



**EFFECT OF COMBINED APPLICATION OF FARMYARD MANURE AND
INORGANIC FERTILIZER (NP) SOURCE ON YIELD AND QUALITY
OF POTATO (*Solanum tuberosum* L.) IN HADIYA ZONE, DUNA DISTRICT,
SOUTHERN ETHIOPIA.**

MSc. THESIS

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HAWASSA UNIVERSITY

COLLEGE OF AGRICULTURE

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COLLEGE OF AGRICULTURE

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This is to certify that the thesis entitled “**effect of combined application of farmyard manure and inorganic fertilizers (NP) source on yield and quality of potato (*Solanum tuberosum* L.) in Hadiya zone Duna District Southern Ethiopia** “submitted in partial fulfillment of the requirements for the degree of **Master of science** with specialization in **Horticulture** the Graduate Program of the School of **Plant and Horticultural Sciences** and has been carried out by **Demeke Woemebo Selato** under my/our 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 well acknowledged. Therefore I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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DEDICATION

I dedicate this thesis to my friends and all family members, for nursing me with affection and love for their dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOUR

I declare that this thesis is my original work and all sources of materials used for this Thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Demeke Woemebo Selato
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Date

Place: Hawassa University, Hawassa

Date of Submission _____

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LISTS OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of variance
CEC	Cat-ion Exchange Capacity
CIMMYT	Centro International De Mesoramiento De Maiz Y Trigo
CSA	Central Statistical Agency
CV	Coefficient of variation
FAO	Food and Agricultural Organization
FYM	Farmyard Manure
LSD	Least of significant difference
INM	Integrated Nutrient Management
MoARD	Ministry of Agriculture and Rural Development
NP	Nitrogen and phosphorus fertilizer
P ₂ O ₅	Diphosphorus Penta Oxide
RCBD	Randomized Complete Block Design
RDF	Recommended dose of fertilizer
RNP	Recommended Nitrogen and phosphorus fertilizer
SAS	Statistical Analysis Software
SNNPRS	South Nations Nationalities and Peoples Region Stases

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Effect of Combined Application of Farmyard Manure and Inorganic Fertilizer (NP) Source on Yield and Quality of Potato (*Solanum tuberosum* L.) in Hadiya zone Duna District, Southern Ethiopia.

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ABSTRACT

Potato (Solanum tuberosum.L) is one of the most important tuber crops produced in southern Ethiopia. However, production and productivity of the crop is far below the world average due to inappropriate agronomic management practices including nutrient management. An experiment was conducted to study the effect of combined application of farmyard manure (FYM) and inorganic fertilizer (NP) on yield and quality of potato. Treatments consisted of five levels of NP (0, 25, 50, 75 and 100% of recommended NP) and four levels of FYM (0, 5, 10 and 15 t ha⁻¹). The treatments were assigned in completely Randomized Block Design (RCBD) with a 5x4 factorial arrangement with three replications. Data were collected on growth, yield and quality parameters and analyzed using SAS 9.0 software. Results revealed that most of the growth, yield and quality parameters such as, plant height, days to flowering, main stem number, days to physiological maturity, total tuber number, marketable tuber number, total tuber yield, marketable tuber yield and specific gravity were influenced by the main effect of inorganic NP and farmyard manure. The result also indicated that interaction effect of inorganic NP and farmyard manure significantly affected unmarketable tuber yield, aboveground fresh yield, aboveground dry yield, large sized tuber (%), Medium sized tuber (%) and Dry matter content. The highest aboveground fresh yield, highest aboveground dry yield, highest large sized tuber and medium sized tuber were obtained from application of 100% inorganic NP with 15t ha⁻¹ farmyard manure. While the lowest values of parameters were recorded from the control treatment. Further, the highest marketable yield, total tuber yield and highest tuber dry biomass were obtained from each of 15 t ha⁻¹ FYM and 100% NP fertilizer. From economics point of view, the maximum marginal rates of return (2446.90%) with its net benefit value of 190,128 ETB ha⁻¹ was recorded from the application of 10t ha⁻¹ farmyard manure. With regard to inorganic fertilizer 50% of recommended NP showed the highest marginal rate of return (1176.14%) with a net benefit of 167645ETB. Therefore, farmers in the study area can apply 10t ha⁻¹ farmyard manure or 50% of recommended inorganic NP fertilizer.

Key words: Manure, Phosphorus, Tuber, Quality

1. INTRODUCTION

Potato (*Solanaum tuberosum* L.) belongs to the family *Solanaceae* and genus *Solanum* (Haward, 1969). It is cool-season crop, most dependable and early maturing among root and tuber crops. Potato tuber consists of largely carbohydrates, proteins, and lipids. The tuber is used alone locally or with meat, and vegetables as substituent with pulse in stew preparation in Hadiya Zone, Southern Ethiopia. The potato is one of the broadly grown and major cultivated tuber crops in the area. It is a preferable crop in the study area since that it can be produced more than twice per year (Israel *et al.*, 2018).

Low yield of potato in Ethiopia is related to different factors, such as poor soil fertility (for example, low level of organic matter and /or low pH, binding of phosphorus and not mineralizing nitrate), and sub-optimal fertilizer application rates are most determining factors (Haverkort *et al.*, 2012). Soil fertility reduction owing to high rates of erosion is considered to be the basic biophysical root cause for declining per capita food production in Africa, including Ethiopia in the fields of smallholders (Tesfaye *et al.*, 2011). Potato demands high levels of soil nutrients due to its relatively poorly developed, coarse, and shallow root system (Nigussie *et al.*, 2003). The crop produces much more dry matter in a shorter life cycle that results in large amounts of nutrients detached per unit time, which generally most of the soils are not able to provide (Islam *et al.*, 2013).

Potato was introduced to Ethiopia in the 19th century by a German Botanist called Schimper (Horton, 1987). Since then, potato has become an important garden crop in many

Parts of Ethiopia and it ranks first among root and tuber crops in volume produced and consumed followed by Cassava, Sweet potato and Yam (CSA, 2018). It is a high potential food security crop in Ethiopia due to its high yield potential, nutritional quality, short growing period and wider adaptability (Tewodros *et al.*, 2014). It has been cultivated in Ethiopia for over 150 years; currently it is grown in many parts of the country. According to FAO in Ethiopia, its production area has reached about 69,610.81ha, total production of 9,689,696.44 quintal cultivated by over 1,127,467.00 households). On the other hand, the productivity of this crop in the country is very low (13.9 t ha^{-1} compared to the world's average yield of 38 t ha^{-1}) (CSA, 2018).

Inappropriate agronomic management practices insufficient and inappropriate application of fertilizers, low nutrient reserves in arable soils, and a harmful nutrient balance on crop land by potato growers are the major factors contributing to the potato yield reduction in the study areas. Potato is one of the heavy feeders of fertilizers. However, scarcity of chemical fertilizers coupled with lack of supplementing with organic sources made potato production difficult and inefficient. The high cost of chemical fertilizers and limited availability for the smallholder farmers accompanied with a high amount of rainfall that might have caused leaching of macro and micro-nutrients significantly reduced soil fertility and crop productivity in the study area (Mahajan *et al.*, 2008).

Soil organic and inorganic fertilizers are important for agricultural sustainability because of their possible beneficial effects on soil properties and long-term soil productivity. Several studies have been conducted to assess the effects of soil organic and inorganic fertilizers on

soil properties and crop yields, and different agronomic and environmental outcomes have been observed depending on the specific agro- ecosystem (Saha *et al.*, 2008). Some of the primary effects of use of organic fertilizers are increased soil organic matter (SOM) and improved soil properties for crop growth (Hati *et al.*, 2006; Saha *et al.*, 2008).

Among the benefits of maintaining or increasing soil organic matter are increased soil water-holding capacity, improved soil structure for root growth and drainage, accelerated rates of nutrient cycling (Garcia-Gil *et al.*, 2000) and higher content of soil nutrients over a longer Period of time, increased CEC and greater soil biological activity (Woomer *et al.*, 1994). These changes in soil properties improve soil quality and the long-term sustainability of agro ecosystems (Gupta *et al.*, 1994). Cultivation of soil, especially through tillage affects soil physical properties by altering soil structure and promoting loss of SOM. However, these potentially negative impacts of tillage can be minimized by adding large amounts of crop residues (Karlen *et al.*, 1994) or organic fertilizers, such as farm manure (Mando *et al.*, 2005).

The excessive use of mineral fertilizers has caused adverse effect on soil nutrient balances and, thus reduced plant growth performance. This further justifies the need to use organic fertilizers. Animal manure is commonly used on higher value commodities such as potato, coffee, and vegetables (Freeman and Coe, 2002; Shapiro and Sanders, 2002).

Low soil fertility is one of the factors limiting the productivity of potato in Hadiya Zone, (Berga *et al.*, 1994). Traditionally, farmers in the study area used to maintain or improve the fertility of farmland soils by practicing fallowing, use of farmyard manure, intercropping and/or crop rotation. Moreover, with rapid population growth, fallow periods practiced in the

study area in particular and in the country in general were replaced by continuous and intensive cropping without restoration of the soil fertility that has depleted the nutrient base of most soils.

1.1 Statement of Problem

Duna District is one of the potential potato producing areas in Hadiya Zone Southern Ethiopia, as it has suitable soil and climatic conditions. About 2,096.16 ha of land in the district were covered by potato with average productivity of 13.7 t ha⁻¹ (CSA, 2017), which is very low compared to world productivity (38 t ha⁻¹) of potato. Although fragmented researches were conducted in the area for nutrient management and other agronomic practices, there is no an absolute recommendation for the use of inorganic (NP) and farmyard manure (FYM) fertilizers for potato production. As a result, soil nutrient management practices in the district is based on traditional practices and experiences, Hence, information is lacking on the site specific recommendation on inorganic NP and farmyard manure fertilizer rates. This remains problem for local farmers to improve potato production and productivity.

Therefore, it is necessary to study the response of potato to inorganic (NP) and FYM fertilizers under this specific agro-ecology to come up with appropriate fertilizer recommendations. This will to help farmers to increase productivity of the potato in the area. In view of this, the study was conducted at Duna District with the following objectives

1.2 Objective

1.2.1 General objective

- To study the effect of combined application of farmyard manure and inorganic (NP) fertilizer on yield and quality of potato in Hadiya Zone, Duna District.

1.2.2 Specific objective

- To determine effect of farmyard manure (FYM) and inorganic (NP) fertilizer on growth, yield and quality of potato in Hadiya Zone, Duna District.
- To determine optimum and economically feasible rate of farmyard manure and/or inorganic (NP) fertilizer for potato production in Hadiya Zone, Duna District.

2. LITERATURE REVIEW

2.1 Origin and Importance of the Potato

Potato (*Solanum tuberosum* L.), which belongs to the family *Solanaceae*, is the fourth most important food crops in the world in terms of area of production following rice, corn and wheat (Horton,1987; FAO,2008). It is a crop with high potential to contribute to poverty reduction and becoming an important food crop in Ethiopia. The potato crop can contribute to improving food and nutritional security. It is regarded as a high potential food security crop for densely populated highland regions because of its ability to provide a high yield per unit input with a short crop cycle than major cereal crops (Hirpa *et al.*, 2010). The potato is one of mankind's most valuable food crops between root crops, potato ranks first in volume produced and consumed, followed by cassava, sweet potato, and yam. The relatively high carbohydrate and low fat content of the potato makes it an excellent energy source for human consumption (MoARD, 2012). The potato crop covers 69,923.33 hectare in area of production in Ethiopia and 2,096.16 hectare in Hadiya Zone (CSA, 2017).

A potato tuber comprises 78 percent water, 18 percent starch and the rest are proteins, minerals and vitamins. The fat content is only 0.1 percent potato though not a very rich source of protein (2 percent); it is an important source of essential amino acids like lysine, methionine cysteine, phenylalanine, tryptophan etc. The biological value of potato protein is 71 percent that of the whole egg protein. Potato is also an important source of minerals like calcium, potassium, phosphorus, magnesium and iron and vitamins like B1, B2, B6 and C.

Daily consumption of an average sized potato provides 45 percent of vitamin C, 10 per cent of thiamin, 8 percent of niacin, 14 percent of vitamin B6, 14 percent folacin, 6 percent phosphorus, 12 percent magnesium and 9 percent of iron requirement. Further, potato produces more dry matter and more calories per unit area of land and time than any other major food crop. The problem of malnutrition and under nutrition of the underdeveloped world can, therefore, be solved to a large extent if potato is accepted as a principal food crop and not merely as a vegetable (Dhaliwal, 2017)

2.2 Ecological Requirement of Potato

Potato is weather sensitive crop with wide difference among cultivars. It is a temperate climate crop and it is fairly tolerant to frost. Elevations range between 1800 to 2500 meters above sea level is regarded as suitable for seed and ware potato production (Woldegiorgis, 2012). On the other hand, recently released cultivars are performing well at intermediate elevation in Ethiopia (Adamu and Asnakech, 2010). A rainfall ranging between 500 and 750 mm uniformly distributed during the growing period is required for best growth (Stol *et al.*, 1991). Irrigation is required where rainfall is variable (Makani *et al.*, 2013).

2.3 Soil Fertility in Response to Integrated inorganic (NP) Fertilizer and Farmyard Manure.

Intensification of agriculture can have negative consequences such as increased erosion, reduced biodiversity and a reduction in soil organic matter content resulting in a decline in the quality of agricultural soils (Hosea *et al.*, 2012). The organic matter content of cultivated soils of the sub-tropics is comparatively low because of high temperature and intense

microbial activity (Patra *et al.*, 2007). This requires application of external nutrients inputs via inorganic fertilizers and legumes, in combination with effective recycling of nutrients in production systems by means of proper handling and utilization of animal manure, leaving some portion of crop residues during harvest, biodegradable waste and green manure crops (Paul *et al.*, 2013). For sustainable crop production, integrated use of inorganic and organic fertilizers has proved to be highly beneficial (Gruhn *et al.*, 2000).

Integrated application of organic and mineral fertilizers helps to improve the physico-chemical properties as well as biological properties of soils (Swift *et al.*, 1994). Several researchers have demonstrated the beneficial effect of the combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years without any micronutrient or organic fertilizer (Hosea *et al.*, 2012). Dutta *et al.* (2003) reported that the use of organic fertilizers together with chemical fertilizers resulted in a higher positive effect on microbial biomass and hence soil organic matter compared to the addition of organic fertilizers alone. According to Silva *et al.* (2004), cattle manure increased water retention and availability of phosphorus, potassium and sodium contents in the soil layer from 0-20 cm, but did not influence pH, calcium, sum of bases and organic matter contents.

The application of manure can contribute to agricultural sustainability. Kaur *et al.* (2005) reported that soils receiving FYM, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers improved the soil organic C, total N, P and K status and increased microbial biomass, C and N. Evaluations of integrated supply of FYM and

mineral NPK fertilizers along with *Sesbania* green maturing for seven years on fertility build-up and nutrient uptake in a mint (*Mentha arvensis*) and mustard (*Brassicajuncea*) cropping sequence indicated that integrated supply of organic and mineral fertilizers played a significant role in sustaining soil fertility and crop productivity (Chand *et al.*, 2006). Many reports in the literature have showed that continuous use of sole artificial fertilizer nutrient sources may lead to shortage of nutrients not supplied by the chemical fertilizers which will in turn lead to chemical soil degradation (Mafongoya *et al.*, 2006).

On the other hand, sole application of organic matter is constrained by low availability of N to the current crop, low or imbalanced nutrient content, unfavorable quality and high labor demands for transporting bulky materials (Palm *et al.*, 1997). The low phosphorus content of most organic materials indicates that in the long term addition of external sources of P will be needed to sustain crop productivity. The alternative is to combine application of organic matter and fertilizer so that improved crop yields are maintained without degrading soil fertility status (Swift *et al.*, 1994). Furthermore, to reduce the amounts of increasingly expensive inorganic P fertilizers, the combined application of P fertilizer and organic resources such as organic manure, crop residues, and other rural and urban organic wastes has frequently been suggested (Khan and Joergensen, 2012).

2.4 Integrated Nutrient Management in Potato

A lot of research findings have shown that neither mineral fertilizers nor organic sources alone can result in sustainable productivity (Satyanarayana *et al.*, 2010). Furthermore, the price of mineral fertilizers is increasing and becoming unaffordable for resource poor

smallholder farmers. The best remedy for soil fertility management is therefore, a combination of both mineral and organic fertilizers, where the mineral fertilizer provides readily available nutrients and the organic fertilizer mainly increases soil organic matter and improves soil structure and buffering capacity (Yadavsak *et al.*, 2017). The combined application of mineral and organic fertilizers, usually termed as integrated nutrient management, is widely recognized as a way of increasing yield and or improving the productivity of the soil sustainably (Simon *et al.*, 2019). Several researchers Agegnehu *et al.* (2009) have verified the beneficial effect of integrated nutrient management in moderating the deficiency of a number of macros- and micro-nutrients. In view of this fact, identifying the optimum dose of integrated nutrients application is crucial and is required for maintaining sufficient amount of nutrients for increased yield of the crop.

Incorporated nutrient management is an approach that seeks both increased agricultural production and maintains the environment for future generation. It is a strategy that incorporates both organic and inorganic plant nutrients to attain higher crop productivity, prevent soil degradation, and thereby help meet future food supply needs. The residual effect was more pronounced with integrated use of inorganic (NP) fertilizers and organic manures. Furthermore, integrated nutrient management needed for proper plant growth, together with effective crop, water, soil and land management, will be critical for sustaining agriculture over the long term (Lander *et al.*, 1998). Vegetable crops put tremendous pressure on soil for nutrient demand because of their high productive and nutrient mining. As such, generous application of fertilizers is needed to meet their nutritional requirements. However, in the wake of energy crisis and the ever-increasing price of chemical fertilizers, there is a need to

reduce the dependence on such a costly input. This can be accomplished through an integrated nutrient management which involves conjunctive use of chemical fertilizers and organic manures to sustain crop production and maintenance of soil health (Srivastava *et al.*, 2012). Organic manures supply traces of micronutrients which are not supplied by chemical fertilizers (Gopinath *et al.*, 2008).

2.5 Effect of Combined Application of FYM and Inorganic Fertilizer on Potato

Combined application of farmyard manure with inorganic (NP) increased the tuber yield as compared to the application of organic or inorganic fertilizers in isolation. Application of farmyard manure with inorganic fertilizers (NP) increased tuber yield over control by 393.9%. Yield advantage achieved by application of farmyard manure with inorganic (NP) fertilizer was higher by 136.2 and 38.3% over farmyard manure and inorganic (NP) fertilizer alone, respectively. The higher benefits from combined applications might be attributed, in part, to enhanced fertilizer recovery (increased uptake) due to increased soil physical and chemical properties as a result of increased soil organic matter. Besides increasing soil physical and chemical properties, by providing macro and micronutrient organic manure improve crop production (Shiferaw, 2014).

Application of recommended mineral fertilizers does not improve the negative nutrient balance due to the higher nutrient removal from the soils (Drechsel *et al.*, 2001). Many researches recommend integrated soil amendment practices because single application or practices could not reverse the existing problem (Eichler *et al.*, 2007). It is crucial to note that greater crop productivity induced by the use of mineral fertilizers does not translate into

better soil fertility in the long term when large amounts of carbon and nutrients are removed every season from the fields with the crop harvests residue (Bekunda *et al.*, 2010). Lander *et al.* (1998) reported that the application of integrated nutrient management is very important and best approach to maintain and improve soil fertility thereby to increase crop productivity in an efficient and environmentally friendly manner without sacrificing soil productivity of future generations.

2.6 Response of Potato to Nitrogen Fertilizer

Nitrogen (N) is very vital nutrient in potato production that the value of the other inputs cannot be fully realized unless N is applied to the crop in an optimum amount (Grewal *et al.*, 1993). Several N fertilization rates have been advised as optimum for potato production in some European countries and the USA. Potatoes need high amount of nutrients in order to produce high quantity of tubers per unit area (Nigussie *et al.*, 2003). Plant tissues usually contain more N than any other nutrient usually applied as a fertilizer. Nitrogen is an integral component of many essential plant compounds. It is a major part of all amino acids and many other molecules essential for plant growth and other critical nitrogenous plant.

Both leaf maturation and tuber separation are delayed and the length of tuber bulking period, yield and tuber dry matters are reduced (Goffart *et al.*, 2008). Conversely, a lack of N restricts the growth of all plant organs, roots, stems, leaves, flowers, fruits including seeds and plants become underdeveloped and yellow in appearance (Barker and Bryson, 2007). Shortage of N also restricts tuber size due to reduced leaf area and early defoliation (Goffart *et al.*, 2008).

Which are important sources bulking the tuber Nitrogen provide also play an essential role in the balance between vegetative and reproductive growth for potato (White *et al.*, 2007). Nitrogen fertilization has been reported to enhance the average fresh tuber, plant height, leaf number and tuber weight per plant (Kandil, 2011).

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

2.7 Response of Potato to Phosphorus Fertilizer

Phosphorus (P) is an important plant macronutrient, making up about 0.2-0.5% of a plant's dry weight and it is second only to N as the most limiting element for plant growth (Bielecki, 1973). Phosphorus is present to some extent in all soils and unlike nitrogen it is held tightly by soil particles and therefore it is not easily leached from the soil. However, because of its non-availability in the water soluble form, it is usually not available to plants in the amounts needed, which means that extra phosphate fertilizer should be applied (Reiley and Shry, 1979).

Elevated phosphorus applications are particularly necessary in tropical and subtropical areas where soils are of lateritic and similar types which as a rule are very poor in phosphate (DeGeus, 1973). But, after application, a considerable amount of P is rapidly transformed into less available forms by forming complexes with Al or Fe in acid soils (Norrish and

Rosser, 1983) or Ca in calcareous soils (Lindsay *et al.*, 1989) before plant roots have had a chance to absorb it. However, the use of rock phosphate as a phosphate fertilizer and its solubilization by microbes, through the production of organic acids (Maliha *et al.*, 2004), have become a valid alternative to chemical fertilizers.

The physical and chemical properties of soil were reported to influence the solubility of P and its adsorption reaction in soils. These include the nature and amount of soil minerals, soil pH, cat-ion effect, anion effects, extent of P saturation, reaction time and temperature, flooding, and fertilizer management (Tisdale *et al.*, 1995). Moreover, availability of P from fertilizer may be affected by the soil reaction, the degree of soil P deficiency, rate and method of application, needs of the specific crops and certain soil differences.

Phosphorus is basically an immobile nutrient and sustained application of phosphate fertilizers tends in time to increase the levels of this nutrient in the soil and particularly its level in the liable forms that can release phosphorus to the soil solution (Brady, 1990). On soils containing sub-optimum levels of available phosphorus, potato crops show economic responses to the application of phosphate fertilizer (Johnston *et al.*, 1986) and, as a result, relatively large amounts are applied in commercial practice. Surprisingly, very few studies have attempted to analyze the mechanism by which this nutrient influences crop growth although some reports have suggested that adequate levels of P promote early leaf canopy growth but may advance senescence (Dyson, Watson, 1971 and McCollum, 1977). Such responses might be expected to influence the temporal patterns of radiation interception, and

there by dry matter accumulation (Allen and Scott, 1980) under varying conditions of P supply.

2.8 Effect of farmyard Manure on Potato

Application of farmyard manure had absolutely influence on vegetative growth characters of potato plants (Ahmed. *et al.*, 2011). 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 only may not fully satisfy crop nutrient demand, especially in the year of application (Patel *et al.*, 2009). Animal manures are also helpful in improving the efficiency of fertilizer recovery thereby resulting in elevated crop yield (Gedam *et al.*, 2008). Organic material is used to prevent or improve the negative stresses effects in plants and yield decreasing. It is material to decrease soil salinity, increase the organic matter, improve the soil structure and increase water and air permeability by root developing in soil. It is one the best used fertilizers (Anonymous, 2010).

The application of organic manure as a fertilizer in less developed countries like Ethiopia has received much attention from economic point of view. Organic fertilizers were regarded as important, but it was realized that organic fertilizers would not be available in sufficient amounts to increase food production drastically (Place *et al.*, 2003). Farmyard manure and solid bio-slurry not only provide nutrients for crops but also increasing ability to transform difficultly decayed compounds into soluble elements to provide nutrients to plants, most obviously in the metabolisation of phosphorus compounds in the soil by improving soil pH.

2.9 Yield and Dry Matter Content in Response to Nutrient Management of Potato

Marketable yield is a function of total biomass production, the percentage of biomass that is partitioned to the tubers, the moisture content of the tubers and the proportion of tubers that are acceptable to the market, in terms of size and lack of defects (Ewing, 1997). Great opportunities exist to increase potato yield and quality by improving nutrient management. Potato demands high level of soil nutrients due to relative poorly developed and shallow root system in relation to yield (Perrenoud, 1993). Dry matter content in potato tubers depends on the environmental condition and their changes; however, the highest possible amount of dry matter is limited by genetic characteristics of the potato variety. Potatoes are plants with a long vegetation period; therefore they assimilate nutrients from organic and mineral fertilizers rather intensively. Content of dry matter, starch, protein, sugar in potato tubers can increase or decrease, depending on the mineral fertilizers forms and rates as well as their correlation (Makaraviciutte, 2003).

Compared with cereal crops, potato produces much more dry matter in a short cycle (Singh and Trehan, 1998). The same authors stated that this high rate of dry matter production results in large amounts of nutrients removed per unit time, which generally most of the soils are not able to supply. According to Tekalign and Hammes (2005), dry matter production and distribution are crucial processes in determining crop productivity. Hence, nutrient application from external sources as fertilizer becomes essential. The amount of nutrients taken up by potato depends on the amount of dry matter produced. This in turn is influenced

by a number of genetic and environment variables. Dry matter production and nutrient uptake are very closely related (Hegde, 1993).

2.10 Effect of Fertilizer on Specific Gravity Potato Tuber

Specific gravity is the measure of choice for estimating dry matter, total solids and starch content and ultimately for determining the processing quality of potato varieties (Tesfaye *et al.*, 2013). There is a very high correlation between the specific gravity of the tuber and the starch content and also the percentage of dry matter or total solids (Tekalign and Hammes, 2005). Fertilizer application has important effects on the quality of potato (Westermann, 2005). Excess usage of fertilizers reduces tuber quality. Kleinkopf *et al.* (1981) reported that the specific gravity of tubers decreased with increasing rates of N fertilizer. This appears to be a reflection of the delay in maturity due to high nitrogen treatment. After a long series of field experiments in the USA, Kunkel and Holstad (1972) concluded that specific gravity of potato often decreased with increasing levels of N and P. Contrary to this, Gautam *et al.* (2013) noted non-significant difference in specific gravity of tubers due to N treatment.

Similarly, Abo-Sedra and Shehata (1994) reported that specific gravity of potato tubers is not affected by the application of nitrogen at the rate of 180 kg N ha⁻¹. On the other hand, Kara (2002) who reported the positive effects of nitrogen fertilization on specific gravity of potato tubers while phosphorus doses has not affected this parameter. A combined application of FYM at 5 t ha⁻¹ with 200kg K₂O ha⁻¹ resulted in higher specific gravity as compared to potassium fertilizer alone and controls (Pervez *et al.*, 2000). Kandil *et al.* (2011) found the

highest specific gravity after harvest where 60% mineral nitrogen (238 kg N ha⁻¹) was combined with 40% organic chicken manure (158 kg N ha⁻¹).

2.11 Economic Values of Integrated Nutrient Management

The effect of increased combined rate was found highly significant on yield parameters such as Marketable tuber number and total number and average tuber weight (Israel *et al.*, 2018). In term of profitability, evidence of positive returns is often found for integrated mineral organic system (Place *et al.*, 2002). For example, the integration of manure and fertilizer on potato in Ethiopia resulted in net maximum benefit of about 171,596 birr per hectare, while the best single fertilizer without manure treatment yielded only 24,450 birr per hectare (Biruk *et al.*, 2015). The profitability of alternative nutrient input sources depends not only on yield gains but also on market conditions; as underscored by generally greater use on higher valued commodities (Place *et al.*, 2003). Several studies have found that the poor farmers' inability to access mineral fertilizers has adverse consequences on soil fertility and incomes.

3. MATERIALS AND METHODS

3.1 Description of the Study Site

The experiment was conducted in Duna District Hadiya Zone, Southern Ethiopia during April to July in 2019, It is located about 274 km away from Addis Ababa, 217 km from regional city of Hawassa and 42 km from Hossana Adimistiretive city of Hadiya Zone .The experimental area is found at $07^{\circ} 20' 21''$ N and $37^{\circ} 36' 40''$ E. The altitude of the area is 2608 meter above sea level (masl). The area receives an annual rainfall of 801-1800 mm in bi-modal pattern which extend from March to September and the mean annual maximum 24°C and minimum 12°C temperatures with nitisol soil type (ATA, 2016).

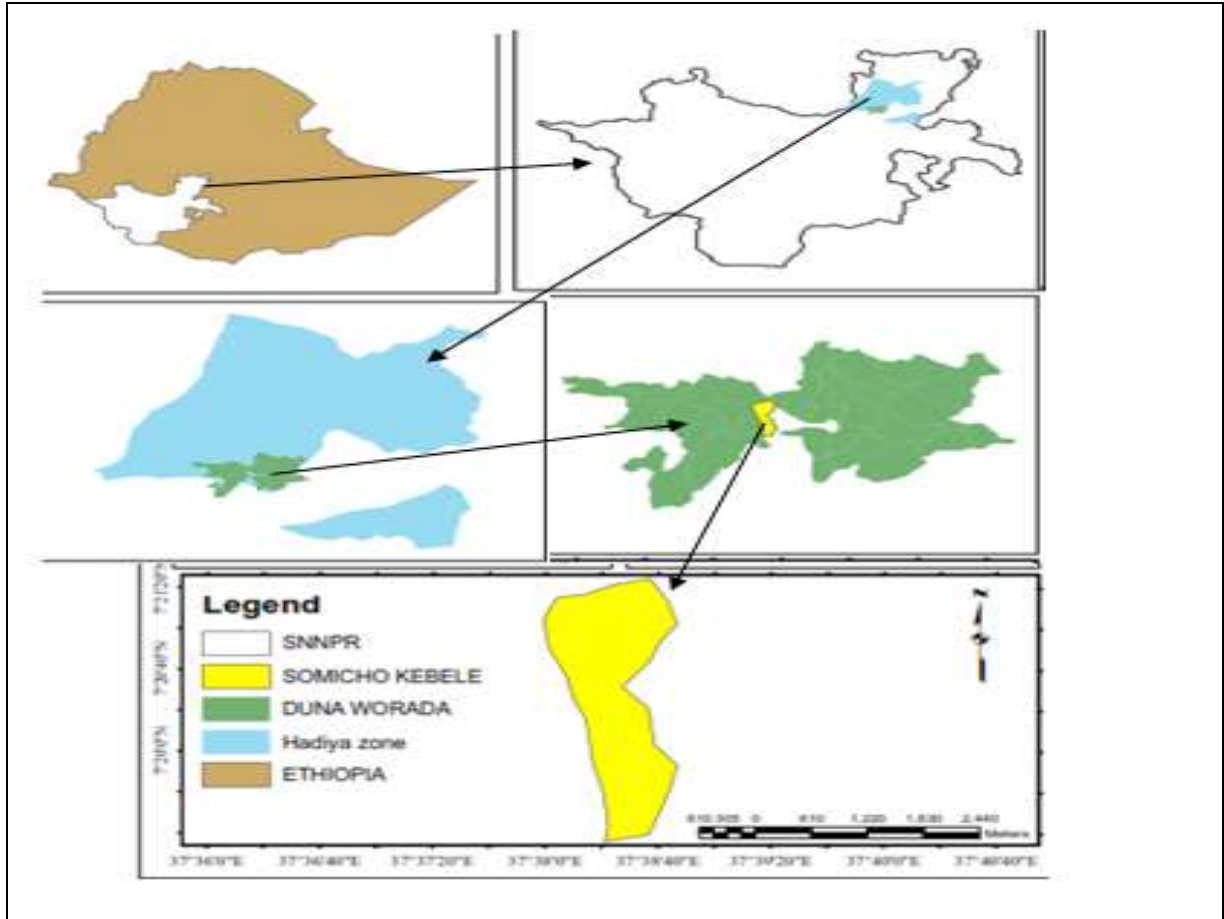


Figure 1 Location map of study area

3.2 Experimental Materials

The improved potato variety called ‘Gudanie (CIP-386423-13) was used for this study (test crop). The variety was released by the Holletta Agricultural Research Center (HARC) in 2006 (MoARD, 2009). This variety is the prominent variety adapted and selected for Hadiya Zone. It has wide-range environmental adaptation in Ethiopia. The variety requires up to 120 days for physiological maturity and considered moderately resistant to the late blight disease (Woldegiorgis *et al.*, 2008). Nitrogen in the form of urea (46% of N) and phosphorous in the

form of TSP (46% P_2O_5) was used as inorganic fertilizer and farmyard manure was bought from the licha dairy farm.

3.3 Treatments and Experimental Design

Factorial combination of five levels of recommended inorganic (NP) fertilizer (0, 25% (27.75N kg ha⁻¹ and 22.5 P_2O_5 kg ha⁻¹), 50 % (55 N kg ha⁻¹ and 45 P_2O_5 kg ha⁻¹), 75% (83.25 kg N ha⁻¹ and 67.5 P_2O_5 kg ha⁻¹), and 100 % (111N kg ha⁻¹ and 90 P_2O_5 kg ha⁻¹) and four levels of farmyard manure(FYM) (0, 5,10 and 15 t ha⁻¹) arranged in a randomized complete block design (RCBD) with three replications. Each block and plot within block was spaced 1 m and 0.5 m apart respectively .Each plot was divided in to seven rows of 75 cm apart, the spacing between plants was 30 cm. The gross plot size was therefore, 3m × 5.25m (15.75m²).In each plot, one plant at the end of each row was left to avoid the border effect and from each plot the four central rows were considered for yield and quality.

Table 1. Treatment Combination.

Trt	Description					
	Inorganic(NP) + Farmyard manure	Inorganic (NP) fertilizer	FYM		Total	
		N + P ₂ O ₅ kg ha ⁻¹	N kg ha ⁻¹	P ₂ O ₅ kg ha ⁻¹	N kg ha ⁻¹	P ₂ O ₅ kg ha ⁻¹
T1	Control(0 t ha ⁻¹ + 0% RNP fertilizer	0 N kg+0 P ₂ O ₅ kg	0 kg	0kg	0	0
T2	0 t ha ⁻¹ FYM + 25% RNP fertilizer	27.75 N kg+22.5 P ₂ O ₅ kg	0 kg	0kg	27.75	22.5
T3	0 t ha ⁻¹ FYM + 50% RNP fertilizer	55.5 N kg + 45 P ₂ O ₅ kg	0 kg	0kg	55.5	45
T4	0 t ha ⁻¹ FYM + 75% RNP fertilizer	83.25 N kg+ 67.5 P ₂ O ₅ kg	0 kg	0kg	83.25	67.5
T5	0 t ha ⁻¹ FYM + 100% RNP fertilizer	111 N kg + 90 P ₂ O ₅ kg	0 kg	0kg	111	90
T6	5 t ha ⁻¹ FYM + 0% RNP fertilizer	0 N kg + 0 P ₂ O ₅ kg	3.5 kg	32.5kg	3.5	32.5
T7	5 t ha ⁻¹ FYM + 25% RNP fertilizer	27.75 N kg + 22.5 P ₂ O ₅ kg	3.5 kg	32.5kg	31.25	55
T8	5 t ha ⁻¹ FYM + 50% RNP fertilizer	55.5 N kg + 45 P ₂ O ₅ kg	3.5 kg	32.5kg	59.0	77.5
T9	5 t ha ⁻¹ FYM + 75% RNP fertilizer	83.25 N kg + 67.5 P ₂ O ₅ kg	3.5 kg	32.5kg	86.75	100
T10	5 t ha ⁻¹ FYM + 100% RNP fertilizer	111 N kg + 90 P ₂ O ₅ kg	3.5 kg	32.5kg	114.5	122.5
T11	10 t ha ⁻¹ FYM + 0% RNP fertilizer	0 kg + 0 kg	7 kg	65kg	7	65
T12	10 t ha ⁻¹ FYM + 25% RNP fertilizer	27.75 N kg + 22.5 P ₂ O ₅ kg	7 kg	65kg	34.75	87.5
T13	10 t ha ⁻¹ FYM+ 50% RNP fertilizer	55.5 N kg + 45 P ₂ O ₅ kg	7 kg	65kg	62.5	110
T14	10 t ha ⁻¹ FYM + 75% RNP fertilizer	83.25 N kg +67.5 P ₂ O ₅ kg	7 kg	65kg	90.25	132.5
T15	10 t ha ⁻¹ FYM + 100% RNP fertilizer	111 N kg+ 90 P ₂ O ₅ kg	7 kg	65kg	118	155
T16	15 t ha ⁻¹ FYM + 0% RNP fertilizer	0 + 0 kg	10.5 kg	97.5kg	10.5	97.5
T17	15 t ha ⁻¹ FYM + 25% RNP fertilizer	27.75 N kg + 22.5 P ₂ O ₅ kg	10.5 kg	97.5kg	38.25	120
T18	15 t ha ⁻¹ FYM + 50% RNP fertilizer	55.5 N kg + 45 P ₂ O ₅ kg	10.5 kg	97.5kg	66.0	142.5
T19	15 t ha ⁻¹ FYM + 75% RNP fertilizer	83.25 N kg + 67.5 P ₂ O ₅ kg	10.5 kg	97.5kg	93.75	165
T20	15 t ha ⁻¹ FYM + 100% RNP fertilizer	111 N kg + 90 P ₂ O ₅ kg	10.5 kg	97.5kg	121.5	187.5

Where RNP = Recommended Nitrogen and phosphorus fertilizer, N = Nitrogen, P= Phosphorus, FYM= Farmyard manure, P₂O₅= Phosphorus Penta oxide.

3.4 Experimental Procedures and Crop Management

3.4.1 Land preparation and planting

In order to have a better for proper root development, the experimental field was ploughed and the plots were leveled by hand. A total of 60 experimental plots were used and the required numbers of ridges were marked and ridges were formed by hand. Under sufficient soil moisture, well sprouted medium-sized tubers of the potato tuber was planted on the

ridges at the spacing of 75 cm between ridges and the intra row spacing of 30 cm (Mahmood *et al.*, 2001).

3.4.2 Fertilizer application

The full dose Phosphorous was applied depending on treatments as side banding at planting time. Nitrogen at the specified rates was applied in two times splits in the form of urea (1/2th at plant emergence, 1/2th at mid-stage of vegetative growth (about 40 days after planting). Urea was applied by slightly opening the soil at each hill and cover with soil to prevent loss by volatilization. The decomposed cattle manure was bought from the local dairy farm and full doses which varied depending on treatments were applied before planting.

3.4.3 Other cultural practices

Weeds were controlled by hand picking and hoeing. Earthling-up was done as required to prevent exposure of tubers to direct sunlight and for promoting tuber bulking and for ease in harvesting. Late Ridomil MZ 63.5% WP at the rate of 2 Kg ha⁻¹ and Mancozeb at the rate 3 Kg ha⁻¹ were applied for late blight (EARO, 2004). Field inspection was done at every two days to check the occurrence of disease and pests and necessary measures were undertaken.

3.4.4 Harvesting

The haulms were removed two weeks before harvesting when the plants reached physiological maturity and senesced. This was done to toughen the periderm in order to reduce bruising and skinning during harvesting and post-harvest handling. For yield estimation, tubers were harvested from plants grown in the five middle rows, leaving the

plants growing in the two border rows as well as two plants at both ends of each row to avoid border effects.

3.5 Soil Sampling and Analysis

Before planting, the soil samples were taken by chance in a W-shaped pattern from the entire experimental field of the study site. Ten samples were taken using an auger from each arm of the W-shaped lines of the field from 0-30cm depth. From this mixture, a sample weighing one kg was taken for analysis. Before analysis, the sample soil was air-dried and sieved through a 2mm sieve mesh. The composite soil samples were analyzed for selected physicochemical properties, textural analysis (sand, silt and clay), soil pH, total nitrogen, available phosphorus, cat-ion exchangeable capacity and organic carbon. Farmyard manure was also analyzed for selected chemical composition such as pH, total nitrogen, available phosphorus, cat-ion exchange capacity (CEC) and organic carbon. Using the appropriate laboratory procedures soil texture analysis was performed by Bouyoucous hydrometer method (Day, 1965). Total nitrogen was determined using the Kjeldhal method (Bremner and Mulvancy, 1982). The pH of the soil was measured in water at soil to water ratio of 1:2.5 soil: water ratio using a glass electrode attached to a digital pH meter. Cat-ion exchange capacity (CEC) was measured by ammonium acetate method after saturating the soil with 1 NH₄OAC (Chapman, 1965). Available phosphorous was determined by Olsen *et al.* (1954) method (Appendix 7).

3.6 Data Collected

3.6.1 Phenological parameters

Days to flowering: It was recorded as the number of days from planting to when 50% of the plants in each plot produced flowers.

Days to physiological maturity: It was recorded as the number of day from planting to 90 % of the plants in plots is standing by for harvest as indicated by senescence of leaves and haulms.

3.6.2 Growth parameters

Main stems number per hill: the genuine numbers of main stems per hill were recorded as the average stem count of five hills per plot at 50% flowering. Only stems that emerged independently above the soil from a single hill were considered as main stems. Stems branching from other stems above the soil were not considered as main stems.

Plant height (cm): Ten plants were taken randomly and height was measured with meter from the ground level to the tip of the main stem at full blooming, and average was recorded.

3.6.3 Yield and yield components

Total tuber yield (t ha⁻¹): All tubers from the central rows were harvested and weighed using balance and were converted into ton per hectare basis.

Total tuber numbers per hill: was recorded tuber numbers randomly selected plant.

Aboveground fresh biomass ($t\ ha^{-1}$): Leaves, branches and stems were harvested at maturity from the central rows. Then weighed soon after harvest and converted to $t\ ha^{-1}$.

Aboveground dry biomass ($t\ ha^{-1}$): was obtained after drying the samples taken for determination of the above ground fresh weight in open sun for 7 to 9 days and then oven dried at $72^{\circ}C$ to a constant weight and converted to $ton\ ha^{-1}$.

Tuber dry biomass ($t\ ha^{-1}$): was obtained after drying the samples taken for determination of the tuber fresh weight in open sun for 7 to 9 days and then oven dried at $72^{\circ}C$ to a constant weight and converted to $ton\ ha^{-1}$.

3.6.4 Potato tuber quality parameters

Marketable tuber yield ($t\ ha^{-1}$): The total tubers were harvested from net plot area and free from diseases, not insect attacked and not under sized were sorted and weighed and converted to $ton\ ha^{-1}$.

Unmarketable tuber yield ($t\ ha^{-1}$): Weight of tubers which was harvested from net plot area and separated as insect attacked, diseased, cracked and under sized ($<25\ g$) were measured and converted to $ton\ per\ ha^{-1}$.

Tuber size distribution in weight: At harvest, tubers were collected from two central rows in each plot, and categorized into small ($< 38\ g$), medium ($39-75\ g$) and large ($>75\ g$). Then converted to $ton\ ha^{-1}$ and % for each of the three categories (Lung'aho *et al.*, 2007)

Dry matter content (%): Five fresh tubers were randomly selected from each plot and weighed. The tubers were sliced and dried in oven at 70°C until a constant weight was obtained. The dry weight was recorded and dry matter percent was calculated according to Williams (1968) as:

$$\text{Dry matter (\%)} = \frac{\text{Weight of sample after drying(g)}}{\text{Initial weight of sample(g)}} \times 100$$

Specific gravity of tubers (gcm⁻³): This was determined by the weight in air /weight in water method. Five kg tubers of all shapes and sizes were randomly taken from each plot. The selected sample unit was first weighed in air and then the same unit was re-weighed suspended in water. Specific gravity was calculated using the following formula (Kleinkopf *et al.*, 1987).

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}$$

3.7 Data Analysis

The collected data were subjected to analysis of variance (ANOVA) using GLM procedure within SAS version 9.0 (SAS Institute, 2012). The significant treatment means were separated using the LSD test at 5% level of significance.

3.8 Partial Budget Analysis

To support the statistical analysis of the agronomic data, economic analysis was done for each treatment. For economic evaluation, cost and return was calculated according to the

procedure given by CIMMYT (1988). To estimate economic parameters, potato was valued at an average open market price per kg, work days per hectare for collection and transportation of farmyard manure and cost of inorganic fertilizer inputs.

Gross average yield (kg ha⁻¹ or ton ha⁻¹): is an average yield of each treatment.

Adjusted yield: is the average yield adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers. $AJY = GAY - (GAY * 0.1)$

Gross field benefit: was computed by multiplying field/farm gate price that farmers receive for the crop when they sell it as adjusted yield. $GFB = AJY * \text{field/farm gate price of a crop}$.

Total cost: mean current prices of urea (16 birr kg⁻¹), DAP (17 birr kg⁻¹), Variable costs for decomposing, transporting, application and spreading farmyard manure were taken as Birr 160/Qt. Net benefit (NB): was calculated by subtracting the total costs from the gross field benefit for each treatment. $NB = GFB - TC$.

Marginal cost = change in costs between treatments.

Marginal benefit = change in benefits between treatments.

Marginal rate of return {MRR (%)} = $(MB/ MC)*100$

4 RESULTS AND DISCUSSION

4.1 Phonological Parameters of Potato

4.1.1 Days 50% to flowering

There were significant ($P < 0.01$) differences in days to flowering of potato due to the main effect of inorganic (NP) fertilizers and farmyard manure (FYM) while the interaction effect was not statistically significant (Appendix Table 1). Flowering of potato was delayed when 75 and 100% recommended NP fertilizers from inorganic source were applied as compared to other lower rates of NP from the same source (Table 2). Full recommended dose of inorganic NP (100% RNP) delayed flowering of potato in average by about four days as compared to the control treatment (no NP). Similar to the inorganic NP fertilizer, increasing the rate of FYM significantly delayed days to flowering of potatoes (Table 2). Application of FYM at rates of 10 and 15t ha⁻¹ significantly delayed flowering of potato compared to the other lower rates of FYM (Table 2).

This result is similar with the findings of Cole (1975) and Zelalem *et al.* (2009) who reported that application of higher rate of nitrogen fertilizer delayed days to flowering and maturity. Similarly, Alemayehu *et al.* (2015) and Biruk (2015) also reported increasing nitrogen and phosphorus fertilization significantly delayed days to flowering in potato. Application of N at a rate of 55 kg or 0 kg ha⁻¹ with 90kg ha⁻¹ P₂O₅ reduced the time required by the potato plant to attain 50% flowering stage optimum rates of phosphorus fertilizer applications mostly enhance early crop development and that the responses to phosphorus

application decrease with time (Jenkins and Ali, 1999). Israel *et al.* (2018) also report that high dosage of cattle manure with mineral NP fertilizer levels promoted excessive vegetative growth and delayed flowering.

Table 2. Main effects of farmyard manure and inorganic (NP) fertilizers on potato days of 50% flowering and days of 90% Physiological maturity.

Treatment		
Inorganic fertilizer (RNP %)	Days of 50% flowering	Days of 90% physiological maturity
0	59.83 ^d	92.91 ^d
25	61.16 ^c	94.33 ^d
50	62.33 ^b	97.08 ^c
75	63.41 ^a	100.25 ^b
100	63.66 ^a	106.58 ^a
LSD (0.05)	0.83	2.04
Farmyard manure(FYM)t ha ⁻¹		
0	61.33 ^c	95.80 ^c
5	61.86 ^{bc}	97.60 ^{bc}
10	62.66 ^{ba}	99.00 ^{ba}
15	62.46 ^a	100.53 ^a
LSD (0.05)	0.74	1.83
CV (%)	1.62	2.51

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

4.1.2 Days of 90% physiological maturity

Days to 90% physiological maturity for potato is defined as number of days from planting to maturity. Maturity of potato is determined by senescence of the haulm. Highly significant ($P < 0.001$) effect was observed for main factors of inorganic (NP) fertilizer and farmyard manure (FYM). However, interaction effect of inorganic (NP) fertilizer and farmyard manure (FYM) was not significant (Appendix Table 1). Delayed physiological maturity was recorded from the 100% inorganic NP treatment and real maturity was recorded from control

treatment (Table 2). This may be due to enhanced vegetative growth thereby increasing days to flowering and physiological maturity, (Ouda and Mahadeen, 2008) Plots that received 100% inorganic (NP) fertilizer delayed physiological maturity 14 day compared to control treatment (Table 2). Similarly the application of farmyard manure from 10 to 15 t ha⁻¹ delayed physiological maturity of potato. Application of FYM at the rate of 15 t ha⁻¹ delayed maturity of potato by about five days as compared to the control (no FYM). The findings of this study are in agreement with the work of Zelalem *et al.* (2009) which was reported that rising N rates extended days to flowering and physiological maturity.

Similarly findings were reported by Daniel *et al.* (2008) indicated higher N rates promoted too much vegetative growth leading to late flowering and physiological maturity. Earlier results of Brady and Weil (2002) showed that sufficient nitrogen application enhances many aspects of physiological processes like photosynthesis, flowering, seed formation and maturation with extension of phonological processes like flowering.

4.2 Growth Parameters

4.2.1 Plant height

Plant height was highly significantly ($P < 0.001$) influenced by inorganic NP fertilizer and Farmyard manure (FYM) rates. However there was no any interaction effect between these two factors (Appendix Table 2). The highest plant height was recorded from plant which grows with application of 100% inorganic (NP) fertilizer. The shortest plant height was recorded from control treatment (Table 3). Due to the fact that nitrogen is considered as one of the major limiting nutrients in plant growth and the adequate supply of it promotes the

formation of chlorophyll which in turn resulted in higher photosynthetic activity, vigorous vegetative growth and taller plants. Phosphorus is required in large quantities in shoot and root tips where metabolism and cell division are high.

This result is also in agreement with the findings of Girma *et al.* (2017) who indicated that plant height tended to increase with increasing N rate, thus increasing N rate from 0 to 138 kg ha⁻¹ increased plant height from 62.05 to 77.51 cm. Similarly Fekadu (2016) has also reported that both organic and inorganic fertilizers produced plants with more height as compared to plants in control plot. The increase in plant height in the presence of inorganic fertilizer might be due to better availability of nutrients for increasing the cell division and elongation.

Similar to the inorganic NP fertilizer, increasing the rate of FYM significantly improved plant height (Table 3). The maximum plant height was recorded from application of 15 t ha⁻¹ FYM. However, minimum plant height was recorded from control treatment (Table 3). The increase in plant height due to the increased application of the farmyard manure may be attributed to the nutrient contents of the farmyard manure and improved soil physical properties. Corresponding to results of this study, Arshad *et al.* (2004) reported that, the positive effect of cattle manure on soil structure enhanced root development resulted in more nutrient uptake. Cattle manure is not only slowly releases nutrients but also prevents the loss of chemical fertilizers through de-nitrification, volatilization and leaching by binding to nutrients and releasing them with the passage of time. In the same way, Jayramaiah *et al.*

(2005) showed that enhanced plant heights of potato were obtained in response to the application of suitable amounts of farm yard manure.

4.2.2 Main stem number

The analysis of variance showed highly significant differences in main stem number due to the main effects of inorganic NP fertilizer and farmyard manure ($P < 0.001$) but not for the interaction effect (Appendix Table 2). Potato grown with the highest rate of inorganic NP fertilizer (100 % RNP) produced the highest main stem number. On the other hand, the lowest main stem number was obtained from the control treatment (Table 3). This result was consistent with that of Manochehr *et al.* (2009) who reported that increasing inorganic NP level from zero to 100 kg N ha⁻¹ recorded higher main stem number. Similar with inorganic NP fertilizer, highest main stem number was recorded with rate of 15t ha⁻¹ farmyard manure (FYM), which is also statistically at par with 10 t FYM ha⁻¹. Conversely, the lowest main stem number was recorded with the control treatment.

The results revealed that increasing the rate of FYM increased the number of main stems produced per plant. The current result is similar with the result obtained by Jayrmaiah *et al.* (2005) who reported that increasing cattle manure from 0 to 30t ha⁻¹ resulted in increased main stem number by 23%.

Table 3. Main effect of inorganic (NP) fertilizers and farmyard manure rates on main stem number and plant height of potato.

Treatment		
Inorganic fertilizer ((RNP %)	Plant height(cm)	Main stem number
0	52.39 ^e	3.75 ^e
25	56.43 ^d	4.50 ^d
50	61.70 ^c	5.52 ^c
75	66.17 ^b	6.80 ^b
100	69.65 ^a	7.23 ^a
LSD(0.05)	1.62	0.406
Farmyard manure (t ha ⁻¹)		
0	58.67 ^d	4.78 ^c
5	60.29 ^c	5.42 ^b
10	62.19 ^b	5.84 ^a
15	63.92 ^a	6.20 ^a
LSD (0.05)	1.45	0.36
CV (%)	3.56	8.8

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

4.3 Yield and Yield Components

4.3.1 Marketable tuber number per hill

Marketable tuber number per hill was highly significantly ($P < 0.001$) influenced by the main effect of inorganic NP fertilizer and farmyard manure. However, the interaction effect was not significant (Appendix Table 3). The higher marketable tuber number was obtained from the treatment that received 100% inorganic NP ha⁻¹ fertilizer. Whereas, the lowest marketable tuber number was obtained from the control plots (Table 4). This might be due to the fact that these two important plant nutrients have complementary metabolic and physiological functions, thereby affecting the yield and yield components of the potato plant.

The result is in agreement with the result of Shahzad *et al.* (2011) who reported that there was an increase in number of tubers with increasing nitrogen rates up to 160 kg N ha⁻¹ and 90 kg P₂O₅ ha⁻¹. But further increase resulted in a decrease in number of tubers.

Similarly, increasing FYM rate resulted in increased marketable tuber and the highest marketable tuber number was recorded from 15 t ha⁻¹ FYM. While, the lowest marketable tubers number was recorded from control treatment (Table 4). The present study is in conformity with Atiyeh *et al.* (2000) who reported that the use of compost and vermin compost led to significantly increased tuber number. Also, Khajehpour (2006) approved increase in marketable tuber number with increasing nitrogen fertilizer at certain rate of application.

4.3.2 Unmarketable tuber number per hill

The analysis of variance indicated that the main effects of inorganic NP fertilizer had highly significant ($P < 0.01$) effect on unmarketable tuber number, while farmyard manure and interaction effect was non-significant (Appendix Table 3).

The lowest unmarketable tuber number was obtained from the treatment that received 75-100% inorganic NP (Table 4). Contrasts to this result Berga *et al.* (1994) and Burga (2010) reported that the highest unmarketable tuber yield was obtained in the treatment of 50 kg N ha⁻¹ and 90 kg P₂O₅ ha⁻¹ followed by plants in the control treatment. The unmarketable tuber yield was significantly decreased as inorganic (NP) fertilizer increased. The number of unmarketable tubers could be reduced more importantly through manipulating other factors

such as disease incidence, pest incidence, harvesting practice, etc than with mineral nutrition (Berga *et al.* (1994).

Table 4. Marketable tuber number, Unmarketable tuber number and total tuber number per hill as influenced by application of inorganic NP fertilizer and farmyard manure at Duna District.

Treatment	Tuber number per hill			
	Inorganic fertilizer (RNP %)	Marketable	Unmarketable	Total tuber number per hill
0		3.783 ^e	3.483 ^a	7.266 ^e
25		5.216 ^d	3.191 ^a	8.408 ^d
50		6.425 ^c	3.016 ^{cb}	9.441 ^c
75		8.525 ^b	2.741 ^{cd}	11.266 ^b
100		9.433 ^a	2.681 ^d	12.115 ^a
LSD(0.05)		0.56	0.28	0.63
Farmyard manure(FYM) t ha ⁻¹				
0		5.626 ^c	3.196	8.823 ^c
5		6.493 ^b	3.060	9.553 ^b
10		6.933 ^b	2.935	9.868 ^b
15		7.653 ^a	2.900	10.553 ^a
LSD(0.05)		0.50	0.24	0.57
CV (%)		10.19	11.03	7.90

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

4.3.3 Total tuber number per hill

The main effect of inorganic NP fertilizer and FYM rates were highly significant ($P < 0.001$) on the total tuber number per plant; but the interaction effect was not significant (Appendix Table 3). The maximum total tuber number was obtained from the treatment that received 100% inorganic NP fertilizer ha⁻¹. On the other hand, the minimum total tuber number was recorded from the control plots (Table 4). The increase in total tuber number in response to

the increased application of the inorganic NP fertilizers might be due to the increased photosynthetic activity and translocation of photosynthetic to the root, which might have helped in the instigation of more stolon in potato (Annad and Krishinapp, 1989). Tuber number is also determined by the number of stems produced which in turn depends up on the tuber size and variety as reported by Ebwongu *et al.* (2001).

Similarly, total tuber yield increased significantly with the increased rate of farmyard manure. Thus, increasing the rate of farmyard manure from 0 to 15t ha⁻¹ increased total tuber. The maximum total tuber number was obtained from the treatment that received 15 t ha⁻¹ of farmyard manure. While the minimum total tuber number obtained from the control plot (Table 4). Due to the release of nutrient from the farmyard manure may have enhanced tuberous root bulking not only due to ability of farmyard manure to provide and encourage uptake of nitrogen, but also due to the catalytic role it plays in attractive dissolution and uptake of other nutrients from the soil. Consistent with this result, Beukema and Van der Zaag (1990) suggested that the crop benefited from the application of FYM not only the amounts of nitrogen, phosphorus, potassium, and other nutrients it contains but also from improved soil tilth and the moisture retaining properties of the soil. In agreement with the result of the present study, Tesfaye (2012) reported that total tuber yield was significantly different for each FYM level and increased linearly with rising FYM levels.

4.3.4 Aboveground and Dry biomass

The main effect of inorganic (NP) and Farmyard manure (FYM) and further the interaction effect of these two factors had significant ($P < 0.01$) effect on the aboveground fresh and dry biomass of potato (Appendix Table 6).

Maximum aboveground fresh and dry biomass was recorded from the combined application of 100% RNP and 15 t ha⁻¹ FYM (Table 5). While, small amount of fresh and dry biomass was recorded from the control plots. Increasing both inorganic fertilizers (NP) and FYM progressively increased aboveground fresh and dry biomass of potato. This result is in conformity with the findings of Abdulaziz *et al.* (2018) who reported the highest above ground biomass with application of N at the rate of 111 kg N ha⁻¹. The results indicated that inorganic fertilizer (N) increased the above ground biomass from 0.2 kg ha⁻¹ to 0.24 kg ha⁻¹ when the rates of nitrogen fertilizer rose from 55.5 kg N ha⁻¹ to 111 kg N ha⁻¹. Similarly this experiment is in agreement with that of Zelalem *et al.* (2009) who reported that aboveground fresh weight and aboveground dry weight yields of potato found to be significantly influenced by inorganic (NP) fertilizer and FYM fertilization as compared to the control, Fertilized potato plant produced 224.5 and 32% more aboveground biomass yield in response to the application of 207 kg N and 60 kg ha⁻¹ P₂O₅, respectively.

Table 5. Interaction effects of inorganic NP fertilizer and farmyard manure on aboveground fresh and dry yield of Potato.

Farmyard manure(t ha ⁻¹)	Inorganic fertilizer (RNP %)	Aboveground fresh biomass (t ha ⁻¹)	Aboveground dry biomass (t ha ⁻¹)
0	0	11.85 ⁱ	2.77 ⁱ
	25	12.54 ^{ih}	2.77 ⁱ
	50	12.85 ^{ji}	2.94 ^{ih}
	75	13.42 ^{igh}	3.14 ^{igh}
	100	15.19 ^{fge}	3.55 ^{fgh}
5	0	12.82 ^{ih}	3.00 ^{ih}
	25	13.34 ^{ih}	3.12 ^{ih}
	50	13.99 ^{fgh}	3.27 ^{fgh}
	75	15.54 ^{fde}	3.63 ^{fde}
	100	14.21 ^{ih}	3.32 ^{fgh}
10	0	12.58 ^{ih}	2.94 ^{ih}
	25	13.06 ^{ih}	3.05 ^{ih}
	50	15.19 ^{fgh}	3.62 ^{fgh}
	75	16.58 ^{cde}	3.88 ^{cde}
	100	17.94 ^{cb}	4.20 ^{cb}
15	0	13.46 ^{igh}	3.15 ^{igh}
	25	13.99 ^{fgh}	3.27 ^{fgh}
	50	17.24 ^{cd}	4.03 ^{cd}
	75	19.29 ^b	4.51 ^b
	100	21.39 ^a	4.67 ^a
LSD(0.05)		1.80	0.5
CV (%)		7.56	9.01

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

The main effect of both inorganic (NP) fertilizer and farmyard manure were significant ($P < 0.001$) on the tuber dry biomass. However, the two fertilizers did not interact to influence the tuber dry biomass. The highest tuber dry biomass obtained from 100% inorganic NP application. However, the lowest tuber dry weight was obtained from the control treatment (Table 6). Similarly increasing the rate of FYM fertilizer resulted in the highest tuber dry biomass obtained from 15 t ha⁻¹ farmyard manure. While, the lowest tuber dry biomass were

obtained from control treatment (Table 6). This result is in conformity with the findings of Israel *et al.* (2012) who report that application of 165 kg N ha⁻¹ the highest root dry biomass (11.56g/hill).

Table 6. Main effect of inorganic (NP) fertilizer and farmyard manure on tuber dry biomass and Total tuber yield of potato in Duna District.

Inorganic fertilizer (RNP %)	Tuber dry biomass (t ha ⁻¹)	Total tuber yield t ha ⁻¹
0	5.19 ^c	23.727 ^c
25	6.05 ^d	27.669 ^d
50	7.22 ^c	33.010 ^c
75	8.34 ^b	38.121 ^b
100	8.71 ^a	39.800 ^a
LSD (0.05)	0.34	1.55
Farmyard manure t ha ⁻¹		
0	6.57 ^c	30.061 ^c
5	7.08 ^b	32.361 ^b
10	7.16 ^b	32.740 ^b
15	7.59 ^a	34.700 ^a
LSD (0.05)	0.30	1.39
CV (%)	2.38	5.79

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

4.4.2 Total tuber yield of potato

The main effects of FYM and inorganic (NP) fertilizers were significant ($P < 0.01$) on total tuber yield. However, the effect from the interaction was not (Appendix Table 4). Total tuber yield increased significantly and linearly in response to increasing the rate of FYM application from nil up to the highest rate of the fertilizer. The lowest total tuber yield was

obtained for the plot that received nil FYM rate. Whereas, the highest total tuber yield was obtained from treatment that received 15 t ha⁻¹ (Table 6) .Total tuber yields were also increased significantly and linearly in response to increasing the rate of inorganic NP fertilizer application from nil up to the highest rate of the fertilizer. Thus, the lowest total tuber yields were obtained from the plot that received 0 NP rate. Whereas, the highest total tuber yield was obtained from treatment which received the 100% inorganic (NP) fertilizer ha⁻¹ (Table 6).

The possible reason for the increment in total tuber yield of potato by the application of either FYM or inorganic fertilizer could be attributed to their favorable effects on yield components, like average number of tubers per hill, and dry matter production. This might be due to FYM fertilizer or in inorganic fertilizer satisfies the nutrient requirement of the plant. This result agrees with the results reported by Simon (2019), who reported increasing the rate of mineral NP fertilizer application resulted in the highest yield. Thus, the lowest total tuber yield was obtained from zero mineral NP fertilized treatment whereas the highest was obtained from treatment that received the highest mineral NP fertilizer. This clearly showed that, the applied nutrients increased tuber quality and weight. From the findings of Israel *et al.* (2012), this can be attributed to increased vegetative growth of the aerial parts and hence, prolonged the duration of photosynthesis.

4.4 Tuber Quality Attributes

4.4.1 Size categories of tubers

The analysis of variance revealed that the main effect of NP and FYM as well as interaction effect of NP and FYM significantly ($P < 0.05$) influenced the proportion of potato tuber size distribution (Appendix Table 5). Medium and large sized tubers significantly increased with the increased rates of inorganic NP fertilizers and FYM. Therefore, the highest proportion of medium and large sized tubers were obtained from the application of 100 % inorganic (NP) fertilizer ha^{-1} and 15 t ha^{-1} farmyard manure (FYM) (Table 7). In broadly increasing the amount from 0 to 100% inorganic (NP) fertilizers with 15 t ha^{-1} farmyard manure (FYM). The improvement in the size of the potato tubers in response to the application of fertilizers could be ascribed to enhanced nutrient status and physicochemical property of the soil in the area.

In line with this result, Fekadu (2016) reported the highest medium size tuber weight with the application 5.0 t ha^{-1} FYM + 5.0 t ha^{-1} cattle manure + 100% RNP and the lowest with the control. A close perusal of the data revealed that in general, the treatments which had more large tuber size had lower medium tuber size and vice versa. In a similar experiment, Hossain *et al.* (2007) found maximum tuber size with combined application of organic and mineral fertilizers. Haase *et al.* (2007) also reported that composted cattle manure increased the number of tubers with diameters > 65 mm as a result of N mineralization. Taheri *et al.* (2010) also found the highest ratio number of large tubers as a result of application of 20 t ha^{-1} of compost combined with 225 kg ha^{-1} phosphorus.

Table 7. Interaction effects of inorganic (NP) fertilizer and farmyard manure on medium and large sized tubers (%) of Potato in Duna District.

Treatment		Tuber size	
Inorganic fertilizer (RNP %)	FYM t ha ⁻¹	% medium sized tuber(39-75 g)	% large sized tuber(> 75g)
0	0	28.76 ^m	15.86 ⁱ
	5	28.85 ^k	18.42 ^{hi}
	10	29.73 ^{jk}	22.49 ^{hg}
	15	31.47 ^{ih}	23.79 ^g
25	0	28.63 ^l	33.07 ^f
	5	30.75 ⁱ	40.96 ^e
	10	32.15 ^h	42.67 ^e
	15	33.11 ^{fge}	43.69 ^e
50	0	30.62 ^{ji}	44.55 ^e
	5	32.41 ^{fgh}	59.27 ^c
	10	33.16 ^{fge}	59.97 ^c
	15	33.68 ^{ccde}	60.84 ^c
75	0	32.15 ^{gh}	52.31 ^d
	5	33.26 ^{fde}	67.33 ^b
	10	33.68 ^{cde}	70.23 ^{ba}
	15	34.19 ^{cd}	71.32 ^{ba}
100	0	33.68 ^{cde}	44.70 ^d
	5	34.44 ^{cb}	70.53 ^{ba}
	10	35.18 ^b	71.23 ^{ba}
	15	36.35 ^a	72.94 ^a
LSD (0.05)		0.57	2.72
CV (%)		1.79	5.47

Means sharing the same letter(s) are not significantly different at 5% level of significance

The analysis of variance revealed that the main effect of inorganic(NP) fertilizer and farmyard manure (FYM) but interaction effect of NP and FYM was not significantly ($P < 0.05$) influenced part of potato tuber size distribution (Appendix Table 5). Small-sized potato tubers significantly decreased with increasing rates of inorganic NP fertilizers. The highest proportion of small-sized tubers was recorded in the control. While, the lowest proportion of small-sized tuber was obtained from application of 100% inorganic (NP) application. Similar

to inorganic NP fertilizer, maximum small-sized tubers was recorded from control treatment increased. While minimum small sized tuber was recorded from 15 t ha⁻¹ FYM (Table 8). The finding of Simon *et al.* (2019) who reported that large amount of small sized tubers were obtained from plots which received lowest application of FYM and mineral NP while, low amount of small sized tubers contributed by the high application of FYM and NP fertilizers.

Table 8. Main effect of inorganic (NP) fertilizer and farmyard manure on small sized tubers (%) of potato in Duna District

Treatment	Variable
Inorganic fertilizer (RNP %)	Small sized % tuber (<39kg)
0	68.48 ^a
25	47.59 ^b
50	41.77 ^b
75	26.89 ^c
100	20.01 ^c
LSD (0.05)	9.58
Farmyard manure(FYM)t ha ⁻¹	
0	42.87
5	42.83
10	39.88
15	38.22
LSD(0.05)	8.57
CV (%)	24.97

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

4.4.3 Marketable tuber yield (t ha⁻¹)

The Main effect of inorganic (NP) fertilizers and farmyard manure (FYM) were significantly ($P<0.001$) influenced the marketable tuber yield (Appendix Table 4). However, marketable yield was not affected by the interaction effect of the two factors. Maximum marketable

tuber yield was obtained from application of 100% inorganic (NP) fertilizer ha^{-1} . However, minimum marketable tuber yield obtained from control treatment (Table 9). This result is in line with the finding of Simret *et al.* (2010) who reported that the optimum marketable tuber yield was attained at $100 \text{ kg ha}^{-1}\text{N}$, signifying that increasing nitrogen fertilizer more than this level would be wasteful for ware potato production. Zelalem *et al.* (2009) also reported that nitrogen application beyond 138 kg ha^{-1} did not bring significant yield advantage.

With regard to farmyard manure the highest marketable tuber yield was obtained from application of 15 t ha^{-1} .while lowest marketable tuber yield obtained from control treatment (Table 9). This result is also in line with that of Simon *et al.* (2019) Marketable tuber yield increased significantly and linearly in response to increasing the rate of FYM application from nil up to the highest rate of the fertilizer. Increasing the rates of nitrogen increased marketable tuber yield across all the increased rates farmyard manure. The control plot produced the lowest values for marketable tuber yield of potato, due to the absence of adequate nutrient needed for proper growth, development and yield.

Table 9. Main effect of inorganic (NP) fertilizer and farmyard manure on marketable tuber yield and total tuber yields.

Inorganic fertilizer (RNP %)	Tuber yield t ha ⁻¹	
	Marketable tuber t ha ⁻¹	Total tuber yield t ha ⁻¹
0	19.268 ^e	23.727 ^e
25	22.725 ^d	27.669 ^d
50	27.777 ^c	33.010 ^c
75	32.803 ^b	38.121 ^b
100	35.586 ^a	39.800 ^a
LSD (0.05)	1.37	1.55
Farmyard manure t ha ⁻¹		
0	24.863 ^c	30.061 ^c
5	27.384 ^b	32.361 ^b
10	28.116 ^b	32.740 ^b
15	30.164 ^a	34.700 ^a
LSD (0.05)	1.22	1.39
CV (%)	6.01	5.79

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

4.4.4 Unmarketable tuber yield (t ha⁻¹)

The analysis of variance revealed that the main effects of inorganic NP fertilizer and interaction effect had significant effect on unmarketable tuber yield. However, the main effect of farmyard manure was not show significant effect (Appendix Table 4). Increasing the rate of the fertilizers from increasing the rates of inorganic (NP) fertilizer further from 0 to 75% inorganic NP fertilizer increased unmarketable tuber yield. However, increasing the rate of the FYM fertilizer beyond this level did not change unmarketable tuber yield. Thus, the higher unmarketable tuber yield was obtained from the treatment that received 75% inorganic (NP) fertilizer and zero FYM. However, the lower unmarketable tuber yield was obtained from the 100% inorganic (NP) fertilizer and 15t ha⁻¹ (FYM) (Table 10). The reason that unmarketable tuber yield increased highly significantly in response to the increasing of

inorganic (NP) fertilizers level is probably due to its effect on physiological activities of the plant and the effect in availing macro and micro nutrients unlike inorganic fertilizer that contain only single nutrient element in increasing total tuber yield by increasing yield of all tuber size grade. Nevertheless, this finding suggests that unmarketable tuber yield can be reduced by optimum application of N or by deprivation of N together with other factors such as disease incidence and poor managing and harvesting practices (Berga *et al.*, 1994).

Table 10. Interaction effects of inorganic (NP) fertilizers and farmyard manure on unmarketable tuber yield.

Unmarketable yield t ha ⁻¹					
Farmyard manure t ha ⁻¹	Inorganic fertilizer (RNP %)				
	0	25	50	75	100
0	3.32 ^{ec}	5.24 ^{bac}	5.60 ^{ba}	6.31 ^a	5.50 ^{ba}
5	4.41 ^{fdec}	5.56 ^{ba}	5.26 ^{ba}	5.11 ^{bdac}	4.53 ^{bdec}
10	5.22 ^{bac}	4.11 ^{bdec}	4.88 ^{bdc}	5.06 ^{bdac}	3.83 ^{fde}
15	4.88 ^{bdc}	4.86 ^{bdc}	5.17 ^{bdac}	4.78 ^{bdc}	2.98 ^f
LSD (0.05)	1.34				
CV (%)	17.19				

Means sharing the same letter(s) are not significantly different at 5% level of Significance.

4.4.5 Dry matter content of potato tubers

The interaction of inorganic NP fertilizer and farmyard manure significantly ($P < 0.01$) influenced dry matter content of potato tubers (Appendix Table 5). The highest dry matter percentage of potato tuber was recorded from control treatment. While the lowest value of dry matter content was obtained from application of 100% inorganic NP fertilizer and zero level of farmyard manure (Table 11). The possible reason may be the fact that nitrogen application might have resulted in low partitioning of assimilate to tubers and availability of

sulfur, zinc and boron facilitates uptake and use efficiency of plants to nitrogen. In addition, Farmyard manure increases availability of nitrogen and phosphorus by favoring soil physicochemical property and releasing nitrogen and phosphorus. This result is in line with the results of Mousavi *et al.* (2007) and Verma *et al.* (2005) who reported that high nitrogen and organic matter level decreases starch content of potato tuber. Similarly Zelalem *et al.* (2009) and Israel *et al.* (2012) who reported that high nitrogen and phosphorus level reduce the dry matter content of potato tubers.

Table 11. Dry matter content was influenced by application of inorganic (NP) fertilizers and farmyard manure at Duna District.

Dry matter content (DMC)					
Farmyard manure t ha ⁻¹	Inorganic fertilizer (RNP %)				
	0	25	50	75	100
0	25.52 ^a	24.32 ^{ba}	20.77 ^{dc}	20.84 ^{dc}	20.01 ^d
5	24.85 ^a	23.66 ^{ba}	23.20 ^{bac}	22.70 ^{bdac}	21.92 ^{bc}
10	24.25 ^{ba}	22.71 ^{bdac}	23.43 ^{bac}	23.08 ^{bac}	23.91 ^{ba}
15	24.35 ^{ba}	23.11 ^{bac}	22.65 ^{dc}	22.68 ^{bdac}	24.15 ^{ba}
LSD (0.05)	2.38				
CV (%)	5.05				

Means sharing the same letter(s) are not significantly different at 5% level of Significance.

4.4.6 Specific gravity (g/cm^3)

The specific gravity of tubers was significantly ($P < 0.01$) affected by inorganic NP fertilizer and farmyard manure (FYM). However, there was no significant effect from the interaction of inorganic NP fertilizer and FYM application (Appendix Table 5). The maximum tuber specific gravity was obtained from control treatment. On other hand the, lowest value was recorded from application of $100\% \text{ ha}^{-1}$ inorganic (NP) fertilizer (Table12).

Application of 15 t ha^{-1} farmyard manure resulted in the specific gravity. On the other hand, the lowest highest specific gravity was recorded from the control treatment which was statistically similar with the application of 5 t ha^{-1} (Table 12). This might be due to the fact that nitrogen decreases the solid constituent of tuber and increases the water content of tubers and this result agrees with Ahmed *et al.* (2015) who report that rising of inorganic N fertilizer levels up to 210 N kg ha^{-1} decreasing the specific gravity.

Table 12. Specific Gravity as influenced by application of inorganic (NP) fertilizer and farmyard manure at Duna District.

Inorganic fertilizer (RNP %)	Specific gravity (SG)
0	1.28 ^a
25	1.09 ^b
50	1.04 ^{cb}
75	1.031 ^c
100	1.03 ^c
LSD(0.05)	0.058
Farmyard manure(FYM)(t ha ⁻¹)	
0	1.15 ^a
5	1.11 ^{ba}
10	1.07 ^{bc}
15	1.05 ^c
LSD(0.05)	0.051
CV (%)	6.40

Means followed by the same letter(s) in the same column are not significantly different at 5% level of significance. LSD (0.05) and CV (%) stands for least significant difference at 5% level and Coefficient of variation in percent, respectively.

4.5 Partial Budget Analysis

Partial budget averaged over the 20 treatments combinations is presented in Table 13. From the final experimental data the gross yield for all treatments was obtained. Then the recommended level of 10% was adjusted to obtain net yield. Net yield was multiplied by the market price to obtain gross field benefit. Costs and benefits were calculated for each treatment. All variable costs were calculated based on the current market price especially for fertilizers and farmyard manure.

The selling price of potato at the local market at the harvest time was taken as Birr 6 per kg. Variable costs were summed up and subtracted from gross benefits. This was taken as the net benefit. The highest net benefit was obtained from treatment that received 100% inorganic

NP fertilizer with nil farmyard manure and the application of 10 t ha⁻¹ farmyard manure alone was obtained highest net benefit. This application generated Birr 20, 0868 and 19, 0128ha⁻¹ respectively, more compared to the control treatment. Based on the above information, the final step was to calculate Marginal Rate of Return (MRR %) for identifying the best one that is economically attractive (Table 13). Marginal analysis is a procedure for calculating marginal rates of return between technologies in a stepwise manner from a lower cost technology to the next higher cost technology and comparing marginal rates of returns to acceptable minimum rates of return. When the new technology surpassed the conventional practice, it is said to be un-dominated (CIMMYT, 1988). MRR% measures the increase in the net income. It becomes unnecessary when the new technology costs less than the farmers' present technology. When the new technology yields lower benefit, then the technology is said to be dominated. MRR is calculated by dividing the marginal increase in net benefit with the marginal increase in variable cost and multiplying the result by 100. The MRR% at the maximum net benefit which was obtained from the treatment that received 100% inorganic NP fertilizer with nil farmyard manure and the application of 10 t ha⁻¹ FYM alone was acceptable.

The maximum net benefit from the marketable tuber yield due to the application of inorganic NP fertilizer with zero farmyard manure and organic fertilizers at the maximum rates might be due to the profitability and feasibility of using organic manure and inorganic fertilizers alone. Nutrients present in organic matter are not fully available to the crops in the season of its application (Ramamurthy and Shivashankar, 1996), they are released more slowly and are stored for a longer time in the soil, thus ensuring a long residual effect

(Sharma and Mittra, 1991), supporting improved root development, leading to higher crop yields. Residual effect of organic matter added to the soil by the manure refers to the carry-over benefit of the application on the succeeding crop.

Table 13. Partial budget averaged from inorganic (NP) Fertilizer and farmyard manure t ha⁻¹

(RNP %)	TY (t ha ⁻¹)	ATY (t ha ⁻¹)	GFB (ETBha ⁻¹)	FC (ETBh ⁻¹)	HTC (ETBh ^{a-1})	TVC (ETBha ⁻¹)	NB (ETBha ⁻¹)	MRR (%)
0	23.72	21.34	128040	0	6402	6402	121638	0.00
25	27.66	24.89	149340	826.5	7467	8293.5	141046.5	1026.09
50	33.01	29.70	178200	1645	8910	10555	167645	1176.14
75	38.12	34.30	205800	2479.5	10290	12769.5	193030.5	1146
100	39.80	35.82	214920	3306	10746	14052	200868	611.1
FYM								
0	30.06	27.05	162300	0	4328	4328	157972	0.00
5	32.36	29.12	174720	800	4659.2	5459.2	169260.8	997.94
10	32.74	29.45	196440	1600	4712	6312	190128	2446.90
15	34.70	31.23	187380	2400	4996.8	7396.8	179983.2	D

TY = Tuber yield, ATY (10%) = Adjusted tuber yield, GFB = Gross field benefit, FC = Fertilizer cost (which includes transport and application cost) HTC = Harvesting and transport cost, TVC = Total variable cost, NB = Net benefit, MRR = Marginal Rate of Return (%), RNP = Recommended nitrogen and phosphorus, FYM = Farmyard manure ETB = Ethiopian Birr, D = Dominated

5. SUMMARY AND CONCLUSION

Potato is one of the most widely cultivated vegetable crops in the Hadiya zone Duna District. Farmers in the study area produce potato both as food and cash crop under rain fed conditions. Productivity of potato is low compare to world average yield particularly under rain fed potato production conditions, due to several factors. Poor crop management practice and low soil fertility are the serious problems observed in most farmers' field. To improve the production and productivity of the crop, soil fertility management has to be the primary role of the producers. Fertility status of the soil is one of the most important factors for cost-effective and sustainable crop production. To this result, a study was conducted to examine the effect of inorganic (NP) fertilizer and farmyard manure (FYM) application on the yield and quality of potato.

The study was conducted in Hadiya Zone Duna district, which lies at an elevation of 2608 meters above sea level. The experiment was laid out in a Randomized Complete Block design in factorial combinations with three replications. The treatment consists of the combinations of five levels of recommended inorganic NP fertilizer (0, 25, 50, 75 and 100 %) and four levels of farmyard manure (0, 5, 10, and 15 t ha⁻¹).

The results revealed that both inorganic NP fertilizer and farmyard manure had highly significant effects on growth, yield and quality of potato. Characters viz. days of flowering, days of maturity, plant height, stem number, marketable tuber number, unmarketable tuber number, small sized tuber number, total tuber number, marketable yield, total tuber yield and specific gravity were influenced by main effect of inorganic NP and farmyard manure.

While, Characters viz. unmarketable tuber yields, dry matter content, aboveground fresh yield, aboveground dry yield, large sized tuber and medium sized tuber were influence by the interaction effects of inorganic (NP) and farmyard manure.

The application of 100% and 75% inorganic NP fertilizer delayed days to 50% flowering (by about 3 days) and physiological maturity (by about 4 days), respectively, as compared to the control .While application of farmyard manure at 15t ha⁻¹ delayed the days required to reach 50% flowering by about 9 days and physiological maturity by about 13 days as compared to the days required by plants grown in the control treatment to reach the same stage of growth. However, inorganic NP fertilizer and FYM did not interact to influence these phenological parameters. Growth parameters, like plant height and main stem number were significantly affected by the main effect of inorganic (NP) fertilizer. The highest plant height and main stem numbers were recorded at the level of 100% inorganic NP fertilizer.

Similarly, the main effect of farmyard manure significantly influenced the plant height and the stem number of potato. The highest plant height and main stem number was recorded at the level of 15 t ha⁻¹ farmyard manure. Moreover, inorganic NP fertilizer and farmyard manure did not interact to affect these growth parameters. It was also observed that among the yields and yield components studied, marketable and total tuber number per hill were significantly affected by application of inorganic (NP) and farmyard manure fertilizers. The maximum marketable and total tuber numbers were attained at 100% inorganic NP ha⁻¹ and 15 t ha⁻¹ FYM. While their respective minimum tuber numbers were attained at the control

treatment. On the other hand, application of FYM had non-significant effect on unmarketable tuber number per hill.

Application of both of these fertilizers also had significant influence on the large sized tuber and medium sized tuber; and their application beyond 100% inorganic (NP) ha^{-1} and 15t ha^{-1} farmyard manure had significant increment on tuber size. From these results, it was observed that increasing the level of inorganic (NP) and FYM increased some yield components (like number of tubers) of the plant linearly and significantly up to the maximum level of fertilizer. This indicated that there is a space for further improvement or increment in these parameters. Generally, in response to inorganic NP fertilizer, the optimum marketable and total tuber yields were attained at the level of 100% inorganic NP fertilizer ha^{-1} . While in case of FYM the optimum marketable and total tuber yields were attained 15 t ha^{-1} .

The highest marginal rate of return (1176.14%) with net benefit value of (167,645 ETB ha^{-1}) was recorded from the application of 50% inorganic NP fertilizer. However, the application of 10 t ha^{-1} had also resulted in higher marginal rate of return (2446.90%) and maximum net benefit (190,128ETB ha^{-1}).

In conclusion the result of this study show that inorganic NP fertilizer and farmyard manure have a sound and promising impact on growth, yield and quality of potato. Therefore, to obtain optimum economic rate return from the production of potato at the study area 50% inorganic NP fertilizer alone or 10t ha^{-1} farmyard manure without inorganic fertilizers could be recommended.

This recommendation is supported by CMMYT which stated that farmers will be able to change from one treatment to another if the marginal rate of return is greater than the minimum acceptable rate of return. Nevertheless, as the study was conducted in a single season at a single location, repeating the experiment in multiple locations and years is very important for a conclusive recommendation.

From the results of the current experiment and literature review for this purpose, the following research area is suggested for further study on potato production in the southern regional state. The current experiment should be conducted for more than two seasons across locations of similar agro-ecology and soil type to recommend the appropriate inorganic NP fertilizer and farmyard manure for potato production, by taking possible measures to improve farmers' practices and factors constraining crop productivity.

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7. APPENDICES

Appendix Table 1. Mean squares of ANOVA for days of flowering and days of physiological maturity.

Source of variation	Mean squares		
	DF	FD	DPM
NP	4	30.75***	355.76***
FYM	3	5.48***	61.00***
Rep	2	1.11NS	48.26**
NP*FYM	12	0.70NS	2.94NS
ERROR	38	1.01	6.12

Where; DF = degrees of freedom, FD = days of flowering, DPM= days of physiological maturity, NS, ** and *** implies non-significant, significant and highly significance differences at 5% level of probability, respectively.

Appendix Table 2. Mean squares of ANOVA for main stem number per plot of potato as affected by NP fertilizer and farmyard manure.

Source of variation	Mean squares		
	DF	PH	MSN
NP	4	590.31***	26.162***
FYM	3	78.03***	5.518***
Rep	2	22.15**	3.382
NP*FYM	12	1.21NS	0.188NS
ERROR	38	3.85	0.242

MSN= main stem number, PH = plant height. NS, ** and *** implies non-significant, significant and highly significance differences at 5% level of probability, respectively.

Appendix Table 3. Mean squares of ANOVA for marketable tuber number per hill, unmarketable tuber number per hill and total tuber number per hill of potato as affected by NP fertilizer and farmyard manure.

Source of variation	DF	Mean squares		
		MTN	UNMTN	TTN
NP	4	64.74***	1.308***	47.82***
FYM	3	10.77***	0.271NS	7.73***
Rep	2	0.66	0.114	0.365
NP*FYM	12	0.38NS	0.045NS	0.39NS
ERROR	38	0.46	0.11	0.587

NS, ** and *** implies non-significant, significant and highly significance differences at 5% level of probability, respectively. MTN= Marketable tuber number, UNMTN = Unmarketable tuber number TTN= Total tuber number.

Appendix Table 4. Mean squares of ANOVA for marketable tuber yield (t ha⁻¹), unmarketable tuber yield (t ha⁻¹) and total tuber yield (t ha⁻¹) of potato as affected by NP fertilizer and farmyard manure

Source of variation	DF	Mean squares		
		MTY	UNMTY	TTY
NP	4	552.21***	2.79***	556.32***
FYM	3	71.86***	1.430NS	54.29***
Rep	2	18.59	0.163	15.35
NP*FYM	12	1.55NS	1.72**	5.67NS
ERROR	38	2.76	0.69	3.54

NS, ** and *** implies non-significant, significant and highly significance differences at 5% level of probability, respectively. MTY = marketable tuber yield (t ha⁻¹), UNMY = unmarketable tuber yield (t ha⁻¹) TTY = Total tuber yield (t ha⁻¹).

Appendix Table 5. Mean squares of ANOVA for large size tuber, medium size tuber, small size tuber, dry matter content and specific gravity of potato as affected by NP fertilizer and farmyard manure.

Source of variation	DF	Mean squares				
		LST	MST	SST	DMC	SGT
NP	4	4687.15***	65.76***	4316.45***	11.22***	0.145***
FYM	3	654.95***	38.78***	79.18NS	5.66**	0.031***
Rep	2	28.82	0.479	2025.27	15.49	0.010
NP*FYM	12	21.37**	2.06***	55.49NS	4.00**	0.00449NS
ERROR	38	6.32	0.32	134.45	1.37	0.0049

NS, * and ** implies non-significant, significant and highly significance differences at 5% level of probability, respectively. LST= large size tuber, MST = medium size tuber SST= small size tuber, DMC= dry matter content and SGT = specific gravity.

Appendix Table 6. Mean squares of ANOVA for aboveground fresh weight, aboveground dry weight and tuber dry weight of potato as affected by NP fertilizer and farmyard manure.

Source of variation	DF	Mean squares		
		AGFB	AGDB	TDBB
NP	4	45.57***	2.498***	26.65***
FYM	3	46.59***	2.555***	2.60***
Rep	2	0.148	0.0081	0.735
NP*FYM	12	4.58***	0.251***	0.27NS
ERROR	38	1.25	0.068	0.169

NS, * and ** implies non-significant, significant and highly significance differences at 5% level of probability, respectively. AGFW = aboveground fresh biomass, AGDW = aboveground dry biomass and TDBM = tuber dry biomass.

Appendix Table 7. Physicochemical properties of the experimental site soil and farmyard manure (FYM) before planting and treatment application during the 2019 growing season at Duna District

Parameter	Soil		Farmyard manure	
	Value	Rating	Value	Rating
pH (H ₂ O)	6.8	neutral	7.3	neutral
OM (%)	2.48	Low	30.75	very high
CEC (meq/100g soil)	45.58	Very high	ND	
TN (%)	0.14	Medium	1.45	very high
Av.P(ppm)	15.2	Medium	7.69	high
Texture				
Clay%	22			
Silt%	12			
Sand%	66			
Textural Class	Sand clay loam			

Where pH = Hydrogen power, OM% = Percent of organic matter, CEC = Cat-ion exchange capacity
 TN% = Percent of total nitrogen, Av.P.ppm = Available Phosphorus in parts per million

Appendix figure 1. Different pictures during research process, during the 2019 growing season Duna District



8. BIOGRAPHICAL SKETCH

The author, Demeke Woemebo Selato, was born in June 1992 in Duna Woreda, Hadiya Zone of Southern Ethiopia. He attended his junior elementary School at second Otoro from 1998 to 2006 and his secondary school at Ansho from 2007 to 2008 and secondary and preparatory School at Gimbichu from 2009 to 2010. Then, he joined Samara University in 2011 and graduated with BSc degree in Horticulture in June 2013. Soon after his graduation he was employed at Hadiya Zone Water, Mine and Energy department from September 2013 to August 2017. After four years of service, he joined the School of Graduate Studies of Hawassa University in 2017 to pursue his MSc. in Horticulture.