mohammed *et al.* (2018) who reported that increasing the rate of FYM application significantly delayed the days required for attaining physiological maturity of potato.

The maximum period required to reach days to 75% maturity (109.92 days) was recorded from the application of 180kgha^{-1} whereas the shortest duration to 75 % maturity (100.75 days) was recorded from the application of 60kgha^{-1}NPS but statically similar days to the control treatment (Table 6). As the finding of Arega Amdie (2018), the delayed maturity of plants in response to the application of the blended NPS fertilizer at higher rates might be due to the effect of nitrogen contained in the fertilizer which may have stimulated plant growth, enlarged leaves which delayed maturity. The current finding was in accord with Melkamu Alemayehu *et al.* (2016) who reported that increasing the rate of NPS fertilizer application delayed days to physiological maturity. Tantowijoyo and Van de Fliert (2006) also reported that the application of inorganic fertilizer at higher rates, enhances vegetative growth by helping the plant to absorb sunlight and produce carbohydrates but delayed the production of reproductive part and thereby maturity.

4.3. Growth Parameters of Potato

4.3.1. Plant height

Plant height was significant ($p \leq 0.01$) affected by farmyard manure, NPS fertilizer and their interaction (Appendix Table 1). The tallest plant height (73.26 cm) was recorded from plants that grow with the combined application of 30 t ha^{-1} farmyard manure and180 kg ha^{-1} NPS fertilizer while the shortest plant height (46.26cm) was recorded from the control treatment. The tallest plant height is increased by 47.52% as compared to plant height (49.66cm) resulted from the nationally recommended dose (area recommendation) of 180 kgha^{-1} NPS fertilizer (Table 7). The increased plant height as Yourtchi *et al.* (2013) and Marschner (1995) reported could be due to the combined application of organic and inorganic fertilizer increased the availability of nutrients this considerably resulting in a positive effect on plant height. This result was in accord with the findings of Melkamu Alemayehu *et al.* (2016) who reported that the combined application of NPS and FYM marks in the higher plant height. The present finding also confirms with Amin (2018) who showed that the combined application of 150 kg NPS ha^{-1} and 30t cattle manure ha^{-1} resulted in the highest plant height

Table 7. The interaction effect of FYM and NPS fertilizer on potato plant height (cm) at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	46.26^{i}	47.93^{hi}	48.96^{hi}	49.66^{gh}
10	50.53^{gh}	53.33^{fg}	55.80^{de}	55.03^{ef}
20	50.66^{gh}	58.66^{de}	55.20^{ef}	59.60^{cd}
30	53.40^{fg}	62.50^{c}	66.33^{b}	73.26^{a}
DMRT (significance)	**			
CV (%)	4.34			

Mean values sharing the same letter in each column are not a significantly different at 5 % probability level.

4.3.2. Main stem number per plant

The main stem number per plant was significantly ($p \leq 0.05$) affected by farmyard manure, NPS and their interaction (Appendix Table1). The maximum stem number per plant (4.73) was recorded by the application of 30 tha^{-1}FYM and 180kgha^{-1} NPS fertilizer while the minimum stem number per plant (1.13) was resulted in the control treatment which was statistically similar with the application of 10,20,30 tha^{-1}FYM alone and 60 and 120 kg ha^{-1} NPS blended fertilizer. The stem number per plant (1.66) was recorded by the application of national recommended dose of 180 kgha^{-1} NPS fertilizer in the study area (Table 8). The maximum stem number exceeds by 184.9% much greater than the recommended dose. The maximum stem number recorded by the application of 30tha^{-1} FYM and 180 kgha^{-1} NPS fertilizer might be due to their synergistic interaction of phosphorus and sulfur on the nitrogen element which stimulates the growth of sprout formed on the mother plant while it grows as the main stem number per plant. This result is coherent with that of Melkamu Alemayehu *et* *al*. (2016) who reported that increasing the rate of FYM and NPS significantly increased the stem numbers of potato. Muluneh Siraj (2018) also reported that increasing the rates of blended fertilizers significantly increased the number of stems per hill in potatoes. On the contrary, Mulubrehan Haile (2005) reported that the stem number was not significantly influenced much by organic and inorganic nutrients.

Table 8. The interaction effect of FYM and NPS fertilizer on main stem number per plant at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	1.13^{i}	1.40^{g-i}	1.60^{f-i}	1.66^{f-h}
10	1.26^{hi}	1.86^{fg}	2.03^{f}	2.70^{e}
20	1.40^{g-i}	2.50^{e}	2.96^{de}	3.20^{cd}
30	1.50^{g-i}	3.56^{c}	4.16^{b}	4.73^{a}
DMRT (significance)	*			
CV%	11.35			

Mean values sharing the same letter in each column are not a significantly different at 5 % probability level.

4.3.3. Number of branches per plant

The analysis of variance indicated that the number of branches was significantly ($p \leq 0.05$) affected by the main effect of FYM, NPS fertilizer and their interaction (Appendix Table 1). The maximum branch number (16.93) was recorded by the combined application of 30tha^{-1} FYM and 180$kgha^{-1}$NPS fertilizer application but the minimum branch number (5.93) was resulted from the control treatment. The maximum number of branches obtained by the combined application of 30 tha^{-1} FYM and 180$kgha^{-1}$ NPS have shown a 143.2% increment in branch number as compared to the recommended dose of 180$kgha^{-1}$ NPS fertilizer (Table 9). The increased in the number of branches as FYM and NPS fertilizer rate increased might be due to the chief nutrient present in FYM and NPS which enhance the growth of vegetative parts, improvement of soil water holding capacity and the presences of phosphorus element in NPS fertilizer that activates the formation of branch number (Badaruddin *et al.,* 1999). The present investigation was in line with Kipkosgeil *et al.* (2003) who reported that the increasing rate of the combined application of organic and inorganic fertilizer resulted in a higher branch number in potatoes.

Table 9. The interaction effect of FYM and NPS fertilizer on number of branches at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	5.93^{j}	6.50^{ij}	6.86^{h-j}	6.96^{h-j}
10	6.43^{ij}	7.30^{hi}	7.66^{gh}	8.56^{g}
20	7.26^{hi}	9.60^{f}	11.33^{e}	13.70^{d}
30	10.16^{f}	14.83^{c}	15.96^{b}	16.93^{a}
DMRT (significance)	*			
CV (%)	6.03			

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.3.4. Leaf number per plant

Leaf number was significantly ($p \leq 0.05$) affected by the application of farm yard manure, NPS fertilizer and their interaction (Appendix Table 1). This finding indicated that the maximum leaf number (378.86) was recorded in the treatment that receives the maximum FYM rate (30tha^{-1}) and NPS (180kgha^{-1}) while the minimum leaf number (201.6) resulted in the control treatment which was statistically similar with application of10,20 and 30 tha^{-1} FYM and 60 and 120 kgha^{-1} NPS blended fertilizer alone. The number of leaves obtained by the combined application of 30tha^{-1} FYM and 180kgha^{-1} NPS was increased by 54.4% greater than the number of leaves obtained by the recommended dose of 180kgha^{-1} NPS fertilizer (Table 10). The increased in leaf number while increasing FYM and NPS fertilizer level might be due to the macro and micro nutrient composition present in FYM and NPS fertilizer, which increased the above-ground biomass (leaves) and produces the maximum leaf number. The combined application of NPS and compost resulted in higher photosynthetic activity and chlorophyll synthesis, which seemed to have a favorable effect on the number of leaves per plant in Maize (*Zea Mays* L.) (Sisay Gurmu and Adugnaw Mintesnot, 2020). The current outcome was in agreement with Kipkosgeil *et al.* (2003) who showed that the combined application of FYM and nitrogen fertilizer resulted in the highest number of leaf $plant^{-1}$ in potatoes. Similarly, Avadh *et al*. (2017) reported that the combined application of FYM and NPK resulted in the maximum number of leaves per plant in sweet potato. In addition, Amana Mama *et al.* (2016) reported that the application of FYM and nitrogen fertilizer on potatoes resulted in the maximum leaf number.

Table 10. The interaction effect of FYM and NPS fertilizer on leaf number at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	201.60^{h}	210.66^{h}	207.00^{h}	245.33^{g}
10	206.33^{h}	273.33^{f}	279.66^{ef}	286.33^{ef}
20	209.66^{h}	309.00^{de}	317.33^{cd}	338.47^{bc}
30	212.33^{h}	342.6^{bc}	361.33^{ab}	378.86^{a}
DMRT (significance)	*			
CV (%)	6.12			

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.3.5. Total leaf area per plant

The analysis of variance indicated that total leaf area was significantly ($p \leq 0.05$) affected by the main effects of FYM and NPS fertilizer and non-significantly affected by their interaction (Appendix Table 1). The result revealed that the highest leaf area (9554.3cm^2) was recorded by 30tha^{-1}farmyard manure application while the minimum leaf area (4948.3cm^2) was recorded by the control treatment but statistically similar with the application of 10tha^{-1} FYM (Table 11).The increased in leaf area might be due to the nutrient composition present on the farmyard manure which increased the vegetative growth phase this enables an increased the amount of solar radiation intercepted and consequently, an expanded leaf size of potato. The current finding was in line with Amana Mama *et al.* (2016) who reported that the increased rate of FYM application resulted in the increased in leaf area of potato. Abdulaziz

Mohammed *et al.* (2018) and Matiwos Taye (2011) also reported that total leaf area was increased as the FYM fertilizer rate increased.

The highest leaf area (8854.4cm^2) was recorded by 180kgha^{-1} NPS application and this result was statistically similar with120 kg ha^{-1}NPS applied. The minimum leaf area (3670.9cm^2) was recorded by the control treatment (Table 11). The increased leaf area as NPS rate increased might be due to NPS fertilizer promotes the growth of plant parts, particularly the presence of Sulfur in NPS increased the utilization of nitrogen and phosphorous which results in the overall increase in leaf area. The present finding was agreed with Tariku Beyene *et al.* (2018) who reported that the increased rate of NPS fertilizer application significantly increased plant leaf area in Food Barley (*Hordeum vulgare*).

Table 11. Leaf area as affected by main effects of FYM and blended NPS fertilizer application rates at Debre Berhan during 2019 crop season

FYM rate (tha^{-1})	Leaf area (cm^2)
0	4948.3^c
10	5651.3^c
20	7323.6^b
30	9554.3^a
NPS rate (kgha^{-1})	Leaf area (cm^2)
0	3670.9^c
60	7067.9^b
120	7884.2^{ab}
180	8854.4^a
DMRT (significance)	*
CV (%)	18.06

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.3.6. Leaf area index (LAI)

Leaf area index was significantly ($p \leq 0.01$) influenced by FYM, NPS fertilizer application, and their interaction (Appendix Table1). The highest leaf area index (6.82) was recorded by the combined application of 30tha^{-1}farmyard manure and 180 kg ha^{-1} NPS fertilizer, but statistically similar with 60 and 120 kgha^{-1} NPS and 30tha^{-1} FYM but the lowest leaf area index was resulted by the control treatment. The leaf area index obtained by the combined application of 30tha^{-1} FYM and 180kgha^{-1} NPS was increased by 223.2% greater than the leaf area index obtained by the recommended dose of 180kgha^{-1} NPS fertilizer (Table 12). The increased in leaf area index might be due to the improved soil property which advances the uptake of soil nutrient by the plant this resulted in expanded potato leaf size, thus plant covered large space per plant this gives to increase in LAI. The appropriate use of organic and inorganic fertilizer expanded the leaf area index (Vaezzadeh, 2012). This research finding was in line with Bewket Getachew (2019) who reported that increasing the rate of organic and inorganic fertilizer application increased the leaf area index per hill in potato. Sisay Gurmu and Adugnaw Mintesnot (2020) also reported that leaf area index was increased with increased NPS fertilizer and compost rate in maize.

Table12. The interaction effect of FYM and blended NPS fertilizer on Leaf area index of potato at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	1.38^{d}	1.86^{cd}	2.26^{cd}	2.11^{cd}
10	1.46^{d}	2.20^{cd}	2.26^{cd}	2.06^{cd}
20	1.50^{d}	2.43^{cd}	3.07^{c}	5.11^{b}
30	1.80^{d}	6.37^{a}	6.43^{a}	6.82^{a}
DMRT (significance)		**		
CV (%)		20.84		

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.4. Yield and Yield Components of potato

4.4.1. Average tuber weight

Average tuber weight was significantly ($p \leq 0.05$) affected by farmyard manure, NPS and their interaction (Appendix Table 1). The highest average tuber weight (88.26g tuber^{-1}) was recorded by the application of 30 tha^{-1} FYM and 180kgha^{-1} NPS fertilizer while the lowest average tuber weight (48.03g tuber^{-1}) was recorded by the control treatment which was statistically similar with the application of 60kg ha^{-1}NPS blended fertilizer. The combined application of 180kgha^{-1} NPS and 30tha^{-1}FYM fertilizer increased the average tuber weight by 67.3% as compared to the recommended dose of 180kgha^{-1} NPS fertilizer (Table 13). The highest average tuber weight might be due to the increased provision of fertilizer nutrients that promote luxuriant growth, more foliage and leaf area and a higher supply of photosynthesis, which may have induced the formation of bigger tubers thereby resulting in higher yields (Patricia and Bansal, 1999). The current investigation is in line with Melkamu Alemayehu *et al.* (2016) who reported that a combined application of NPS fertilizer and FYM resulted in the highest potato tuber weight. Isreal Zewide *et al.* (2018) also reported that the highest average weight of tubers was found in the treatment that received both cattle manure and NP fertilizer.

Table 13. The interaction effect of FYM and blended NPS fertilizer on average tuber weight (g tuber^{-1}) at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	48.03^{n}	48.56^{n}	50.83^{lm}	52.76^{jk}
10	49.40^{mn}	55.43^{hi}	57.06^{h}	61.86^{g}
20	52.26^{kl}	63.86^{f}	66.06^{e}	68.53^{d}
30	54.33^{ij}	74.00^{c}	82.03^{b}	88.26^{a}
DMRT (significance)	**			
CV (%)	4.77			

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.4.2. Marketable tuber number

Marketable tuber number per plant was significantly ($p \leq 0.05$) affected by the main effect FYM, mineral NPS and their interaction (Appendix Table 1). The highest marketable tuber number per plant (25.53) was recorded by the combined application of 30tha^{-1} FYM and 180kgha^{-1}NPS fertilizers while the lowest marketable tuber number per plant was recorded by the control treatment which was statistically similar with the application of 60kgha^{-1} NPS blended fertilizer. The combined application of 180kgha^{-1} NPS and 30tha^{-1}FYM fertilizer increased the marketable tuber number per plant by 63% as compared to the recommended dose of 180kgha^{-1} NPS fertilizer (Table14). From the findings of Daniel Mekonne *et al*. (2008) the possible reason for increased marketable tuber number might be due to applied organic and inorganic fertilizer increased the size of the tuber and there by increased the weight of the tuber and also phosphorus fertilization increased the interception of solar radiation so it might have a positive effect on the number of tubers set at certain conditions. This finding is in agreement with Amin Ababiya (2018) who reported that the combined application of NPS and cattle manure resulted in the higher marketable tuber number plant^{-1}. Isreal Zewide *et al*. (2018) also reported that the application of cattle manure and NP fertilizer significantly increased the marketable tuber number per plant in potato.

Table 14. The interaction effect of FYM and NPS fertilizer on marketable tuber number (plant^{-1}) of potato at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	13.00^{i}	13.66^{hi}	14.66^{gh}	15.66^{f-h}
10	14.86^{gh}	15.83^{f-h}	17.60^{c-f}	17.16^{d-g}
20	14.66^{gh}	16.83^{e-g}	18.50^{c-e}	19.66^{b-d}
30	15.30^{f-h}	20.00^{bc}	21.66^{b}	25.53^{a}
DMRT (significance)		*		
CV (%)		8.29		

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.4.3. Unmarketable tuber number per plant

The analysis of variance showed that the main effect of FYM and NPS fertilizer significantly ($p \leq 0.01$) affected unmarketable tuber number per plant. However, their interaction was non-significantly affected by this parameter (Appendix Table 1). Increasing the application of FYM to 30tha^{-1}significantly decreased the unmarketable tuber number per plant. The lowest unmarketable tuber number (3.36) plant^{-1} was recorded from treatment that received the highest rate (30tha^{-1}) of FYM while the highest unmarketable tuber number (5.38plant^{-1}) was recorded from the control treatment (Table 16). The lowest unmarketable tuber number record might be due to the important plant nutrient present in FYM signifies the vegetative part which improves photo assimilate to produced large size tuber and the small number of unmarketable tuber number. This result was compatible with Simon Koroto (2019) who reported that the increased rate of FYM application brings about the decreased amount of unmarketable tuber number.

The increasing rate of NPS application to 180 kg ha^{-1}significantly reduced the unmarketable tuber numbers (Table 16). The lowest unmarketable tuber number might be due to the highest magnitude of nutrient present in NPS produced the smallest sized and weight of unmarketable tuber number. Those supplied with the highest NPSB fertilizer rate produced the lowest unmarketable tuber numbers per hill (Bruk Namena, 2018). The present finding is in line with Solomon Fantaw *et al*. (2019) who reported that the increased application rate of NPS fertilizer results in lower numbers of unmarketable tuber numbers as compared to unfertilized treatment.

4.4.4. Marketable tuber yield

The main effects of FYM, NPS fertilizer and their interaction significantly ($p \leq 0.05$) affected marketable tuber yield (Appendix Table 1). The highest marketable tuber yield (29.66 tha$^{-1)}$ was recorded by the combined application of 30 tha^{-1}FYM and 180kg^{-1} NPS fertilizer while the lowest marketable tuber yield(16.5tha^{-1}) was recorded by the control treatment. The combined application of 180kgha^{-1} NPS and 30tha^{-1}FYM fertilizer increased the marketable tuber yield by 58.9% as compared to the recommended dose of 180kgha^{-1} NPS fertilizer (Table15). The increased marketable tuber yield with the supply of fertilizer nutrients could be due to more comfortable growth, more foliage and the increased leaf area and a higher supply of photosynthesis that helped in producing bigger tubers resulting in higher yields (Sharma and Arora, 1987). The present finding was in agreement with Melkamu Alemayehu *et al.* (2018) who reported that the combined application of FYM and NPS fertilizer recorded the highest marketable yield. Bewket Getachew (2019) also showed that the combined application of organic and inorganic fertilizer resulted in the highest marketable tuber yield

Table 15. The interaction effect of FYM and blended NPS fertilizer on marketable tuber yield (tha^{-1}) of potato at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	16.50^{e}	17.83^{e}	17.68^{e}	18.66^{e}
10	17.18^{e}	18.14^{e}	20.00^{de}	19.33^{de}
20	17.16^{e}	19.37^{de}	19.50^{de}	22.31^{cd}
30	18.50^{e}	23.51^{bc}	26.33^{b}	29.66 ^{a}
DMRT (significance)	*			
CV (%)	8.29			

Mean values sharing the same letter in each column are not a significantly different at 5 % probability level.

4.4.5. Unmarketable tuber yield

Unmarketable tuber yield was significantly ($p \leq 0.01$) affected by the main effects of FYM and NPS fertilizer and was not affected by their interaction (Appendix Table1). Increasing the rate of FYM from 0 to30 tha^{-1} decreased the number of unmarketable tuber yield from 5.25 to 3.41tha^{-1} (Table 16). This would be due to the increase in nutrient availabilities in FYM which leads to producing in a significantly higher yield of bigger-sized tuber and a small amount of unmarketable tuber yield. The present investigation was in line with Simon Koroto (2019) who reported that the increasing rate of FYM application decreased the amount of unmarketable tuber yield.

Increasing the rate of NPS from 0 to 180 kg ha^{-1} decreased the number of unmarketable tubers yields from 4.86 to 4.05 t ha^{-1} (Table 16). The decrease in unmarketable tuber yield might be due to the increased in NPS level brings an increased nutrient availability which resulted in the larger sized tuber and lower amount of deformed and small-sized tuber. Similarly, Solomon Fantaw *et al*. (2019) reported that increasing the NPS fertilizer rate significantly reduced the unmarketable tuber yield. Biruk Namena (2018) also reported that increasing the rate of NPSB decreased unmarketable tuber yield. On the contrary, Arega Amdie (2018) reported that increasing the rate of NPS fertilizer significantly increased the unmarketable tuber yield

Table 16. The main effect of FYM and NPS fertilizer rates on unmarketable tuber number and unmarketable tuber yield at Debre Berhan during 2019 crop season

FYM (tha^{-1})	Unmarketable tuber number (plant^{-1})	Unmarketable tuber yield (tha^{-1})
0	5.83^{a}	5.25^{a}
10	4.75^{b}	4.66^{b}
20	4.38^{c}	4.42^{c}
30	3.36^{d}	3.41^{d}
DMRT (significance)	**	**
NPS (kg ha^{-1})		
0	4.92^{a}	4.86^{a}
60	4.53^{b}	4.53^{b}
120	4.34^{c}	4.28^{c}
180	4.08^{d}	4.05^{d}
DMRT (significance)	**	**
CV %	4.27	5.02

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.4.6. Total tuber yield

Total tuber yields significantly ($p \leq 0.05$) affected by farmyard manure, NPS and their interaction (Appendix Table1). The maximum total tuber yield (32.68tha^{-1}) was recorded by the application of 30 tha^{-1} FYM and 180kgha^{-1} NPS fertilizer while the minimum total tuber yield (21.33tha^{-1}) was recorded by the control treatment which was statistically similar with the application of 10,20,30 tha^{-1} alone and 60,120 and 180kgha^{-1} blended NPS fertilizer alone. The combined application of 180kgha^{-1} NPS and 30tha^{-1}FYM fertilizer increased the total tuber yield by 39.7% as compared to the recommended dose of 180kgha^{-1} NPS fertilizer (Table 17). The maximum total tuber yield recorded could be due to the complementary effects of plant nutrients available in NPS and FYM improved soil condition attributes, which may contribute to growth and development and thus improvement of potato total tuber yield. The growth in total tuber yield with the supply of fertilizer nutrients could be due to more comfortable growth, more foliage and leaf area and a higher supply of photosynthesis that helped in producing bigger tubers resulting in higher yields (Sharma and Arora, 1987). The increased rate of combined application of blended NPSZnB fertilizer and cattle manure resulted in the highest total tuber yield (Bewket Getachew, 2019). The current finding is in line with Melkamu Alemayehu *et al.* (2016) who reported that the combined application of FYM and NPS fertilizer recorded the highest total tuber yield. Moreover, this result also confirmed with Tesfaye Balemi (2012) who reported that integration of organic and inorganic fertilizers resulted in the highest total tuber yield due to positive interaction and complementarities between them.

Table 17. The interaction effect of FYM and NPS fertilizer on total tuber yield of potato at Debre Berhan during 2019 crop season

	NPS rate (kg ha^{-1})			
FYM rate (tha^{-1})	0	60	120	180
0	21.33^{e}	23.26^{de}	22.74^{de}	23.39^{de}
10	22.06^{e}	22.89^{de}	24.60^{c-e}	23.73^{c-e}
20	22.05^{e}	23.77^{c-e}	23.79 $^{c-e}$	26.39^{cd}
30	22.39^{e}	27.04b^{c}	29.51^{b}	32.68^{a}
DMRT (significance)	*			
CV (%)	7.75			

Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.5. Quality Parameters of Potato

4.5.1. Tuber dry matter content

Tuber dry matter content was significantly ($p \leq 0.05$) affected by NPS fertilizer, farmyard manure and their interaction (Appendix Table1). The highest tuber dry matter content (25.83%) was recorded in the control treatment, while the lowest tuber dry matter content (19.83%) was resulted in the application of 30tha^{-1}FYM and180kg NPS ha^{-1} but statistically similar with the application of some other FYM and NPS rates (Table 18). Low nitrogen-containing fertilizer applications increased the dry matter content of the tubers, whereas large applications tend to the opposite effect (Zaag, 1992). From the finding of Bewket Getachew (2019) the lowest tuber dry matter content resulted by combined application of organic and inorganic fertilizer might be due to the high nitrogen application that may have resulted in low partitioning of assimilating to tubers and phosphorus that have an inverse relation with tuber dry matter content. The present finding agreed with Sincik *et al. (*2008) who showed that increasing organic and inorganic fertilizer rate reduces dry matter content in tubers. Similar results are reported by Sebastian *et al.* (2007) who reported that increasing soil nitrogen content led to a decrease in the dry matter content of potato tubers. This result also in accordance with Arega Amdie (2018) who reported that the lowest dry matter content was recorded with the maximum dose of NPS fertilizer rates. In contrast with this result, Daniel Mekonne *et al*. (2009) found the higher dry matter content of tuber was recorded due to the combined application of organic and inorganic fertilizers relative to the unfertilized treatments.

4.5.2. Specific gravity

The specific gravity of tubers was significantly ($p \leq 0.01$) affected by farmyard manure, NPS fertilizer and their interaction (Appendix Table 1). The highest specific gravity (1.096g/m^3) was recorded in the control treatment, while the lowest specific gravity (1.059g/m^3) was resulted in the application of 30tha^{-1}FYM and180kg NPS ha^{-1} (Table 18). The lowest specific gravity recorded due to the application high rate of organic and inorganic fertilizer might be due to the fact that increasing the rate of FYM and NPS fertilizer increases the amount of nitrogen content which results in decreasing the solid constituent of tuber and increases the water content of tubers and this result agrees with Bewket Getachew(2019) who reported that application of the maximum dose of inorganic and organic fertilizer resulted in the lowest tuber specific gravity. Hay and Walker (1988) and Klein Kopf *et al.* (1981) also reported that the specific gravity falls with an increase in the quantity of inorganic and organic fertilizer application. Contrary, to this Kandil *et al.* (2011) noted that increasing rate of organic and inorganic fertilizer application resulted in the highest specific gravity.

4.5.3. Tuber starch content

The analysis of variance indicated that the main effect FYM, NPS fertilizer and their interaction had a significantly ($p \leq 0.01$) effect on tuber starch content (Appendix Table 1). The highest tuber starch content (17.11g/100g) was recorded in the control treatment, while the application of 30tha^{-1}FYM and180kg NPS ha^{-1} resulted in the lowest tuber starch content (9.75g/100g) (Table 18). The possible reason may be the fact that nitrogen-containing fertilizer application like FYM and NPS results in low partitioning of assimilating to the tubers and the availability of sulfur facilitates uptake and use efficiency of plants to nitrogen. In addition, farmyard manure increases the availability of nitrogen and phosphorus by favoring soil physic-chemical property and releasing nitrogen, phosphorus and sulfur nutrients. The present finding was in accordance with Bewket Getachew (2019) who reported that high inorganic and the organic fertilizer level decreases the starch content of potato tuber.

Table 18. Effect of FYM and NPS fertilizer on tuber dry matter content, specific gravity of tubers and tuber starch content at Debre Berhan area of North Shewa zone during 2019 main cropping season

FYM rate(tha^{-1})	NPS rate (kgha^{-1})	TDM (%)	SGT (g/m^3)	TSC (g/100g)
0	0	25.83^{a}	1.096^{a}	17.11^{a}
	60	24.50^{b}	1.092^{b-d}	16.32^{a-d}
	120	23.00^{cd}	1.094^{a-c}	16.58^{a-c}
	180	20.50^{e}	1.091^{c-e}	16.05^{b-d}
10	0	24.33^{b}	1.095^{ab}	16.85^{ab}
	60	23.16^{c}	1.090^{d-f}	15.79^{c-e}
	120	22.00^{d}	1.088^{ef}	15.52^{de}
	180	20.66^{e}	1.086^{fg}	15.06^{ef}
20	0	23.00^{cd}	1.091^{c-e}	15.59^{de}
	60	22.33^{cd}	1.084^{gh}	14.59^{fg}
	120	20.50^{e}	1.080^{hi}	13.86^{gh}
	180	20.00^{e}	1.079^{i}	13.60^{h}
30	0	22.16^{cd}	1.084^{gh}	14.59^{fg}
	60	20.66^{e}	1.084^{gh}	14.59^{fg}
	120	20.00^{e}	1.067^{k}	11.21^{j}
	180	19.83^{e}	1.059^{l}	9.75^{k}
DMRT (significance)		*	**	**
CV (%)		2.70	0.19	3.01

TDM=tuber dry matter, SGT=specific gravity of tuber and TSC=tuber starch content. Mean values sharing the same letter in each column are not significantly different at 5 % probability level.

4.5.4 Total soluble solid (TSS) and pH

The total soluble solid of tubers did not significantly affect by farmyard manure, NPS and their interaction (Appendix Table 1). The pH of tubers was significantly ($p \le 0.05$) affected by farmyard manure and non-significantly affected by NPS and their interaction (Appendix

Table 1). The highest value (6.29) was recorded by the control treatment and the lowest value (6.18) was by the application of 30tha^{-1} FYM (Table 19). The pH of the tuber affected by farmyard manure might be due to the high nutrient composition present in FYM which makes a difference in the pH content. This result was similar to Sisay Hailu (2008) who showed that the application of chicken manure resulted in an elevated pH value in carrots.

Table 19. Effect of FYM and NPS fertilizer on total soluble solids (TSS) and pH at Debre Berhan area of North Shewa zone during 2019 main cropping season

FYM rate (tha^{-1})	TSS (^{0}brix)	pH
0	1.428	6.29^{a}
10	1.387	6.23^{b}
20	1.387	6.19^{bc}
30	1.378	6.18^{c}
DMRT (significance)	NS	*
CV%	5.04	0.88

Mean values sharing the same letter in each column are not a significantly different at 5 % probability level.

4.6. Partial Budget Analysis

The result of partial budget analysis revealed that application of 30tha^{-1} FYM and 180 kg NPS ha^{-1} resulted in the highest net benefit of (119,758 ETB ha^{-1}) with the acceptable marginal rate of return (1,636.1%) which generated (Birr 49,508 ha^{-1}) more as compared to the control treatment (Table 20). Based on this result, 30tha^{-1} FYM and 180 kg ha^{-1} NPS resulted in the highest adjustable marketable tuber yield 26.69 t ha^{-1} which is recommended for profitable products to the farmers in the study area.

Table 20. Summary of partial budget and marginal rate of return analysis for response of potato production to FYM and NPS fertilizer rate

Treatment combination							
FYM *	NPS	AV MY (tha^{-1})	AJMY (tha^{-1})	*TVC*	GFB	NB	MRR
0	0	16.50	14.85	4000	74250	70250	-
	60	17.83	16.04	1464	80200	78736	D
	120	17.68	15.91	2328	79550	77222	D
	180	18.66	16.79	3192	83950	80758	409.2
10	0	17.18	15.46	4100	77300	73200	D
	60	18.14	16.32	4964	81600	76636	397.6
	120	20.00	18	5828	90000	84172	872.2
	180	19.33	17.39	6692	86950	80258	D
20	0	17.16	15.44	7600	77200	69600	D
	60	19.37	17.43	8464	87150	78686	1,051.6
	120	19.37	17.43	9328	87150	77822	D
	180	22.31	20.07	10192	100350	90158	1,427.7
30	0	18.50	16.65	11100	83250	72150	D
	60	23.51	21.15	11964	105750	93786	2,504.1
	120	26.33	23.69	12828	118450	105622	1,369.9
	180	29.66	26.69	13692	133450	119758	1,636.1

Where: AVMY= Average marketable yield; AjMY= adjustable marketable yield; TVC = Total variable cost; GFB=growth field benefit; NB= Net benefit; D=Dominated treatment; Selling price of potato at farm gate = 5 Birr kg^{-1}; Purchasing costs of NPS fertilizer=14.4Eth-Birr kg^{-1}; Cost of FYM = 350 Eth-Birr t^{-1}; Labor cost = 100 Eth-Birr Man-day^{-1}; Purchasing costs for potato seed 10Eth-Birr kg^{-1}.

4.7. Correlation Analysis

The Pearson correlation analysis was executed to determine a simple correlation coefficient between phenological, growths, yield and quality parameters as a result of applied NPS and FYM fertilizer. Plant height was significantly and positively correlated with days to 50% flowering ($r=0.57^{**}$), days to physiological maturity ($r=0.61^{**}$), main stem number($r=0.92^{**}$) and number of branches (r = 0.89**) (Table 21). This might be due to increasing the level both FYM and NPS application increased in plant height, which brings increment in the number of branch and main stem number and the increase in the size of plant parts resulted in staying as vegetative which brings an extended day to flowering and maturity. The combination of farmyard manure and mineral fertilizer resulted in increased plant height due to the availability of nutrients which have a positive effect on growth parameters in potato (Yourtchi *et al.*, 2013; Alam *et al*., 2007)

Main stem number was significantly and positively correlated with days to 50% flowering ($r=0.69^{**}$) and days to physiological maturity ($r=0.68^{**}$) (Table 21.). This might be due to the increasing level of both FYM and NPS fertilizer application resulted in the growth of the main stem number which leads to an extended day to reach 50% flowering and maturity.

Leaf number was significantly and positively correlated with days to 50% flowering ($r=0.74^{**}$), days to physiological maturity ($r=0.67^{**}$), main stem number ($r=0.91^{**}$), number of branch ($r=0.85^{**}$) and plant height ($r=0.87^{**}$) (Table 21.). This might be due to the increasing level of NPS and FYM resulted in favorable soil condition for plants to increase the above-ground biomass (leaf number) which resulted in increase in main stem number, the number of branches and plant height consequently prolonged in days to 50% flowering and maturity. The increased rates of both organic and inorganic fertilizer increased plant height, leaf number, leaf length, stem number of the aerial parts and hence, prolonged the duration of photosynthesis (Israel Zewdie *et al.*, 2012; Alemu Lelago *et al.*, 2016).

Leaf area was significantly and positively correlated with days to flowering ($r=0.73^{**}$), days to maturity ($r=0.66^{**}$), main stem number ($r=0.90^{**}$), number of branches ($r=0.83^{**}$), plant height ($r=0.82^{**}$) and leaf number ($r=0.89^{**}$) (Table 21.). This might be due to the increased leaf area brings in the increment photosynthesis ability which implies suitable for the growth of plant height, stem number, number of branch and leaf number which leads to prolonging days to maturity of potato. Combined application of organic and inorganic fertilizer was resulted increased plant height, leaf number, leaf area and leaf area index (Sisay Gurmu, 2020; Alemu Lelago *et. al.,* 2016; Kandil *et al*., 2011).

Average tuber weight was found to be strongly and positively associated with days to flowering ($r=0.65^{**}$), days to maturity ($r=0.68^{**}$), main stem number ($r=0.97^{**}$), number of branches ($r=0.95^{**}$), plant height ($r=0.94^{**}$), leaf number ($r=0.91^{**}$), plant leaf area ($r=0.90^{**}$) and leaf area index (0.89^{**}) (Table 21.). This might be due to the increased average tuber weight resulted from the increase in main stem number which facilitates the increase in branch number which immediately produced a profuse leaf number which resulted in an increased in leaf area and leaf area index which holds staying in days to flowering and maturity. The increase in average tuber weight in response to the increased supply of fertilizer nutrients could be due to more luxuriant growth, more foliage and leaf area and higher supply of photosynthates which may have induced the formation of bigger tubers thereby resulting in higher yields (Patricia and Bansal, 1999).

Marketable tuber yield increment was found to be strongly and positively associated with main stem number (r =0.87**), number of branch ($r=0.83^{**}$), plant height ($r = 0.87^{**}$), days to flowering (r=0.58**),days to maturity(r=0.59**), leaf number($r=0.78^{**}$), plant leaf area($r=0.79^{**}$), leaf area index($r=0.79^{**}$), average tuber weight ($r= 0.87^{**}$) and marketable tuber number (r = 0.87**) (Table 21). This might be due to the increase in main stem number leads to an increment in the number of branches which results in increase in the number of profuse leaves this advocate extended days to flowering and physiological maturity. The expansion in leaf area resulted in the production of high photo assimilation this implies increasing the average tuber weight and more production of marketable tuber yield. The use of organic and inorganic fertilizer has been reported as a potential factor for better vegetative growth and increased tuber yield (Amir Ali *et al.*, 2005; Gezahegn Garo *et al.*, 2014; Simon Koroto, 2019).

Total tuber yield increment was found to be strongly and positively related with days of flowering ($r=0.55^{**}$),days to maturity($r=0.55^{**}$),main stem number(r=0.83**),number of branch ($r=0.77^{**}$), plant height ($r = 0.82^{**}$), leaf number($r=0.74^{**}$), plant leaf area($r=0.76^{**}$), leaf area index ($r=0.75^{**}$), average tuber weight($r= 0.83^{**}$),marketable tuber number (r = 0.84**) and marketable tuber yield ($r=0.99^{**}$) (Table 21). This could be due to the synergistic effect of both organic (FYM) and inorganic (NPS) fertilizer to the overall growth and development of tuber. Organic and inorganic fertilizer application increase the total tuber yield increment due to their favorable effects on yield components and enhanced all nutrient requirements of the plant (Simon Koroto, 2019; Bekunda *et al.*, 2010; Melkamu Alemayehu *et al.*, 2019).

The specific gravity was positively correlated with tuber dry matter ($r=0.76^{**}$) and tuber starch content also strongly correlated with a specific gravity and tuber dry matter ($r=0.9^{**}$) ($r=0.7^{**}$) respectively. But with most of the growth and yield issue of potato were negatively correlated with those tuber quality parameters (Table 21). This might be due to the increasing rate of organic (FYM) and inorganic (NPS) fertilizer application did not have a significant impact on quality parameters (Bewket Getachew, 2019). Dry matter content, specific gravity, and starch content fall with an increase in the quantity of inorganic and organic fertilizers application (Hay and Walker, 1988).

Table 21. Correlation analysis of phenological, growth, yield and quality parameter of potato as affected by application of NPS and FYM fertilizer

PAR	DE	DF	DM	MSN	NOB	PH	LN	PLA	LAI	ATW	MTN	UNTN	MTY	UNTY	TTY	TDM	SGT	TSC	TSS	pH
DE	1																			
DF	0.032	1																		
DM	0.094	0.778**	1																	
MSN	0.114	0.69**	0.68 **	1																
NOB	0.065	0.55**	0.63**	0.913 **	1															
PH	0.126	0.572**	0.609**	0.915**	0.897**	1														
LN	0.043	0.735**	0.671**	0.912**	0.85**	0.87**	1													
PLA	0.017	0.733**	0.662**	0.901**	0.833**	0.824**	0.891**	1												
LAI	0.212	0.591**	0.554**	0.87**	0.895 **	0.813**	0.8**	0.823**	1											
ATW	0.064	0.649**	0.678**	0.965**	0.948**	0.935**	0.91**	0.904**	0.892**	1										
MTN	0.059	0.646**	0.679**	0.879 **	0.86**	0.85**	0.82**	0.825**	0.809**	0.924**	1									
UNMTN	0.069	-0.51**	-0.606**	-0.825**	-0.894**	-0.866**	-0.772**	-0.766**	-0.766**	-0.868**	-0.799**	1								
MTY	0.112	0.577**	0.585**	0.87**	0.828**	0.865**	0.775**	0.792**	0.785 **	0.872 **	0.868 **	-0.762 **	1							
UNMTY	-0.088	-0.409	-0.611**	-0.8 **	-0.866**	-0.839**	-0.736**	-0.706**	-0.741 **	-0.841 **	- 0.743 **	-0.879**	-0.753**	1						
TTY	0.115	0.55**	0.547 **	0.831**	0.773 **	0.82 **	0.736 **	0.761**	0.746 **	0.827 **	0.839 **	-0.698**	0.992 **	-0.673 **	1					
TDM	-0.11	-0.79**	-0.79**	0.76**	-0.73**	-0.72**	-0.76**	-0.74**	-0.65$^{* *}$	-0.75**	-0.75**	0.76**	-0.66**	0.67**	-0.62	1				
SG	-0.10	-0.57 **	-0.63**	-0.93**	-0.95**	-0.93**	-0.87**	-0.83**	-0.87**	-0.96**	-0.89**	0.89**	-0.88**	0.88**	-0.83**	0.76	1			

TSC	-0.11	-0.55**	-0.61**	-0.92**	-0.94**	-0.92**	-0.85**	-0.82**	-0.86**	-0.95**	-0.89**	0.89**	-0.87**	0.88**	-0.8**	0.7**	0.9**	1		
TSS	0.19	-0.04	-0.09	-0.11	-0.09	-0.15	-0.14	-0.23	-0.06	-0.13	-0.07	0.16	-0.07	0.18	-0.07	0.12	0.04	0.06	1	
pH	-0.03	0.02	0.02	-0.13	-0.08	-0.19	-0.11	-0.14	-0.16	-0.17	-0.13	0.05	-0.18	0.22	-0.16	-0.15	0.13	0.12	0.13	1

Where: PAR=parameter, DE=days to 50% emergency, DF=days to 50% flowering, DM=days to 75%physiological maturity, MSN=main stem number palnt^{-1}, NOB=number of branch plant^{-1}, PH=plant height(cm), LN=leaf number plant^{-1}, LA=leaf area(cm^{2}), LAI= leaf area index, ATW=average tuber weight (g/tuber),MTN=marketable tuber number plant^{-1},UNMTN=unmarketable tuber number plant^{-1} ,MTY=marketable tuber yield(tha^{-1}),UNMTY=unmarketable tuber yield(tha^{-1}),TTY=total tuber yield(tha^{-1}) ,DM=dry matter of tuber(%), SG=specific gravity(g/m^{3}) , SC=starch content of tuber (g/100g), TSS=total soluble solid (^{o}brix), P^{H}= Power of hydrogen **= highly significant at $P \leq 0.01$ probability level, * = significant at $P \leq 0.05$ probability level

5. SUMMARY AND CONCLUSIONS

Potato (*Solanum tuberosum* L.) is one of the most widely cultivated vegetable crops in the highlands of Ethiopia including DebreBerhan. Farmers in the study area produce potato both as food and cash crop under irrigation and rain fed conditions. The existing potato productivity in DebreBerhan is very low despite the high potential for increased production and yield of the crop. This is due to constraints such as increasing cost of fertilizer, a few trends of farmers using FYM, poor agronomic practice, poor soil fertility, poor cultural practices, diseases and pests are the critical problems observed in most farmers' field. Thus, to improve the production and productivity of the crop, soil fertility management has to be the primary role of the producers. To this effect, a study was conducted to investigate the effect of NPS fertilizer and farmyard manure on growth, yield and quality of potato (*Solanum tuberosum* L.) at Debre Berhan, North Shewa, Ethiopia. The experiment was carried out with Four levels of NPS (0, 60, 120 and 180 kg ha^{-1}) and four levels of FYM (0, 10, 20 and 30 tha^{-1}) in 4 x 4 factorial arrangement laid out in randomized complete block design with three replications and ''Gera" potato was used as experimental material.

The results showed that the main effect of blended NPS and FYM fertilizers were significant on days to flowering, days to maturity, total leaf area, unmarketable tuber number per plant and unmarketable tuber yield tha^{-1}. The combined application of 180 kg ha^{-1} blended NPS fertilizer and 30 t ha^{-1} farmyard manure resulted in the highest main stem number(4.73), the highest number of branch(16.93), the highest leaves number(378.86),the longest plant height (73.26cm),the highest leaf area index (6.82), the highest average tuber weight(88.26g tuber^{-1}), the highest marketable tuber number per plant (25.53),the highest marketable tuber yield (29.66t ha^{-1}) and the highest total tuber yield (32.68tha^{-1}).While with lowering the yield and by maintaining or compensate the quality of potato, the combined application of 60kgha^{-1} blended NPS and 30tha^{-1} FYM resulted in an acceptable tuber quality .On the other hand, both NPS and FYM rates did not significantly affect days to 50% emergence and total soluble solid (^{o}brix) of tuber.

The partial budget analysis revealed that application of 30tha^{-1} FYM and 180 kg NPS ha^{-1} resulted in the highest net benefit of (119,758 ETB ha^{-1}) with the acceptable marginal rate of return (1,636.1%) which generated (Birr49,508 ha^{-1}) more as compared to the control treatment. According to the current investigation, the combined application of 30 tha^{-1} farmyard manure and 180 kg ha^{-1}NPS fertilizer responded well in terms of growth and yield parameter of potato, but not quality elements of potato. Based on these results, it is recommended that a combined application of FYM and NPS fertilizer at the rate of 30tha^{-1} and 180 kg ha^{-1} considered acceptable and can be provisionally recommended for potato growers in DebreBerhan district and other areas with similar agro ecologies. However, as the results are limited to one season and location, further study should be done to establish the conclusive recommendations so as to improve the production and productivity of potato in the study area.

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7. APPENDICES

Appendix Table 1. Mean squares of analysis of variance for the effect of FYM and blended NPS fertilizer on growth, yield and quality parameters of potato at Debre Berhan during 2019 crop season

Parameters/source	Block	FYM	NPS	FYM*NPS	error
df	2	3	3	9	30
DE	0.08	0.03^{ns}	0.13^{ns}	0.15^{ns}	0.57
DF	0.44	14.35^{**}	429.46^{**}	2.46^{ns}	0.77
DM	4.52	48.41^{**}	225.41^{**}	2.76^{ns}	1.96
MSN	0.24	9.15**	6.77 **	0.77**	0.26
NOB	3.77	115.23**	70.30**	14.13**	14.13
PHT	22.82	402.86^{**}	369.05^{**}	60.02^{**}	2.37
LN	477.22	25471.56^{**}	25142.87^{**}	2413.99^{**}	16.77
LA	239195.0	50357971.2^{**}	60958111.8^{**}	5619606.8^{ns}	1241.040
LAI	0.18	30.94 **	13.91**	3.65 **	0.64
ATW	32.02	1339.04^{**}	624.17^{**}	92.73^{**}	1.07
MTN	10.14	76.35 **	48.485 **	8.76^{*}	1.43
UNMTN	0.0099	8.64^{**}	1.506^{**}	0.074^{ns}	0.19
MTY	20	110.47**	56.48**	10.326*	1.88
UNMTY	0.098	7.021 **	1.42**	0.044^{ns}	0.22
TTY	17.81	66.16^{**}	44.64^{**}	9.26^{*}	1.89
DM	2.07	17.95^{**}	29.02^{**}	1.22^{*}	0.59
SG	0.00	0.0012**	0.00034 **	0.00003**	0.0020
SC	3.95	50.02**	12.50**	1.53**	0.44
TSS	0.0048	0.0058^{ns}	0.0025^{ns}	0.0061^{ns}	0.070
P^{H}	0.0054	0.032^{**}	0.0009^{ns}	0.016^{ns}	0.055

Where, df=degree of freedom, DE=days to 50% emergency, DF=days to 50% flowering, DM=days to 75%physiological maturity, MSN=main stem numberpalnt^{-1}, NOB=number of branch plant^{-1}, PHt=plant height(cm), LN=leaf number plant^{-1}, LA=leaf area(cm^{2}), LAI= leaf area index, ATW=average tuber weight (g/tuber) MTN=marketable tuber number plant^{-1} ,UNMTN=unmarketable tuber number plant^{-1},MTY=marketable tuber yield (tha^{-1}),UNMTY=unmarketable tuber yield(tha^{-1}), TTY=total tuber yield(tha^{-1}) ,DM=dry matter of tuber(%), SG=specific gravity(g/m^{3}), SC=starch content of tuber (g/100g), TSS=total soluble solid(^{o}brix), pH= Power of hydrogen **= significant at P ≤0.01 probability level, * = significant at P≤0.05 probability level and ns = non-significant at P > 0.05 probability level.

Appendix Table 2. Mean values from analysis of variance table for the main effect of FYM and blended NPS fertilizer on growth parameters of potato at Debre Berhan during 2019 crop season

FYM (tha^{-1})	PHt	MSN	NOB	LN	LAI
30	63.87^{a}	3.49^{a}	14.47^{a}	323.78^{a}	5.35^{a}
20	56.03^{b}	2.51^{b}	10.47^{b}	293.62^{b}	3.03^{b}
10	53.67^{c}	1.96^{c}	7.49^{c}	261.42^{c}	2.0^{c}
0	48.2^{d}	1.45^{d}	6.56^{d}	216.15^{d}	1.9^{c}
CV	3.9	11.35	5.8	6.12	20.85
NPS (kgha^{-1})					
180	59.39^{a}	3.07^{a}	11.54^{a}	312.25^{a}	4.02^{a}
120	56.7^{b}	2.69^{b}	10.43^{b}	291.33^{b}	3.51^{ab}
60	55.60^{b}	2.33^{c}	9.55^{c}	283.9^{b}	3.2^{b}
0	50.21^{c}	1.32^{d}	7.45^{d}	207.48^{c}	1.5^{c}
CV	3.9	11.35	5.8	6.12	20.85

Where: PHt = plant height (cm), MSN= main stem number plant^{-1}, NOB =number of branch plant^{-1}, LN =leaf number plant^{-1} and LAI= leaf area index. Values connected by a different letter across a column are significantly different at the 5% significance level.

Appendix Table 3. Mean values from the analysis of variance table for the main effect of FYM and blended NPS fertilizer on yield, yield component and quality parameters of potato at Debre Berhan during 2019 crop season

FYM (tha^{-1})	MTN	ATW	MTY	TTY	PDM	SG	SC
30	20.62^{a}	74.65^{a}	24.5^{a}	27.9^{a}	20.66^{d}	1.070^{d}	11.89^{d}
20	17.42^{b}	62.68^{b}	19.58^{b}	24.0^{b}	21.45^{c}	1.083^{c}	14.4^{c}
10	16.36^{b}	55.94^{c}	$18.6b^{c}$	23.32^{b}	22.54^{b}	1.090^{b}	15.84^{b}
0	14.25^{c}	50.0^{d}	17.67^{c}	22.68^{b}	23.45^{a}	1.093^{a}	16.52^{d}
CV	8.53	4.77	9.39	7.75	2.7	0.19	3.01
NPS ($kgha^{-1}$)							
180	19.5^{a}	67.85^{a}	22.49^{a}	26.55^{a}	20.25^{d}	1.079^{d}	13.62^{d}
120	18.10^{b}	64.00^{b}	20.87^{b}	25.16^{ab}	21.37^{c}	1.082^{c}	14.29^{c}
60	16.58^{c}	60.46^{c}	19.72^{b}	24.24^{b}	22.66^{b}	1.084^{b}	14.67^{b}
0	14.45^{d}	51.00^{d}	17.34^{c}	21.96^{c}	23.83^{a}	1.091^{a}	16.04^{a}
CV	8.53	4.77	9.39	7.75	2.7	0.19	3.01

Where: MTN=Marketable tuber number $plant^{-1}$, ATW= Average tuber weight (g $plant^{-1}$), MTY=Marketable tuber yield (tha^{-1}), TTY=Total tuber yield (tha^{-1}), PDM = Percent dry matter (%), SG=Specific gravity of tuber (g/m^3) and SC= Starch content of the tuber (g/100g). Values connected by the different letter across a column are significantly different at the 5% significance level

Appendix Table 4: The amount of rain fall (mm), minimum and maximum temperature (^0C) at Debre Berhan during 2019 crop season

Months	2010-2019 Metrological data			2019 Metrological data	
	Monthly Mean Rainfall (mm)	Mean Minimum Temperature (^0C)	Mean Maximum Temperature (^0C)	Mean Minimum Temperature (^0C)	Mean Maximum Temperature (^0C)
January	3.6	10.5	25.6	9.8	26.4
February	7.9	22.8	28.1	12.6	27.8
March	27.6	26.2	28.9	14.5	28.5
April	46.4	28.1	29.1	15.6	28.4
May	159.4	28.2	26.6	16.1	27.9
June	182.1	26.6	23.9	14.9	24.1
July	380.3	25.1	20.5	14.1	21.3
August	359.7	24.8	20.2	13.7	20.5
September	208.6	24.7	21.7	13.9	21.2
October	75.2	21.7	22.6	11.8	22.6
November	27.1	20.2	22.8	12.4	22.7
December	10.8	18.8	23.6	10.6	23.4
Sum	1488.7	-	-	-	-
Average	-	23.14	24.4	13.3	24.