Evaluation of Blended and Non-blended Fertilizer Types and Rates on Potato (*Solanum tuberosum L.*) Yield and Yield Components at Assosa, Western Ethiopia

MSc Thesis

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Hawassa, Ethiopia

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DEDICATION

This work is dedicated to my father, **Bekele Dichi,** and my mother, **Diribe Roro**, who brought me up with affection and taught me the value of education, an opportunity they themselves unable to have.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my genuine work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for a Degree of Master Sciences at the Hawassa University. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Name signature Date

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TABLE CONTENTS

Content **Page**

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF TABLES IN THE APPENDIX

Table **Page**

LISTS OF ACRONYMS AND ABBREVIATION

ANOVA	Analysis of Variance
ARE	Apparent Recovery Efficiency
AsARC	Assosa Agricultural Research Centre
CEC	Cation Exchange Capacity
CIP	International Potato Centre
CSA	Central Statistic Authority
EIAR	Ethiopian Institute of Agricultural Research
ETB	Ethiopian Birr
EthioSIS	Ethiopian Soil Information System
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
HARC	Holeta Agricultural Research Centre
IAR	Institute of Agricultural Research
LAI	Leaf Area Index
LSD	Least Significant Difference
MoARD	Ministry of Agriculture and Rural Development
MRR	Marginal Rate of Return
NPSB	Nitrogen, Phosphorus , Sulfur and Boron
NPSZnB	Nitrogen, Phosphorus , Sulfur, Zinc and Boron
OC	Organic Carbon
OECD	Organization for Economic Co-operation and Development
OM	Organic Matter
SAS	Statistical Analysis System
RCBD	Randomized Complete Block Design
TCV	Total Cost that Vary
TSP	Triple Super Phosphate

Evaluation of Blended and Non-blended Fertilizer Types and Rates on Yield and Yield Components of Potato (*Solanum Tuberosum L.*) at Assosa, Western Ethiopia

Desta Bekele (BSc), Girma Abera (PhD) and Amsalu Gobena (PhD)

ABSTRACT

Potato (Solanum tuberosum L.) plays a major role in national food security, poverty alleviation and income generation. However, the yield of the crop is constrained by a number of biotic and abiotic factors, among which soil fertility decline is one of the major factors limiting productivity. The study was designed to evaluate the effects of blended and non-blended fertilizers types and rates on yield and yield components of potato at Assosa, in Western Ethiopia. The treatments consisted of control, three rates of NP combinations (55 kg N and 45 kg P_2O_5, 110 kg N and 90 kg P_2O_5, 165 kg N and 135 kg P_2O_5 kg ha^{-1}), one NPK combination (110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1})and two different formula of blended fertilizers with two N rates for each, formula 2 (100 % NPSB with adjusted N kg ha^{-1} and 200% NPSB with adjusted N ha^{-1}) and formula 4(100 % NPSZnB with adjusted N ha^{-1} and 200% NPSZnB with adjusted N ha^{-1}). The treatments were laid out as a Randomized Complete Block Design with three replications. The experimental soil was strongly acidic in pH, clay loamy in texture, medium in organic carbon and CEC, low in total N and B, low in available P, sulfur and exchangeable K. Potato variety called Belete (CIP-393371.58) was used for the study. Analysis of variance revealed that the blended and non-blended fertilizers had highly significant influence on days to 50% flowering, leaf area index, underground dry biomass, plant height, mean tuber weight, marketable and total tuber yield, tuber dry matter content and large tuber size. It was observed that the maximum yields for marketable tuber yield (30.03 t ha^{-1}) and total tuber yield (34.58 t ha^{-1}) were obtained from the application of 110 kg N+90 kgP_2O_5+ 69kg K_2O ha^{-1}. The lowest marketable and total tuber yields were recorded with control. The highest N tuber concentrations were recorded at application of 100% NPSB+ 91.9 kg N ha^{-1}.The maximum P concentration in tuber were obtained at application of 110kgN+90kgP_2O_5+ 69kg K_2O ha^{-1} and 165 kg N+ 135 kg P_2O_5 ha^{-1}. Highest nitrogen uptake of tuber was observed at application of 100% NPSB with adjusted N kg ha^{-1} whereas the lowest was recorded from control treatment. Maximum phosphorus uptake of tuber was obtained at application of NPK (110 kg N ,90 kg P_2O_5, 69 kg K_2 ha^{-1}) whereas minimum phosphorus uptake was obtained at control treatment. The highest agronomic efficiencies of tuber yield were recorded from application of 100% NPSB with adjusted N kg ha^{-1}. Furthermore, 98.38 and 22.3% tuber apparent recovery efficiencies of N and P were obtained at 100% NPSB with adjusted N kg ha^{-1}. Tuber nutrients uptake was positively and significantly correlated to total dry tuber yields. The cost-benefit analysis indicated that application of 110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1} resulted in highest net benefit and marginal rate of return. Therefore application of 110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1} fertilizers can preferably be used as the most appropriate for potato production at Assosa area. However, since this experiment was conducted only for one season, further studies involving more levels of blended fertilizer including potassium over multi-locations should be conducted to give conclusive recommendation.

Keywords: Blended fertilizer, nutrient uptake, nutrient use efficiency, potato tuber yield

1. INTRODUCTION

Potato *(Solanum tuberosum* L.*)* belongs to the *Solanaceae* family and genus solanum. The genus *Solanum* is a polymorphous and largely tropical and subtropical genus containing more than 1000 species (Spooner and Knapp, 2013). Potato (*Solanum tuberosum* L.) is a crop of major economic importance worldwide. It is the fourth most important crop after rice, wheat, and maize, and has historically contributed to food and nutrition security in the world (FAOSTAT, 2015; FAO, 2015). It is playing a major role in national food and nutrition security, alleviation of poverty, generating income , and providing job opportunity in line with production, processing and marketing sub-sectors (Lung'aho *et al.*, 2007). Potato has very good nutritional importance and it can produce more energy and protein per unit and area per unit time than most other major cereal food crops; It is fat-free and contains substantial amounts of minerals (Lutaladio and Castaldi, 2009). The crop is also rich in several micronutrients and vitamins, especially vitamin C; a single medium sized potato of 150 g provides nearly half of the daily adult requirement (100 mg) (FAO, 2008).

Potatoes are a versatile crop that can be cultivated in diverse environments and are currently grown in 100 different countries. Africa takes 10% of potato production in hectares from the world (FAOSTAT, 2015). From Eastern Africa Kenya takes the highest potato production. Potato production in Kenya was increased from 1084412 ton in 2004 to 2192885 ton in 2013 (FAOSTAT, 2015).

Ethiopia has about 70% of the available agricultural land suitable for potato production (Gebremedhin *et al*., 2008a). In recent years, potato production has dramatically increased in Ethiopia by about 96.54 %, from 349,000 tons in 1993 to 863,348 tons in 2010 (FAO, 2013). Since the highlands are also home to 88% of Ethiopia's population (Gebremedhin *et al.,* 2008b) the potato could play a key role in ensuring national food security. Despite high potential production environments and marked growth, the national average potato yield on farmers field in Ethiopia is only 11.1 t ha^{-1}, which is lower than the experimental yields of over 38 t ha^{-1}, which is also very low compared to the world average of 17.6 t ha^{-1} (FAOSTAT, 2015; Woldegiorgis, 2013).

In Ethiopia, the area of potato cultivation was 50,000 hectares by the mid 1980's, whereas the 2001 production area rose up to 160,000 hectares by 2001, with average yields around eight tons per hectare (Gebremedhin *et al.*, 2001). Potato is one of the tuber crop grown in Benishangul Gumuz region whereby the number of farmers growing potato is increasing from time to time in region. The number of farmers growing potato in Benishangul Gumuz region was approximately 3,277 in 2015/16 and increased to 8,359 farmers in 2016/17 (CSA, 2016/17).

Potato demands high level of soil nutrients due to its limited potential in extending the root system and un-ability to exploit soil nutrients (Nigussie, 2001). Compared with cereal crops, potato has a potential to accumulate more dry matter within the growth period (Singh and Trehan, 1998). This high rate of dry matter production results in larger amounts of nutrients removed per unit time. Due to this most of the soils are unable to supply adequate amounts of nutrients for potato. Thus, external nutrient application in as fertilizer forms becomes crucial for achieving high yields. The decline in yield of potato is affected by a number of factors, including decline in soil fertility, use of low yielding varieties, size of the tuber, planting space, poor agronomic management practices, and poor climatic conditions (Arsenault *et al*., 2001).

Crop production could be increased either by balanced fertilizers ,improving the genetic potential of the crop (high yielding improved varieties) or through better agronomic management, use of optimum plant density and better tuber quality seed. According to Muriithi and Irungu (2004), low soil fertility is one of the most important constraints limiting potato production in eastern Africa. Potato crop production could be increased either by improving the inherent genetic potential of the crop or through application of better agronomic management, such as through the use of optimum plant density and application of fertilizers.

Efficiency has defined as crop production per unit input, which means nutritional efficiency consists in the amount of dry matter production per unit nutrient elements usage or uptake (Hashemidezfooli *et al*., 1998). The most nutrient element efficiency is attained, while its concentration reaches critical level, because without excessive elements, greatest yield can be gain. The nutrients use efficiency can be defined as the maximum economic yield produced per unit of nutrient applied, absorbed or utilized by the plant to produce yield and straw (Fageria and Baligar, 2003).

Based on the national soil data base, the EthioSIS soil fertility mapping project in Ethiopia reported that the deficiencies of K, S, Zn, B and Cu in addition to N and P in major Ethiopian soils and hence recommended customized and balanced fertilizers (EthioSIS, 2013). Balanced fertilization not only guarantees optimal crop production, better food quality and benefits for the growers, but is also the best solution for minimizing the risk of nutrient losses to the environment. Nutrients such as N, P, K, S, Zn and B can often be included relatively cheaply in new fertilizer formula; when targeted to deficient soils, these nutrients can dramatically improve fertilizer-use efficiency and crop profitability (Esayas, 2015).

However, there is little information on the impact of different types of fertilizers on the growth and productivity of potato and their interaction on the availability of micro nutrients. According to Bekabil *et al*. (2011), there is a lack of appropriate fertilizer blends and lack of micronutrients in fertilizer blends are the major constraints to crop productivity. According to EthioSIS (2013) Assosa area soils are deficient with in N, P, S, Zn and B , fertilizer practices in the region have been mainly based on blanket recommendations. There is little information on the response of the crop to different fertilizers type and blended fertilizers under Benishangul Gumuz region condition. Thus, the study was initiated with the following objectives.

General Objective

- To investigate the effect of different rates of blended fertilizers and the recommended blanket fertilizer on yield and yield components of selected potato.

Specific Objectives:

- To evaluate the effect of blended and non-blended fertilizers types and rates on potato tuber yield, yield components and tuber quality
- To determine economically optimum and agronomically efficient blended and non-blended fertilizers types and rate (s) for potato production at Assosa area

2. LITERATURE REVIEW

2.1. Origin and Distribution of Potato

Potato *(Solanum tuberosum* L.*)* ultimately traces its origin to Andean and Chilean landraces developed by pre-Colombian cultivators. These landraces exhibit tremendous morphological and genetic diversity and are distributed throughout the Andes, from western Venezuela to northern Argentina, and in southern Chile. Forms of the introduced *S. tuberosum* subsp. *andigena* were adapted to the longer day lengths and climate of European latitudes through selection (OECD 1997).

From Europe, *S. tuberosum* was transported to North America. It may first have been transported from England to Bermuda in 1613 and then from Bermuda to the North American mainland in 1621, a hypothesis favoured by Hawkes (1990). Potato was present in India by 1610 and mainland China by 1700 (Sauer, 1993). Potato was taken to New Zealand in 1769 by Captain Cook and gained agronomic significance for the native Maori by 1840 (Sauer, 1993). Missionaries may have played a crucial role in the distribution of *S. tuberosum* from Europe throughout the world (Sauer, 1993). Potato has been introduced to Ethiopia in 1859 by a German Botanist called Schimper (Berga *et al*., 1994b).

2.2. Botany and Ecology of Potato

The potato is a cool-season crop. The rate of development of sprouts from seed pieces depends on soil temperature. Very little sprout elongation occurs at 6°C; elongation is slow at 9°C and is maximized at about 18°C. The optimum soil temperature for initiating tubers is 16-19°C (Anonymous, 2003). Best suited altitudes ranged between 1500-2800m a.s.l. However, for healthy tuber production, particularly for planting purpose, it should strictly cultivate in high altitude areas. For high yields, the total crop water requirements about 500 to 700 mm (MOA, 2011).

Better tuber yields have been obtained from potatoes grown at soil reaction ranging from pH 5.2 to 6.5 (Fageria *et al*., 2011). The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favour development of large tubers. Yields are highest when average daytime temperatures are about 21°C (Anonymous, 2003). Cool night temperatures are important because they affect the accumulation of carbohydrates and dry matter in the tubers. At lower night temperatures, respiration is slowed, which enhances storage of starch in the tubers (Anonymous, 2003).

Potatoes are shallow-rooted and more sensitive to soil moisture stress than crops with deeper roots. The root system develops rapidly during early growth and achieves maximum development by mid-season. Thereafter, root length, density and root mass decrease as the plant matures. The potato tuber is an enlarged portion of an underground stem although these stems sometimes grow aboveground as well, in which case they are termed stolons (Anonymous, 2013). Tuber eyes are the buds from which next season's growth will emerge. Eyes are concentrated near the apical end of the tuber, with fewer near the stolon or basal end. Eye number and distribution are characteristic of the variety (Anonymus, 2003).

2.3. The Current Status of Potato Production in World and Ethiopia

FAO (2008) reported that potato is one of the world most important crops and consumed for more than 8,000 years. Nowadays, the annual world potato production is estimated to 376 million tons in 2013 (FAOSTAT, 2015). Among this, Asia and Europe are the major potato producing contents, which cover more than 80% of the world production. Today, China is the biggest potato producer in the world which covered about 25% of world production in 2013 (FAOSTAT, 2015).In recent time Algeria is the biggest potato producer in Africa which is estimated to 5 million tons in 2013 (FAOSTAT, 2015). Kenya is the biggest potato producer in East Africa with a total production of about 2.2 million tons in 2013 while Kenya, potato is the second most important crop following maize (FAOSTAT, 2015). Here it is cultivated by about 500,000 smallholders, making it one of the most important sources of income and employment in rural areas (Obare *et al*. 2010). In Ethiopia, according to Gebremedhin *et al.* (2008a), the major potential areas for potato production are the Central, Southern, Southeastern, Southwestern and Northwestern part of the country, where altitude ranges from 1500 to 3000 m and the annual rain fall between 600 to 1200 mm. Potato is produced in the belg (short rain season-February to May) and meher (long rain season June to October) periods. Potato is also grown off-season under irrigation (October to January) in Ethiopia.

Potato is one of the tuber crops growing in Ethiopia. It is grown by approximately 1,197,018 farmers (CSA, 2017). Among African countries, Ethiopia has possibly the greatest potential for potato production (Firew *et al*., 2016). At present, potatoes are still widely regarded as a secondary crop, and annual per capita consumption is estimated at 5 kg. The production of potato is expanding at a faster rate than other food crops in developing countries, including Ethiopia. The crop has also proved that it has great potential for adaptation to the diverse growing conditions of the tropics where the majority of the developing countries are located. According to CSA, (2017) report potato production area in Ethiopia decreased from 70131.32 ha in 2016 to 66,923.33ha in 2017, but average potato yield ton ha^{-1} increased in 2017, from 13.5 ton/ha in 2016 to 13.8 ton/ha in 2017.

2.4. Major Constraints to Potato Production in Ethiopia

Potato production like other crops is affected by both biotic and abiotic stresses. Biotic factors affecting potato production and productivity include; insect pests, bacteria, fungi and viruses. The abiotic agents limiting potato production include low soil fertility, inadequate moisture supply, stress due high temperatures and drought. The national average potato yield is very low as compared to the potential yield (38 t ha^{-1}) obtained under research conditions. This is due to narrow genetic basis of potato varieties, poor seed quality, susceptibility to diseases and poor farmers' management practices including soil fertility and nutrient management problems (Haverkort *et al*., 2012; Tewodros, 2014).

Most Ethiopian soils are deficient in N, P and some micro-nutrients content; hence, they can limit potato tuber yield and quality unless applied in the form of fertilizer. Nutrient mining due to sub optimal fertilizer use in one hand and unbalanced fertilizer uses on other have favored the emergence of multi nutrient deficiency in Ethiopian soils (Wassie and Shiferaw 2011); that in part may contributed to fertilizer factor productivity decline experienced over recent past. The national soil inventory data also revealed that in addition to nitrogen and phosphorus, sulfur, born and zinc deficiencies are widespread in Ethiopian soils, while some soils are also deficient in potassium, copper, manganese and iron (EthioSIS, 2013), potentially hold back crop productivity despite continued use of N and P fertilizer as per the blanket recommendation.

2.5. Effect of Nitrogen on Yield, Yield Components and Quality of Potato

Nitrogen is very important nutrient in potato production. Nitrogen is taken up from the soil in the form of nitrate (NO_3^-) or ammonium (NH4+). A good supply of nitrogen stimulates root growth and development as well as the uptake of other nutrients (Brady and Weil, 2002). It is a very dynamic plant nutrient that can be used to enhance growth and productivity. In the plant N combines with compounds produced by carbohydrate metabolism to form amino acids and proteins. However, unless it is utilized by plants it can be also a means to pollute the environment (Moreno *et al*., 2003). An excess of this nutrient promote excessive stolon and leaf growth (Marti and Mills, 1991), both leaf maturation and tuber differentiation are delayed and the length of tuber bulking period, yield and tuber dry matter can be reduced (Goffart *et al*., 2008). Shortage of N restricts the growth of all plant organs such as roots, stems, leaves, flowers, fruits and finally gives stunted plant architecture with yellow leaf appearance

(Barker and Bryson, 2007). Shortage of N also restricts tuber size due to reduced leaf area and early defoliation (Goffart *etal*., 2008).

Several N fertilization rates have been advised as optimal for potato production (Ruža *et al*., 2013). The recommended N fertilization rates vary from 70 to 330 kg ha^{-1}, and the most economically efficient rates from 147 to 201N kg ha^{-1} (Fontes *et al*., 2010). Researchers in the Czech Republic advise a fertilization rate of 140 N $kgha^{-1}$ as the optimal for tuber yield above 30 t ha^{-1} (Ruža *et al*., 2013). Many experiments have shown that total tuber yield and size of potato tubers increase with increasing nitrogen (Sanderson et al., 1987). Zabihie *et al*. (2011) also reported that increase in nitrogen application raises tuber number, but that too much nitrogen has the opposite effect. Generally, potato is a crop that is highly responsive to N fertilizer (Sincik *et al.*, 2008).

2.6. Effect of Phosphorus on Potato Tuber Yield, Quality and Yield Components

Phosphorus (P) is the most important nutrient element, after nitrogen, limiting agricultural production in most regions of the world (Kogbe and Adediran, 2003). Potato is highly responsive to soil-applied nutrients, especially to phosphorus (P), due to its short cycle and high yield potential (Fernandes and Soratto, 2012). The P requirement for potatoes is frequently higher than the requirement for other field crops due to the high nutrient demand of potatoes and their relatively shallow root system (Robert, 2006). Previous report indicated that plant deficient in P has stunted growth, lower leaf area index , imbalance in plant nutrition level and lower photosynthetic rate, than plant grown under optimum phosphorus availability (Hue *et al*., 2010). Low P availability in soil also limit the efficiency of potato plants and reduced tuber size (Dechassa *et al*., 2003). Potato tuber yield increased with increasing P fertilizer (Jenkins and Ali, 1999).

2.7. Effect of Potassium Fertilizer on Yield, Yield Components and Quality of Potato

Potassium is one of the major plant nutrients that affect both the growth and physiological performance of crops (Marschner, 1995). Potatoes require large amounts of K, since this nutrient is crucial to metabolic functions such as the movement of sugars from the leaves to the tubers and the transformation of sugar into potato starch. Recommended rates of K fertilization ranged from 150 to 300 kg ha^{-1} where potatoes are grown on K deficient soils, depending on the yield potential of the area (Roberts and McDole, 1985 as quoted by Habtam, 2012). In Indonesia, the recommended rate of K fertilization for potatoes ranges between 100 and 150 kg K_2O ha^{-1} (Rosliani *et al*., 1998).

A healthy crop of potato removes about 170-230 kg K_2O ha^{-1} indicating that potato needs much higher K than of cereals (Trehan *et al*. 2008). And also potato plants require much more K than any other vegetable crops. The fertilizer use efficiency of K in potato ranges between 50-60 percent (Bansal and Trehan, 2011). An increase in potato tuber might be related to its effect on the regulation of photosynthesis, translocation and storage of assimilates and maintenance of tissue water relations. Tuber yield is affected significantly by the K fertilizer sources and application methods (Gunadi, 2009).

A lack of adequate K is also associated with low specific gravity in potatoes (Robert, 2006). Potato has shallow root system compared to other crops limiting its foraging capacity in the soil. Its deficiencies decrease photosynthesis, reducing dry matter and starch formation. When K uptake is excessive, surplus K is translocated to the tubers causing increased tuber water content and decreased specific gravity.

2.8. Effect of Sulfur Fertilizer on Yield, Yield Components and Quality of Potato

Sulfur is one of the sixteen essential nutrient elements and fourth major nutrient after NPK, required by plants for proper growth and yield as it is known to take part in many reactions in all living cells (Sud and Sharma, 2002). Sulfur deficient plants had poor utilization of nitrogen, phosphorus and potash and a significant reduction of catalase activities at all age (Nasreen *et al*., 2003).

Sulfur fertilization increased yield of potato tubers, improved tuber quality (increased content of protein, starch, carotene, vitamin C, macro- and microelements) and resistance against *Streptomyces scabies* and *Rhizoctonia solani*. It has now been rated as fourth major nutrients after N, P and K and its importance is being recognized in view of its role in improving crop quality and balance of anions *viz.*, N, P and S in agricultural crops including potato (Tandon, 1991). In potato, sulfur is required in many metabolic activities in the plant. Sulfur deficiency is similar to N in many ways. In case of N deficiency, the yellowing of leaves starts from lower leaves while in case of S, it is upper leaves which show chlorosis (Trehan *et al*., 2008). Severe deficiency of S results in retarded plant growth, reddening of stems and curling of leaves inward. Potato response to applied S depends upon the S status of the soils. The need of application of sulfur along with its beneficial effects on yield and quality (Chettri *et al*., 2002).

2.9. Effect of Zinc Fertilizer on Yield, Yield Components and Quality of Potato

Zinc is considered as the important micronutrient for potato and low recovery of applied Zn is the main limitation in enhancing the yield of potato (Singh *et al*., 2014). Depending upon the duration of variety potato crop is highly sensitive to Zn application was found to increase ascorbic acid content, but reduce the tyrosine and total phenol content in tubers which are important criteria for the processing quality (Mondal *et al*., 2015). Effect of Zn on the vegetative growth coupled with its probable influence on the productive part (tuber), which may provide an explanation of its effect on the yield components (Kumar *et al*., 2008). Several researchers demonstrated positive influence of Zn fertilization on yield and qualitative parameters of potato crop (Mousavi *et al*., 2007).

Previous report indicated that an increase in the application of Zn significantly increased potato tuber size as compared to Zn untreated plant. Response of potato to micronutrients differed with soil group. Zinc is the most deficient micronutrient in almost all potato growing soils. The response of potato to applied micronutrients depends on the magnitude of the deficiency in the soil. Responses of potato are strikingly higher on micronutrient deficient soils than on other soils.

2.10. Effect of Boron on Potato Tuber Yield , Quality and Yield Components

Boron (B) is a micronutrient necessary for plant growth. Potatoes are heavy nutrient requiring crop because of their bulk yields within a short time having shallow root systems. In potato cultivation, some elements like Zn, B, S, and Mg can help in increasing the foliage coverage at initial growth stages and in the later stages, the translocation of assimilates is responsible for higher yield. The findings of (Bari *et al*., (2001) showed that application of 1.1 kg B/ha from borax increased potato fresh haulm weight/hill, number of tuber/hill, dry matter % of tubers and yield of tuber/ha. Similarly, Puzina (2004) reported that using boric acid in potato fertilization caused an increased in tuber size and weight by increasing of cell diameter in the tuber perimedullary zone. Tariq and Mott (2007) have also reported that potatoes require widespread application of boron and other micronutrients on the low organic matter content of soils and inefficient rooting system.

2.11. Concentration, Nutrient Uptake and Use Efficiency of Potato

Actual nutrient uptake will vary with crop yield and variety. The nutrient requirement of the crop can be met by nutrients available in the soil and by nutrient additions. The amounts of nutrients exploited in the harvested portion of the crop will depend on the yield and the concentration of the nutrients in time and space, variety, soil and environmental factors (Fageria *et al*., 2011). Fertilizer use efficiency depends to large extent on soil fertility conditions. To use fertilizer in a sustainable manner, management practices must aim at maximizing the amount of nutrients that are taken up by the crop and minimizing the amount of nutrients that are lost from the soil (Bationo *et al.,* 2012).

Adding micronutrients to NPK fertilizer can be increase fertilizer use efficiency and yield for different crops (Malakouti, 2008). Nutrient-use efficiency would be significantly improved with more root hairs per unit of root length, increased root growth longevity and density, and plants with greater rooting depth (Ruza *et al*., 2013). This improvement alone would significantly reduce the potential impact of potato production on water and environmental quality parameters, and decrease the production costs. Nutrient-use efficiency might also be increased by improved nutrient utilization within the plant via increased translocation or recycling. Improving agronomic efficiency provides both direct and indirect economic benefits: larger yield increases can be achieved for a given quantity of fertilizer applied; or less fertilizer is required to achieve a particular yield target (Bationo *et al.,* 2012).

3. MATERIALS AND METHODS

3.1. Description of the Study Site

The experiment was conducted at Asossa Agricultural Research Center (AsARC) in 2017 main cropping season on June under rain fed conditions, at Benishangul Gumuz Regional State of Ethiopia. The experimental site is located at an altitude of about 1553 meters above sea level. Benishangul Gumuz Regional State is geographically located between $9^{O}30'$ to $11^{O}39''$ N latitude and $34^{O}20'$ to $36^{O}30''$E longitude covering a total land area of 50,000 square kilometer.The experimental site is located between 10^{O} 02' 05" N latitude and $34^{O}34'$ 09" E longitudes. The experimental site is situated East of Asossa town and West of Addis Ababa about 4 km and 660 km distance, respectively. The AsARC is located from 10º 01' 25" to 10º 02' 50" N latitude and from 34º 33' 50" to 34º 34' 35" E longitude.

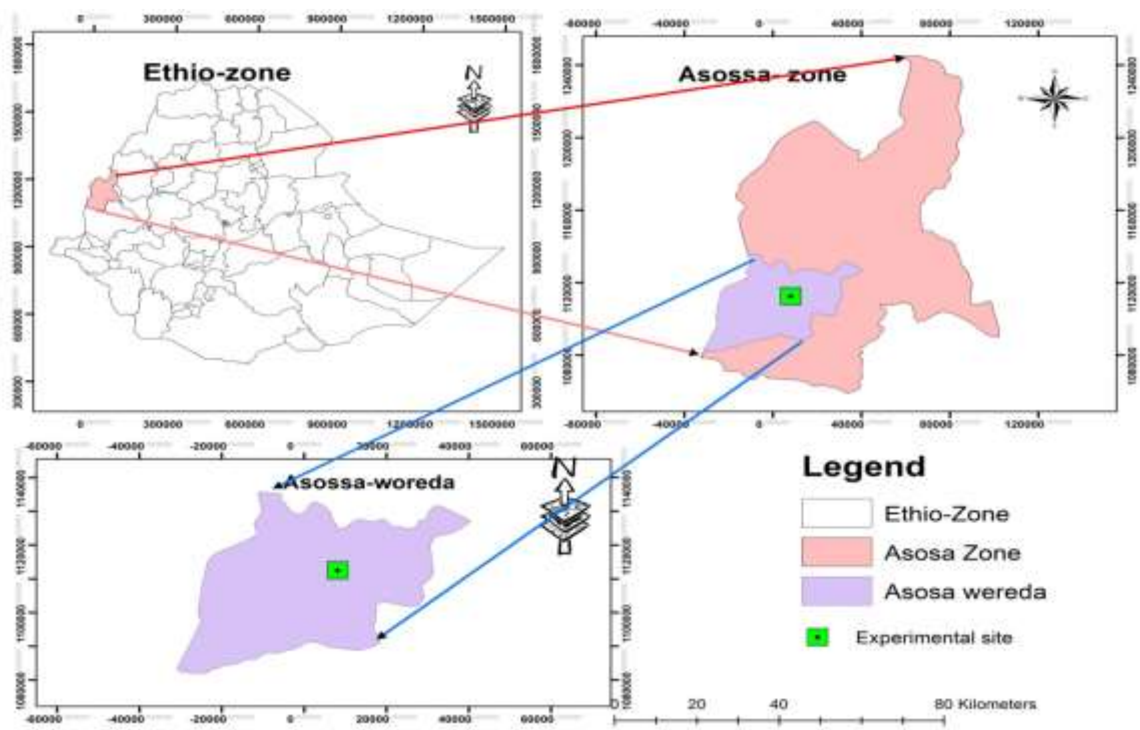

Figure 1. Map of experimental site at Assosa area, western Ethiopia

Asossa has unimodal rainfall pattern, which starts at the end of April and extends to mid-November, with maximum rainfall received in June, July, August, September, and October. The total annual average rainfall of Asossa is 1275 mm. The minimum and maximum temperatures are 14.33^{O}C and 28.43^{O}C, respectively. The dominant soil type of Asossa area is Nitosols and Fluvisols with the soil pH ranges from 5.1 to 6.0 (EARO, 2004). The major crops cultivated in the study area are mango, sorghum, maize, finger millet, soybean and potato (Meseret, 2016).

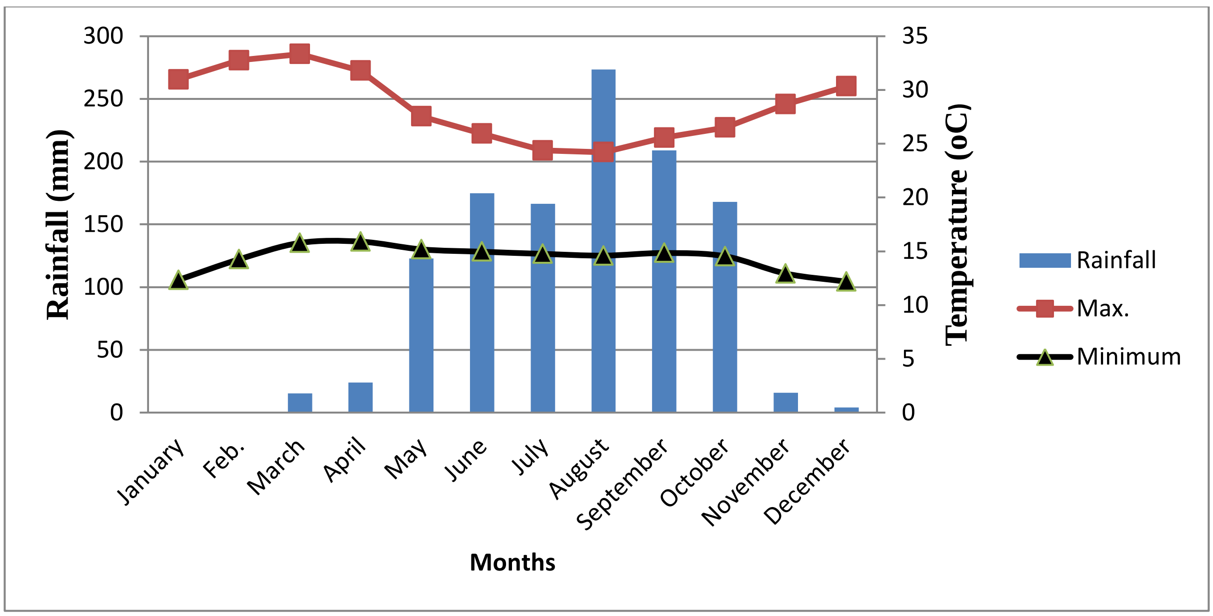

Figure 2. Seven years data of rain fall, average monthly maximum temperature and minimum temperatures at Assosa , western Ethiopia.

3.2. Experimental Procedures

The experimental field was well prepared during May and June 2017 using tractor and then human labour. Ridges were prepared after the plot was harrowed and leveled following the recommended ridge spacing (75cm between ridges) for potato planting. Medium-sized (40-60 g) and sufficiently sprouted potato tubers (with 2-3 cm long sprouts) were planted on one third position of the top of the ridges at the specified spacing (30 cm). Planting was done on 24 June, 2017. All agronomic activities like weeding, hoeing and earthing up were done based on the plant requirements.

3.3. Experimental Materials

The improved potato variety called ‘Belete(CIP-393371.58) released in 2009 by Holeta Agricultural Research Centre (HARC), was used as a planting material which was (MoARD, 2009). The variety is the prominent variety adapted and selected for Assosa areas by the Assosa Agricultural Research Center (AsARC) and it has wide range of environmental adaptation in Ethiopia. It requires from 110 up to 120 days for physiological maturity and considered as resistant to the late blight disease (Wassu, 2014).

NPSB (Formula 2) and NPSZnB (Formula 4) blended fertilizers rates , NPK and national blanket recommended of N and P rates selected for Assosa area were used following the EthioSIS soil fertility map (EthioSIS,2013). Nitrogen in blended fertilizers was adjusted from Urea source. Blended fertilizers, potassium from KCl source and phosphorus from TSP source were basal applied at planting and nitrogen was applied twice. Half of nitrogen was applied at planting time while the rest half applied at 40 days after planting as side dressing. The fertilizer materials are RNP (recommended Nitrogen and Phosphorus fertilizers), NPK, formula 2 (NPSB) and formula 4 (NPSZnB) blended fertilizers based on the soil information data of Ethio SIS (2013) the area.

3.3.1. Treatments and experimental design

The treatments consisted of control, two levels of formula 2:NPSB (100% and 200%) rates, two levels of formula 4:NPSZnB (100% and 200%) rates and three levels of recommended NP (50%, 100% and 150% NP) rates and recommended NPK. Additional N was added to most of the blended fertilizers to meet the N treatment complete (Table 1). Half of recommended NP (55 kg N and 45kg P_2O_5 per ha), full of recommended NP 100% (110 kg N + 90 kg P_2O_5 ha^{-1}) and 150% recommended NP (165 kg

N+135 kg P_2O_5 ha^{-1}) and full recommended NP and K (110 kg N+90 kg P_2O_5+ 69 kg K_2O ha^{-1}) . The experiment was carried out in a Randomized Complete Block Design (RCBD) with three replications. The nine treatments were assigned to each plot randomly. The total numbers of plots were 27 and each plot had a gross area of 11.25 m^2 with 3 m length and 3.75 m width. Spacing of 0.75 m x 0.30m were used in each plot having 50 plants where spacing between plots and adjacent blocks were 1m and 2 m, respectively.

Table 1.List of treatments

TN	Fertilizer type	Rates (kg/ha)	Compound fertilizers' nutrient contents (%)
1	Control	0	0 N - 0 P_2O_5 + 0 S + 0.0 Zn + 0.0 B
2	Half R NP	55 N + 45 P_2O_5	55N kg + 45 kg P_2O_5
3	Full R NP	110 N + 90 P_2O_5	110 N kg + 90 kg P_2O_5
4	150%Recommended NP	165 N+135 P_2O_5	165Nkg + 135kg P_2O_5
5	Recommended NPK	110 N+90 P_2O_5+ 69 K_2O	110 kg N+90 kg P_2O_5+ 69 kg K_2O
6	F2:100%NPSB	100% + 91.9 N	18.1 N +36.1 P_2O_5 + 6.7 S + 0.71 B
7	F2 :200%NPSB	200% + 128.8N	36.2 N + 72.2 P_2O_5 + 13.4 S + 1.42B
8	F4:100%NPSZnB	100% + 93.1N	16.9 N +33.8 P_2O_5 + 7.3 S + 2.23 Zn + 0.67B
9	F4 :200%NPSZnB	200% + 131.2 N	33.8 N +67.6 P_2O_5 + 14.6 S + 4.46 Zn + 1.34 B

TN= Treatment Number, F2= Formula 2, F4= Formula 4.

3.4. Soil and Plant Sampling

3.4.1 Soil sampling and analysis

Twelve random surface soil samples (0-30cm) were collected following diagonal sampling technique from the entire experimental field before planting and a composite was made. The composite sample was air dried ground and passed through 2mm sieve for analysis of selected physicochemical properties. For determinations of organic carbon and total N, 0.5mm sieve was used. Determinations of the soil physicochemical properties were carried out following standard laboratory procedures.

Representative composite soil samples (from 12 spots) were collected at 0-30cm depth with auger using diagonal sampling techniques from the whole field before planting. Thus, soil sample was subjected for physico-chemical analysis (soil texture, organic carbon, soil pH, total N, available P, exchangeable K, S, Zn, B and CEC). Bulk density was taken by using core sampler for analysis. The soil particle size distribution was determined using the hydrometer technique (Ryan *et al.*, 2001) while the soil textural class was identified from textural triangle (Motsara and Roy, 2008). The cation exchange capacity (CEC) was determined using 1N-neutral ammonium acetate method (Jackson, 1967). Soil pH was determined in 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter (Page, 1982).

Organic carbon content of the soil was determined following the wet oxidation method of Walkley and Black (1934). Total nitrogen was determined according to Kjeldahl procedure with sulfuric acid (Dewis and Freitas, 1984). Exchangeable potassium was extracted using 1N neutral ammonium acetate methods at pH 7 (Hesse, 1971) and determined with a flame photometer. Available phosphorus was determined by the Olsen method (Olsen *et al.*, 1954). Available S was determined using calorimeter method and available Zn was determined by dry ashing procedure.

3.4.2. Plant tissue sampling and analysis

Leaf and petiole plant parts were collected from five randomly selected plants from each plot. The samples were collected from healthy plant parts at flowering stage 4^{th} leaf from top and analyzed for N,P,K, S and Zn contents. Mobile nutrients are often found in higher concentrations in the younger, actively growing foliage, whereas immobile nutrients tend to concentrate in older parts of the plant *et al*.(2005).

Tubers were collected randomly from the net plot area at harvest from each plot and bulked over replication based on treatment for the determination of N, P, K, S and Zn contents using standard procedures. The collected samples were air-dried and oven dried (65^0C) plant samples which passed through 200 mesh sieve were used. The plant samples were ashed in furnace at temperature (450°C) for 4 hour with a solution of 1volume of nitric acid (HNO3) diluted in 3 volume of distilled water. Nitrogen content in plant tissue was determined by Kjeldahl method with sulfuric acid (Dewis and Freitas, 1984). Total phosphorus in the filtrate was determined by dry ashing procedures using vanadium phosphomolybdate (yellow color development) method by spectrophotometer at 460 nm wavelength and K was determined by dry ashing procedures using flame photometer after diluting by 20% HNO3 solution procedure as described by Motsara & Roy (2008). The concentration of Sulfur was determined by calorimeter and the concentration of Zn were determined by dry ashing procedure using an atomic absorption spectrophotometer method which described by Okalebo *et al*. (2002).

3.5. Data Collection and Measurements

Data were collected from the three middle rows, leaving aside plants in the border rows in order to avoid edge effects. Data were recorded on different phonological parameter, growth characteristics, yield and yield components, and tuber quality parameters.

3.5.1. Potato phenology

Days to 50% flowering: the numbers of days to 50% flowering were recorded (Shiri-e-Janagrad *et al*., 2009).

3.5.2. Plant growth parameters

Plant height (cm): refers to the height from the base to the apex of the plant. The heights of 10 randomly taken plants from the central three rows were measured using ruler at flowering stage (Zelalem *et al.*, 2009).

Number of main stems per hill: was recorded by counting the stems that originated from the tuber from 10 randomly taken hills.

Leaf area index (LAI): was obtained by dividing the value of the leaf area by the area of the land occupied by the plant using the following formula by Diwaker and Oswalt (1992):

$$Leaf area\ index = \frac{LA}{A} XN$$

Where; LAm = mean leaf area of the plant (cm^2); A = the area (cm^2) occupied by one plant in the cropping area; and N= number of leaves on the plant. Leaf area was calculated as product of the width and leaf length based on pre measured width and length of leaves from five plants randomly selected and tagged at flowering stage multiplied by a constant (0.674).

Leaf area =W*L*0.674, where 0.674 is the correction factor according to (Sakllova, 1979 quoted by Djilani and Senoussi, 2013).

Above ground dry biomass (t ha^{-1}): refers to the dry weight of leaves, stems and branches. It was determined from 5 randomly taken plants from the central rows just before senescence (at physiological maturity). Samples dry weight was taken after air-dried and then followed by oven-drying the samples at 70^{o}C (CIP, 1984).

Underground dry biomass (g): refers to the dry weight of roots, stolons, and tubers. It was determined from 5 randomly taken plants from the central rows at harvesting time. Samples dry weights was taken after air-drying and then followed by oven-drying the samples at 70^{o}C (CIP, 1984).

3.5.3. Potato tuber yield and yield components

Total tuber number per hill was obtained from five randomly selected plants from each plot by adding up the number of marketable and unmarketable tubers. This parameter constituted all tubers: small, medium, large, diseased, deformed and that are produced by the plants.

Mean tuber weight (g): was determined at harvest by dividing the weight of all tubers obtained from randomly taken 5 plants by the total number of tubers.

Marketable tuber yield (t ha^{-1}): the weight of tubers, which were free from diseases, insect pests, and greater than or equal to 25 g in weight, was recorded as marketable tuber yield (Habtam, 2012).

Unmarketable tuber yield (t ha^{-1}): the weight of tubers that are diseased and/or rotting ones and small-sized (less than 25 g in weight) was recorded (Habtam, 2012).

Total tuber yield (t ha^{-1}): the sum of tuber yield weights of marketable and unmarketable tubers

3.5.4. Tuber quality parameters

Specific gravity of tubers: was determined by the ratio of the tuber weight in air to the tubers weight in water method. Tubers of all shapes and size categories, which weighed about 3 kg, were randomly taken from each plot. The selected tuber was washed with water. The samples were first weighed in air and then re-weighed by suspended them in water. Specific gravity was calculated using the formula by Kleinkopf *et al* (1987).

$$Specific\ Gravity = \frac{Weight\ in\ air\ (g)}{Weight\ in\ air(g) - Weight\ in\ Water(g)}$$

Tuber dry matter content (%): Five fresh tubers were randomly selected from each plot and weighed. The tubers were sliced and dried in an oven at 65 ^{O}C for 24 hours. The dry matter percent was calculated according to the following formula (Williams, 1968).

$$Tuber\ Dry\ \ matter\ Content = \frac{\text{Weight of sample after drying (g)}}{\text{Intial weight of sample (g)}}\ \text{X}\ 100$$

Tuber size distribution in weight (g) : refers to the proportional weight of tubers in size categories. All tubers from five randomly taken plants were categorized into small (less than 39 g); medium (39-75 g), and large (greater than 75 g) according to Lung'aho *et al*. (2007).

3.6. Estimation of plant nutrient uptakes and nutrient use efficiencies

The nutrient accumulation and partitioning were calculated by multiplying nutrient concentrations in plant parts by the dry matter yield of the respective plant parts and the uptake of nutrient in economic and by-product of potato plant parts were estimated as Hashemidezfooli *et al*.(1998). The nutrients use efficiencies were calculated following the formula as outlined by Bationo *et al.* (2012).

Tuber nutrients uptake: Nutrients (N, P, K and S) uptakes in the tubers were calculated by multiplying N, P, K and S concentrations with dry matter accumulation of tuber.

Tuber nutrient Uptake = Nutrient concentration *dry matter accumulation of potato tuber

Potato tuber apparent recovery efficiency (ARE): refers to a measure of the ability of the crop to extract nutrients from the soil. Apparent recovery of N and P of tuber for each fertilized treatment was calculated as the uptake of each fertilized treatment minus uptake of control divide by the amount fertilizer applied in kg ha^{-1} .

$$\text{Apparent Recovery (ARE)} = \frac{Tuber\ uptake\ of\ fertilized\ treatment\ \frac{kg}{ha} - Tuber\ uptake\ of control\ kg/ha}{Amount\ fertilizer\ applied\ kg/\ ha} * 100$$

Agronomic efficiency: refers to the amount of additional yield produced for each additional kg of fertilizer applied (Mengel and Kirkby, 2001). Agronomic efficiency (AE) of blended and non-blended fertilizers was calculated as tuber yields of each fertilized treatment minus tuber yield of control divide by the amount fertilizer applied.

$$Agronomic\ Efficiency = \frac{Tuberyieldsoffertilizedtreatment\left(\frac{kg}{ha}\right) - Tuberyieldsofcontroltreatment\left(\frac{kg}{ha}\right)}{Amount\ fertilizer\ applied\ \frac{kg}{ha}}$$

3.7. Partial Budget Analysis

Partial budget analysis was done for each treatment. For economic evaluation, dominance analysis, cost and MRR calculated following the procedure CIMMYT (1988). Partial budget analysis was performed to investigate the economic feasibility of the treatments (fertilizer rates). The field price (6 Birr kg^{-1}) for potato tuber yield at time of harvesting and Urea (8.24 Birr kg^{-1}), TSP (12.75 Birr kg^{-1}), Potassium Chloride (9.08 Birr kg^{-1}) , NPSB (11.02 Birr kg^{-1}) and NPSZnB (11.70 Birr kg^{-1}) were used for analysis.

Gross marketable tuber yield ($kgha^{-1}$): is an average yield of each treatment.

Adjusted marketable tuber yield: is the marketable tuber yield adjusted reduced by 10% to reflect the difference between the experimental yield and yield of farmers (CIMMYT, 1988).

Adjusted marketable tuber yield = Marketable tuber yield - (Marketable tuber yield *0.1).

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

Total costs that vary: is the cost of fertilizers, application and transport that vary.

Calculation of net benefit: This was computed as the gross field benefit less the total costs that vary.

Marginal rate of return (MRR %): was calculated by dividing change in net benefit divided by change in cost. One way of assessing this change is to divide the difference in net benefits by the difference in costs that vary (CIMMYT, 1988).

$$MRR = \frac{Change\ in\ Net\ Benefit}{Change\ in\ Total\ Cost\ \ that\ vary} \text{ Or } MRR\% = \frac{Marginal\ Benefit}{Marginal\ cost} *100$$

3.8. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) according to Proc Mixed SAS (SAS, 2004) version 9.0 and interpretations were made following the procedure of Gomez and Gomez (1984). The correlation analysis was performed following pearson's simple correlation coefficients among dry tuber yield, nutrients concentration and uptake as influenced by nitrogen, phosphorus, potassium, and sulfur application rate when appropriate. The treatments having significant differences were separated by using LSD (Least Significant Difference) at 5% level of significance.

4. RESULTS AND DISCUSSION

4.1. Selected Physicochemical Properties of the experimental Soil

The results revealed that the soil was clay loam in texture with strongly acidic in reaction (pH 5.5). Report from Fageria *et al*. (2011) indicated at optimum growth of potato was found in the soil pH range of 5.2 to 6.5. Furthermore, the clay loamy soil texture was suitable for potato and other major crops production due to its good ability to retain nutrients and available water. High clay content causes .The density of clay is the causes two biggest drawbacks of soils as it swells when wet and creating difficulty to till (heavy soils). Clayey soils are poorly drained and thereby resulting in stunting of plant growth, clayey soils shrink when dry, forming dense colloids and cracking the soil surface. These drawbacks can be lessened by adding organic matter over time (http://www.southernmulch.com/article-what-is-clay-loam.php).

The experimental soil had medium CEC, 22.93 Cmol(+) kg $^{-1}$soil (Hazelton and Murphy (2007), but low in total nitrogen, 0.15% (EthioSIS ,2014). The available phosphorus (4.52 mg kg^{-1}), exchangeable potassium (9.98 mg kg^{-1}), available sulfur (3.01 mg kg^{-1}), zinc (0.34 ppm) were very low at experimental site (Table 2) in accordance with EthioSIS (2014). According to Jones (2003) soil boron content was low (0.61ppm). The organic carbon (1.75%) was medium at experimental site (Tekalign, 1991). These results signify that the soils require additional supply of plant nutrient to enrich the soil and make them available to plants nutrients.

Table 2. Selected chemical and physical properties of the soil of the experimental site before planting

Soil physicochemical properties	Contents	Rating	Reference
pH (H_2O)	5.5	strongly acidic	EthioSIS (2014)
Sand (%)	37		
Silt (%)	25		
Clay (%)	38		
Textural Class	Clay loam		FAO(1990)
Organic carbon (%)	1.75	medium	Tekalign (1991)
CEC (Cmol(+) kg $^{-1}$soil)	22.93	medium	Hazelton and Murphy (2007)
Total nitrogen (%)	0.15	Low	EthioSIS (2014)
Exchangeable potassium (ppm)	9.98	very low	EthioSIS (2014)
Available of phosphorus(mg/kg)	4.52	very low	EthioSIS (2014)
Sulfur (ppm)	3.01	very low	EthioSIS (2014)
Boron (ppm)	0.61	Low	Jones (2003)
Zinc (ppm)	0.34	very low	EthioSIS (2014)

4.2. Potato Phenology

4.2.1. Days to 50% flowering

The analysis of variance showed that blended and non-blended fertilizer types and rates highly significantly ($P < 0.01$) difference on days to 50% flowering of potato (Appendix Table 3). Increasing N and P application ranging from 0 to 165 kg N+ 135 kg P_2O_5 kg ha^{-1} prolonged the days required to attain 50% flowering of potato by about 4 days as compared to control. Similarly, application of NPK 110kg N + 90 kg P_2O_5 + 69 kg K_2O ha^{-1} prolonged the days required by the potato plants to attain 50% flowering by 2 days as compared to control. This is perhaps because of the fact that availability of excess N that enhances the photosynthetic activity and the vegetative growth of potato, while optimum P facilitates cell division and promotes root development of potato.

Optimum phosphorus applications mostly enhance early crop development and that the responses to phosphorus application decrease with time (Ekelof, 2007). Increasing of blended fertilizers slightly prolonged the days to reach 50% flowering of potato plants. This result is in line with the findings of (Zelalem *et al*., 2009; Israel *et al*., 2012) who noted excessive vegetative growth and delayed flowering due to high nitrogen levels. Similarly, Israel *et al*. (2012) reported that increased phosphorus application prolonged the days to 50% flowering.

Table 3. Days to 50% flowering influenced by the application of blended and non blended fertilizer types and rates.

Fertilizers (kg ha^{-1})	Days to 50% Flowering
Control	50.00^{d}
55 N + 45 P_2O_5	51.00^{cd}
110 N + 90 P_2O_5	52.33^{bc}
165 N + 135 P_2O_5	54.33^{a}
110 N + 90 P_2O_5 + 69 K_2O	52.33^{bc}
100% NPSB+ 91.9 N	52.00^{bc}
200% NPSB + 128.8N	53.67^{ab}
100% NPSZnB + 93.1N	51.67^{dc}
200% NPSZnB + 131.2 N	52.67^{abc}
LSD 5%	1.68
CV%	1.86

Means followed by the same letter (s) within a column are not significantly different at P<0.05 of significance; LSD = least significant difference; and CV= Coefficient of Variation.

4.3. Potato Growth Parameters

4.3.1. Plant Height

The analysis of variance showed that blended and non-blended fertilizer types and rates had significantly ($P< 0.05$) influenced potato plant height (Appendix Table 3). Application of 110 kg N+90 kg P_2O_5 + 69 kg K_2O ha^{-1} significantly increased plant height by 16-21 cm, compared to other treatments while plants under control had the shortest shoot length compared to the rest of the treatments. However, shoot elongation was slightly higher with plants treated with unblended fertilizer (average mean difference of 2.3cm) than blended fertilizers. Additionally, significant increase in plant height was observed when K_2O was supplied together with N and P_2O_5 as compared to control and other treatments. This shows that potash contributes to increased cell division and elongation and whereby it resulting in higher canopy development. This is in line with that of Marschner (1995) who reported that potassium results in enhanced cellular growth and development.

Application of potash with recommended rate of nitrogen and phosphorus significantly enhanced height of potato plant (Alemayehu (2017). Increasing application of combined N and P at ranging rates from 0 to 55kg N +45kg P_2O_5 ha^{-1}, 110 kg N+90 kg P_2O_5 ha^{-1}and165 kg N+ 135 kg P_2O_5 ha-^{1} increased plant height by 9 ,15, and 20%, respectively over the control. Increasing application of F2 rates (100% NPSB to 200%NPSB with N adjustment) increased plant height by about 19% and 22%, respectively, over the control.

Similarly, increasing application of blended fertilizers rates (100%NPSZnB to 200% NPSZnB with N adjusted) increased plant height of potato by about 10 and 13% as compared to control treatment. The finding is in line with the finding of Singh and Ragav (2000) who reported that the significant interaction between N and K to the better utilization of N in presence of K attributed in increased plant height. The results are also in agreement with that of Firew *et al*. (2016) who reported that increasing nitrogen and phosphorus rates increased the height of potato plants.

4.3.2. Number of main stems per hill

The analysis of variance revealed that number of main stems per hill was not significantly ($P>0.05$) affected by blended and non-blended fertilizer types and rates (Appendix Table 3). The present results are consistent with finding of Habtam (2012) who stated that number of main stems per hill was not affected by application of phosphorus rates. Similarly, this result is in line with findings of (Israel *et al*. 2012 and Mulubrhan, 2004), who reported that mineral fertilizers like nitrogen and phosphorus did not affect the number of main stem of potato. This is might be due to the influence of variety, seed tuber size, and physiological age of the seed, storage condition, and number of viable sprouts at planting, sprout damage at the time of planting and growing conditions (De La Morena *et al.,* 1994). Others Lung'aho *et al*. (2007) also argued that stem number is basically determined by the number of eyes present on the tubers and the physiological age of the tuber during the storage period rather than by manipulating the supply of plant nutrients.

4.3.3. Leaf area index

The analysis of variance showed that leaf area index was highly and significantly ($P<0.01$) affected by blended and non-blended fertilizer types and rates (Appendix Table 3). Plants treated with 200% NPSB with N adjustment had higher significant leaf area index of 89% as compared to control. However, leaf area index was slightly higher with plant treated with blended fertilizers than non-blended fertilizers. This is might be due to combination of macro with micro nutrients like Zn and B fertilizers blends to NPS. This results are in line with the finding of Salam *et al.* (2004) reported that B increased the plant growth, leaf area index, and root length of crops. Boron improves in growth parameters of tomato which might be due to the enhanced photosynthetic activity and metabolic activity with the application of B (Sathya *et al*., 2009 quoting Lalit Bhatt *et al*., 2004).

The supply of Zn also increased leaf area index of potato during early stage of growth which might be due to its influence on basic plant life process such as nitrogen metabolism and higher rate photosynthetic activity (Paygozar *et al*., 2009). This is indicative of the considerable increase in cytokinin as well as chlorophyll content in the leaves and finally an enhancement of photosynthetic activity of the plant (Puzina, 2004).

Table 4.Growth parameters of potato as influenced by blended and non-blended fertilizer types and rates at Assosa during the main cropping season of 2017.

Fertilizers applied kg/ha	NMS	PH(cm)	LAI	AGDB ton/ha	UGDB (ton/ha)
0 (Control)	3.17	53.17^{c}	1.93^{d}	0.74	0.782^{d}
55N +45P_2O_5	3.27	57.77^{bc}	2.29^{cd}	1.12	3.06^{c}
110 N+90 P_2O_5	3.47	60.93^{bc}	3.25^{ab}	1.64	4.31^{bc}
165N+ 135 P_2O_5	3.83	63.77^{b}	3.12^{abc}	1.92	5.06^{ab}
110 N+90 P_2O_5+ 69 K_2O	2.33	73.93^{a}	3.12^{abc}	2.05	6.31^{a}
100% NPSB+ 91.9 N	3.6	63.2^{b}	3.59^{ab}	1.79	4.41^{bc}
200% NPSB + 128.8N	3.33	65.03^{ab}	3.65^{a}	1.80	5.05^{ab}
100% NPSZnB + 93.1N	3.67	58.5^{bc}	2.71^{bcd}	1.79	3.35^{bc}
200% NPSZnB + 131.2 N	3.7	60.33^{bc}	3.63^{a}	2.50	2.69^{c}
LSD 5%	Ns	5.18	0.91	Ns	1.78
CV %	19.39	8.39	17.39	36.13	21.07

Means followed by the same letter within a column are not significantly different at 5% level of significance; LSD = least significant difference; and CV= Coefficient of Variation; NMS= Number of Main Stem; PH= Plant Height; LAI= Leaf Area Index; AGDB =Above Ground Dry Biomass (tha^{-1}); UGDB= Under Ground Dry Biomass (tha^{-1}).

4.3.4. Above ground dry biomass

The analysis of variance showed that above ground dry biomass was not significantly (P>0.05) affected by blended and non-blended fertilizer types and rates (Appendix Table 3). The highest above ground dry biomass (2.5 t ha^{-1}) was obtained at application of 200% NPSZnB + 131.2 kg N ha^{-1} fertilizer, whereas the lowest above ground dry biomass (0.74 t ha^{-1}) was obtained from control treatment. In fact, increasing nitrogen and phosphorus rates from 0 to 150% NP fertilizer rates increased above ground dry biomass yield. However, increasing NP rates in blended fertilizers with adjusted N did not reveal significant difference among treatments. This might be due to supply of similar nitrogen rates on both blended and non blended fertilizers. The present result is in contrast to the finding of Israel *et al*. (2012) who stated that increasing phosphorus and nitrogen fertilizers rates increased above ground dry biomass yield significantly.

4.3.5. Underground dry biomass

Analysis of variance showed that blended and non blended fertilizer types and rates had highly significant ($P<0.01$) in terms of underground dry biomass yield (Appendix Table 3). The highest underground dry biomass yields (6.31 t ha^{-1}) was obtained at application of NPK (110 kg N+90 kg P_2O_5+ 69 kg K_2O ha^{-1}) whereas the lowest underground dry biomass yields (0.782 t/ha) was obtained at application of zero fertilizer (control treatment). Increasing combined NP fertilizers rates from 0 to 165 kg N +135 kg P_2O_5 ha^{-1} increased underground dry biomass yield of potato linearly. However, plot treated with potassium together with recommended NP fertilizers showed significant response as compared to others treatments. This is due to the fact that potassium application activates number of enzymes involved in photosynthesis, carbohydrate metabolism and assists in the translocation of carbohydrates from leaves to tubers. Potassium increases the yield by increasing the number and yield of large sized tubers. According to Asmaa and Hafez (2010) who stated that higher application of potassium resulted in higher biomass production in potato as compared to lower K application.

Increasing application of blended fertilizers of 100% NPSB to 200% NPSB with N adjustment increased underground dry biomass yield linearly as compared to control treatment. Similarly, increasing application of blended fertilizers of 100% NPSZnB to 200% NPSZnB with N adjustment increased underground dry biomass yield when compared to control. The present finding is in agreement with that of (Zelalem *et al.* 2009; Israel *et al*. 2012 and Mulubrhan, 2004) who reported that interaction of nitrogen and phosphorous significantly influenced tuber dry weight of potatoes. In similar manner FAO (2000) reported that good supply of nitrogen to the plant stimulates root growth and development as well as uptake of other nutrients.

4.4. Yield and Yield Components

4.4.1. Total tuber number per hill

Analysis of variances revealed that blended and non-blended fertilizer types and rates had no significant differences ($P>0.05$) in terms of total tuber number per hill (Appendix table 4). The current results are in contrast to the findings of (Mahmoodabad *et al*., 2010; Israel *et al*., 2012; Birtukan, 2016) who reported that increasing the application of nitrogen and phosphorus increased total tuber number per hill. In fact increasing combined application of nitrogen and phosphorus from zero to full recommended NP fertilizers rate increased number of tuber per hill. Plot treated with 200% NPSB with adjusted N ha^{-1} recorded highest tuber number per hill. This might be due to presence of B in the blends with that of NPS fertilizer. This result confirm the findings of Bari *et al*. (2001) who reported that application of 1.1 kg B ha^{-1} as borax increased potato tuber number $hill^{-1}$. There are controversial reports regarding the influences of nutrition effect on potato tuber number. Tuber number is not an important yield limiting component while studying mineral nutrition (Lynch and Rowberry, 1997) , that could be due to the inverse association between tuber number and average tuber weight (De La Morena *et al*., 1994).

4.4.2. Mean tuber weight (g)

Analysis of variance revealed that mean tuber weight was significantly ($P<0.05$) affected by blended and non-blended fertilizer rates and types (Appendix Table 4). The highest mean tuber weight was obtained from application of 110 kg N+90 kg P_2O_5+ 69 kg K_2O ha^{-1}, while the lowest mean tuber weight was recorded from the control treatment. Application of recommended NPK (110 kg N+90 kg P_2O_5+ 69 kg K_2O ha^{-1}) increased mean tuber weight by 97% as compared to control treatment.

Increasing nitrogen and phosphorus rates from zero to 55 kg N +45 kgP_2O_5, 110 kg N+90 kg P_2O_5, 165kg N+ 135 kg P_2O_5 ha^{-1} increased mean tuber weight by 11 ,6 and 26%, respectively as compared to control treatment. Increasing application of blended fertilizers from 100%NPSB to 200% NPSB with N adjustment increased mean tuber weight of potato crop by about 11% and 16%, respectively over the to control treatment. Similarly, increasing of 100%NPSZnB to 200%NPSZnB with N adjustment fertilizers increased mean tuber weight of potato crop by about 25 and 29%, respectively as compared to control treatment.

In general, higher mean tuber weight was obtained from plots treated with NPK, followed by NP than as compared to those treated with the blended fertilizers. This might be due to the effect of K on potato tuber weight increment. Additionally, the macronutrients in blended fertilizers like S and micronutrients like Zn might have some sort of antagonistic relationship with P that might have negatively affected the efficient utilization of P by potato. The increase in average tuber weight of tubers in response to potassium supply could be due to more luxuriant growth, more foliage and higher supply of photosynthesis which may have induced formation of bigger tubers thereby resulting in higher yields (Patricia and Bansal, 1999). This result is in agreement with the finding of De La Morena *et al.* (1994) who reported significant yield increments due to potassium nutrition, attributing it to effect on average tuber weight. Similarly, average tuber weight was reported to increase in response to the application of K by Panique *et al.*(1997) and Habtam (2012).

4.4.3. Unmarketable tuber yield

Unmarketable tuber yield was not significantly ($P>0.05$) affected by application of blended and non blended fertilizer types and rates (Appendix Table 4). The minimum unmarketable tuber yield (3.53 t ha^{-1}) was received from the application of NP (55kg N +45 kg P_2O_5 ha^{-1}) whereas maximum unmarketable tuber yield (6.35 t ha^{-1}) was obtained at application of 100% NPSB with N adjusted fertilizers. But, the unmarketable tuber yield (4.94 tha^{-1}) obtained from control could be due to small sized tuber and diseased. Application of NPSB fertilizers gave higher number of tuber per hill, but average tuber weight obtained from the application of NPSB with adjusted N rates were lower as compared to others treatments. These small mean tuber weight recorded under unmarketable tuber yield due to under tuber sized and diseased. This result in high unmarketable tuber yield might be due to the increased nitrogen that might have accelerated the growth of aboveground biomass and promoted re-absorption tubers, leading to reduced tuber size and weight and thereby high unmarketable tuber yields as suggested by Gebremedhin *et al.* (2008a) in response to increased rate of nitrogen.

4.4.4. Marketable tuber yield

Analysis of variance showed that marketable tuber yield was significantly ($P < 0.05$) influenced by blended and non- blended fertilizer types and rates (Appendix Table 4). Maximum marketable tuber yield (30.03 t ha^{-1}) was obtained from application of NPK (110kg N + 90 kg P_2O_5 + 69 kg K_2O ha^{-1}) whereas minimum marketable tuber yield (10.23 t ha^{-1}) was recorded from the control treatment. Increasing nitrogen and phosphorus fertilizers rates from 0 to 150% NP (165 kg N+ 135 kg P_2O_5 ha^{-1}) increased marketable tuber yield by 114% as compared to control treatment. Application of potassium 69kg K_2O ha^{-1} with 110 kg N+ 90 kg P_2O_5 ha^{-1} increased marketable tuber yield of potato by about 195% as compared to control treatment. In fact that potassium with NP application gave significant difference on marketable tuber yields when compared to NP and blended fertilizers rates. This is due to potassium increases yield, size of tuber, resistance against drought and diseases.

Increasing blended fertilizers rates of 100% NPSB to 200% NPSB with adjusted N increased marketable tuber yield by 103 and 117 %, respectively as compared to control treatment. Similarly, increasing blended fertilizers rates of 100%NPSZnB to 200%NPSZnB with adjusted N increased marketable tuber yield by 67 and 83%, respectively over the control treatment. Generally, increasing the rates of blended fertilizers with adjusted nitrogen increased marketable tuber yield. However, plots that received NPSZnB with N rates produced low marketable tuber yield as compared to NPSB with N rates. It might be due to the antagonistic interaction of phosphorus with zinc. Similarly, Barben *et al.* (2007) also noted that P interacts with many nutrients, the most commonly observed and studied antagonistic interaction being with Zn. This is might be due to attraction of the positive and negative ions formation of a chemical bond in either the soil or the plant tissue.

The current result is in agreement with work of many researchers (Israel *et al*., 2012; Burtukan, 2016) who had reported that increasing nitrogen and phosphorus increased marketable tuber yield. Similarly, results of the present study are in line to the finding of Mahmoodabad *et al.* (2010) who reported that nitrogen and phosphorus application had significant and synergistic effect in increasing marketable tuber yield of potato.

4.4.5. Total tuber yield

Analysis of variance showed that total tuber yield was highly significantly ($P < 0.05$) influenced by blended and non-blended fertilizer types and rates (Appendix Table 4). The lowest total tuber yield (15.17 t ha^{-1}) and highest total tuber yield (34.58 tha^{-1}) were recorded from control and combined application of NPK (110 kg N+90kg P_2O_5+ 69 kg K_2O ha^{-1}) fertilizers, respectively. Increasing nitrogen and phosphorus fertilizers rates from 0 to 150 % NP (165 kg N+ 135 kg P_2O_5 ha^{-1}) increased total tuber yield of potato by 79% as compared to control. Application of potassium with 110 kg N+ 90 kg P_2O_5 ha^{-1}increased total tuber yield of potato by 128% as compared to potato grown in control treatment. In fact that potassium enhances nitrogen use efficiency by favoring protein formation. This result is in agreement to the finding of Naz *et al.* (2011) indicated that NPK fertilizers improve yield and quality of potato tubers.

The results of the study are also consistent to that of Asmaa and Hafez (2010) who reported significant increments in yield due to potassium application. Similarly, Potato requires high amounts of NPK but more K fertilizer for optimum growth, production and tuber quality (Al-Moshileh and Errebi, 2004). According to Mulubrhan (2004) increasing nitrogen and phosphorus increased total tuber yield. Wassie (2011) also reported potato yield increased of 114-341% on Nitosols using KCl.

Table 5. Influence of blended and non blended fertilizer types and rates application on yield and yield components of potato at Assosa during the main cropping season in 2017.

Fertilizer applied kg/ha	MTW (g)	TTNPH	MTY (ton/ha)	UMTY (ton/ha)	TTY(ton/ha)
0 (Control)	52.96[b]	7.13	10.23[c]	4.94	15.17[c]
55 N +45	58.92[b]	8.73	17[bc]	3.53	20.54[bc]
110 N+90 P_2O_5	56.04[b]	10.33	19.35[b]	4.97	24.32[b]
165 N+ 135 P_2O_5	66.54[b]	10.07	21.88[ab]	5.29	27.18[ab]
110 N+90 P_2O_5+ 69 K_2O	104.4[a]	10.07	30.03[a]	4.55	34.58[a]
100% NPSB+ 91.9 N	55.67[b]	11.33	20.81[b]	6.35	27.16[ab]
200% NPSB + 128.8N	61.52[b]	12.67	22.25[ab]	5.28	27.54[ab]
100% NPSZnB + 93.1N	66.12[b]	8.8	17.12[bc]	3.86	20.99[bc]
200% NPSZnB + 131.2 N	68.68[b]	9.73	18.74[b]	4.67	23.41[b]
LSD 5%	24.15	NS	8.27	NS	7.92
CV%	21.26	20.28	24.23	22.56	18.65

Means followed by the same letter within a column are not significantly different at 5% level of significance; Ns = Not Significant; LSD = least significant difference; and CV= Coefficient of Variation; MTW = Mean Tuber Weight (g); TTNPH= Total Tuber Number Per Hill MTY=Marketable Tuber Yield (ton/ha); UMTY= Unmarketable Tuber Yield (ton/ha); TTY= Total Tuber Yield (ton/ha).

4.5. Potato Tuber Quality

4.5.1. Specific gravity of tubers

Analysis of variances showed that specific gravity was not significantly ($P>0.05$) affected by application of blended and non-blended fertilizer types and rates (Appendix table 5). These results are in agreement with the finding of Simret *et al.* (2010) have noted a non-significant difference in specific gravity of tubers due to nitrogen. Zelalem *et al.* (2009) have also reported non-significant effect of phosphorus on the specific gravity of potato tubers. Similarly, Sharma (2004) have also observed that increasing levels of phosphorus did not influence specific gravity of potato tubers. Eskin *et al. (*1989) as quoted by Firew *et al.* (2016) reported that the specific gravity in potatoes is very variable and may range between 1.050-1.1106.Which was confirmed by the present finding. Tubers with high specific gravity generally give higher yields of chips, have lower oil absorption and better texture and therefore, are more economical to process.

4.5.2. Tuber dry matter content

Analysis of variance showed that tuber dry matter content was significantly ($P<0.05$) affected by application of blended and non-blended fertilizer rates and types (Appendix table 5). The highest tuber dry matter content (26.8%) was obtained at application of NPK (110 kg N+90kg P_2O_5+ 69kg K_2O ha^{-1}) whereas the lowest tuber dry matter content (21.23%) was recorded from the application of half of recommended NP (110 kg N +90 kg P_2O_5 ha^{-1}). The highest dry matter was obtained due to potassium application with NP fertilizers since K is known to play significant role on tuber dry matter content. Similarly, Tawfik (2001) reported that potato plants fertilized with high K had significantly higher dry matter content than those of low ones. Increasing application of fertilizers from 0 to NP rates (55 kg N +45kg P_2O_5, 110 kg N+90 kg P_2O_5 $ha^{-1}$and 165 kg N+ 135kg P_2O_5 ha^{-1}) decreased tuber dry matter content by about 2, 15 and 7% as compared to control treatment, respectively. According to Kanzikwera *et al.* (2001) have reported a significant reduction in percent dry matter content due to an increase in the application rate of N. This may be attributed to the fact that high rates of N stimulate top growth more than tuber growth thereby delaying tuber formation and maturity.

This result is coherent with the finding of Alisson *et al*. (2001) reported that the balanced nutrient management with nitrogen, potassium and phosphorous fertilizers led to highest tuber specific gravity and tuber dry matter in potato. Tubers with high dry matter content better texture and are more economical to process potato tuber with dry matter contents greater than 20% is the most preferred for processing of tuber into different potato products Tesfaye *et al*. (2013).

4.5.3. Tuber size distribution

Small and medium size tubers were non-significantly (P>0.05) affected by blended and non-blended fertilizer rates and types (Appendix Table 5). This study is in contrast to the findings of Firew *et al*.(2016) who reported that small and medium tuber size tubers were affected by nitrogen and phosphorus fertilizers rates. This might be attributed to the type of variety mostly gives large tuber size that does not make significance difference under small and medium tuber size among treatments while blended and non-blended fertilizers rates and types gave significance response under categories of large tuber size either by increasing number of tubers or weight of tubers. The present result is consistent with that of Knowles and Knowles (2006) who reported that tuber number and tuber size frequently have an inverse relationship, but increases in phosphorus fertilization have been accompanied by both increases in tuber numbers and decreases in tuber size (Jenkins and Ali, 2000).

On the other hand, large size tuber was significantly (P<0.05) affected by blended and non-blended fertilizers types and rates (Appendix Table 5). The highest (26.8 t ha^{-1}) and the lowest (6.66 tha^{-1}) yield of large tuber size were obtained at application of recommended NPK (110kg N+90 kg P_2O_5+ 69 kg K_2O ha^{-1}) and control, respectively. Increasing application of fertilizers from 0 to 150% NP (165kg N+

135 kg P_2O_5 ha^{-1}) increased yield of large tuber size by 163% as compared to control treatment. However, a combined application of 69 kg K_2O with 110 kg N+90 kg P_2O_5 ha^{-1} revealed that higher significant response in terms of large tuber size yield than others treatments. Increase in the yield of large-sized tubers due to potassium fertilization may be ascribed to the stimulating effect of potassium on photosynthesis, phloem loading and translocation, as well as synthesis of large molecular weight substances within storage organs that may be contributing to the rapid bulking of the tubers (Singh, 1999). Additionally, it could also be due to the role of K play an important role in carbohydrate formation, transformation and movement of starch from leaves to tubers (Vander Zaag, 1981).

Table 6.Quality parameters of potato as influenced by blended and non blended types and rates of fertilizer at Assosa during the 2017 main cropping season.

Fertilizers (kg ha^{-1})	Potato tuber size distribution in t ha^{-1}			SG	TDMC %
	SSTY (<39g)	MSTY (39-75g)	LSTY (>75g)		
Control	1.77	6.74	6.66^{c}	1.053	24.92^{ab}
55 N +45 P_2O_5	2.66	6.32	11.55^{bc}	1.071	24.41^{ab}
110 N+90 P_2O_5	3.56	6.38	14.38^{bc}	1.074	21.23^{c}
165 N+ 135 P_2O_5	3.68	5.99	17.5^{ab}	1.085	23.15^{bc}
110 N+90 P_2O_5+ 69 K_2O	2.41	5.37	26.8^{a}	1.103	26.8^{a}
100% NPSB+ 91.9 N	4.64	6.66	15.86^{bc}	1.102	22.29^{bc}
200% NPSB + 128.8N	4.56	6.46	16.52^{b}	1.059	22.64^{bc}
100% NPSZnB + 93.1N	2.05	6.2	12.74^{bc}	1.111	23.33^{ab}
200% NPSZnB + 131.2 N	4.03	7.07	12.31^{bc}	1.072	24.34^{ab}
LSD 5%	Ns	Ns	9.45	Ns	2.97
CV %	47.27	30.71	36.59	4.99	7.25

Means followed by the same letter within a column are not significantly different at 5% level of significance; Ns = Not Significant; LSD = least significant difference; and CV= Coefficient of Variation; SG= Specific Gravity; TDMC = Tuber dry matter Content in percentage.

Increasing application of blended fertilizers from 100%NPSB to 200% NPSB with adjusted N increased yield of large size tuber by 138 and 148%, respectively as compared to control. And increasing application of blended fertilizers of 100% NPSZnB with 93.1kg N ha^{-1} to 200% NPSZnB with 131.1kg N ha^{-1} increased potato yield of large tuber size by 91% and 85%, respectively as compared to control. This result in agreement with the finding of Habtam (2012) who reported that potassium increased large tuber size yields. This study is also in line with the finding of Firew *et al*. (2016) who stated that increasing N and P increased large tuber sized yield of potato.

4.6. Nutrients (N, P, K, S,) Uptake and Concentration of Potato

4.6.1. Concentration of nutrients (N, P, K, S) in potato leaf plus petiole and tuber

The analysis of variance showed that application of blended and non-blended fertilizer types and rates had no significant (P>0.05) influence on N concentration in tuber and leaf petiole (Appendix Table 6). Increasing nitrogen fertilizers rates decreased the concentration of nitrogen in potato tuber. This might be due to dilution effect of nitrogen in potato tuber dry matter accumulation. This result in line with the finding of Jarrell and Beverly (1981) who reported that lower nutrient concentrations were associated with the higher dry matter production of the crop as a result of dilution effect.

Bergmann (1992) who stated that the content of nitrogen in potato leaves during the early bloom is in the range from 5.00 to 6.50%. Similarly, Neshev and Manolov (2016) found that nitrogen concentration in shoot ranged between 3.84 to 4.52%. Pushparajah (1997), who classified leaf N as low (< 3.2%), medium (3.2-3.5%), high (3.5-3.7%) and very high (> 3.7%), thus the leaf and petiole N concentration of the present study could be rated as very high.

The analysis of variance showed that application of blended and non-blended fertilizer types and rates had no significant (P>0.05) influence on P concentration in tuber and leaf petiole (Appendix Table 6). Plot treated by potassium with NP decreased in phosphorus concentration in leaf plus petiole.

According to Reis Jr and Monnerat, (2000) reported that phosphorus concentration was decreased due to increasing levels of K concentration in the leaf and petioles. Pushparajah (1997) grouped leaf P as low (< 0.19%), medium (0.20-0.25%), high (0.26-0.28%) and very high (> 0.28%) , thus the leaf and petiole P concentration of the present study could be rated as high and very high.

The analysis of variance showed that application of blended and non-blended fertilizer types and rates had no significant (P>0.05) influence on K concentration in tuber and leaf petiole (Appendix Table 6). Tuber potassium levels tend to decreased with advancing age (Habtam , 2012 quoting Jackson and Haddock, 1959). The authors also found the critical range of potassium concentration level at in early season values range in 3.49 and 2.14 %, mid-season values range in 2.4 and 2.14 %, late season values range in 2.00 and 1.71% and at harvest tuber K ranges in 2.13 and 1.41%.

Tissue nutrient concentrations tend to vary for several reasons, including variation in tissue sampling techniques, type and age of tissue sampled, and potato varieties used (Walworth and Muniz, 1993). Potassium deficiency is found when the content in leaves is below 1.00 % (Kumar and Sharma, 2013).This indicated that potassium in the soil of the study site could be deficient, calling for potassium application via fertilizer. Soil physicochemical analysis before planting revealed that exchangeable potassium in soil was very low. In contrast, according to Ethiosoils (2013) reported that Assosa area has no potassium deficiency.

The analysis of variance showed that application of blended and non-blended fertilizer types and rates had no significant (P>0.05) influence on S concentration in tuber and leaf petiole (Appendix Table 6). Adequate sulfur concentration in leaf plus petiole at flowering was ranged from 0.3 to 0.5% (Hochmuth *et al*., 2015). In this study the S concentration revealed deficient, it calling to add more sulfur than applied. The maximum S concentration (0.17%) in potato tuber was recorded from the application of zero (control) while the minimum lowest concentration (0.12%) in potato tuber was recorded from the application of 100% NPSZnB with adjusted N ha^{-1}. This might be due to the dilution effect of sulfur concentration in the dry matter of potato tuber.

Table 7. Effects of blended and non-blended fertilizer types and rates on nutrients concentrations in leaf, and petiole, and tuber of potato

Treatments ($kgha^{-1}$)	Nutrients concentration in leaf and petiole				Nutrient concentration in tuber			
	N %	P%	K%	S%	N%	P%	K%	S%
Control	4.32	0.28	0.81	0.068	2.49	0.22	0.19	0.17
55N +45 P_2O_5	4.02	0.26	0.89	0.053	2.04	0.23	0.19	0.14
110 N+90 P_2O_5	4.61	0.29	0.75	0.055	1.93	0.26	0.21	0.13
165 N+ 135P_2O_5	4.61	0.29	0.6	0.057	1.89	0.27	0.21	0.13
110 N+90P_2O_5+ 69 K_2O	4.43	0.26	1.07	0.059	1.54	0.27	0.22	0.16
100% NPSB+ 91.9 N	4.62	0.26	0.76	0.058	2.91	0.23	0.2	0.16
200% NPSB + 128.8N	5.13	0.29	0.82	0.070	2.57	0.25	0.19	0.13
100% NPSZnB + 93.1N	4.72	0.31	0.69	0.063	2.09	0.23	0.17	0.12
200% NPSZnB + 131.2 N	4.43	0.29	0.77	0.041	1.98	0.24	0.2	0.16
LSD 5%	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
CV%	8.03	11.19	20.67	27.09	37.69	30.38	12.48	41.33

Means followed by the same letter within a column are not significantly different at 5% level of significance; Ns = Not Significant; LSD = least significant difference; and CV= Coefficient of Variation

4.6.2. Nutrients (N, P, K and S) uptake by tuber

The analysis of variance revealed that N uptakes not significantly (P>0.05) affected by blended and non-blended fertilizer types and rates (Appendix Table 9).The present result in line with finding of Haifa (2016) who indicated that the amount of nutrients removed by a potato crop is closely related to yield. This result also in agreement with the finding of Ruza *et al*. (2013) who reported that N uptake by potato plants was growing in a linear fashion with each subsequent nitrogen dose. Kołodziejczyk (2014) stated that nitrogen uptake and potato tuber yield increased with increasing nitrogen fertilization level from 62 kg N ha^{-1} (control, N0) to 150 kg N ha^{-1} (N180 application). In this study, nitrogen tuber uptake was ranged from 22.21 kg ha^{-1} N (zero N) to 130.43 kg ha^{-1} N (165kg N ha^{-1}). Nitrogen uptake by potato plants might be greatly variable and depends on the cultivar and climatic and environmental conditions affecting N mineralization and losses (Zebarth, 2005).

Analysis of variance revealed that phosphorus tuber uptake highly significantly (P<0.01) affected by blended and non blended fertilizer types and rates (Appendix Table 9). The highest (15.76 kg ha^{-1}) phosphorus tuber uptake was obtained from application of 110 kg N+90 kg P_2O_5+ 69 kg K_2O ha^{-1} while lowest (1.72 kg ha^{-1}) tuber phosphorus uptake was observed at application of control treatment. The uptake of P might have been pronounced by availability of potassium. According to Trehan *et al*. (2008) reported that phosphorus uptake of healthy potato plant was ranged from 25 to 30 kg P_2O_5.

Analysis of variance revealed that potassium tuber uptake highly significantly (P<0.01) affected by blended and non blended fertilizer types and rates (Appendix table 9). The highest (13.94 kg ha^{-1}) potassium uptake of tuber was recorded from the application of 110kg N+90 kg P_2O_5+ 69kg K_2O ha^{-1} while the lowest (1.37 kg ha^{-1}) potassium uptake of tuber was recorded from control treatment. This is due to the uptake of K in *solanaceous* crop highly favored with high NO_3^-/NH_4^+ ratio (Havlin *et al.* (1999). Sharma and Sud (2015) who indicated that the potato responses were subsequently higher with K application.

Analysis of variance revealed that sulfur tuber uptake significantly (P<0.05) affected by blended and non blended fertilizer types and rates (Appendix Table 9). The highest (10.73 kg ha^{-1}) sulfur tuber uptake was observed from application of 110 kg N+90 kg P_2O_5+ 69 kg K_2O ha^{-1} while the lowest (1.32 kg ha^{-1}) sulfur tuber uptake was observed from control treatment.

Table 8. Effects of blended and non-blended fertilizer types and rates on tuber nutrient uptake of potato at Assosa, western Ethiopia.

Fertilizer applied (kgha^{-1})	TDW kg ha^{-1}	Potato tuber nutrient uptake kg ha^{-1}			
		N	P	K	S
Control	782.0^{d}	22.21	1.72^{e}	1.37^{e}	1.32^{c}
55N +45 P_2O_5	3057.3^{c}	68.26	6.68^{de}	6.12^{bc}	4.21^{bc}
110 N+90 P_2O_5	4310.0^{bc}	93.69	9.59^{bcd}	9.16^{bdc}	6.39^{b}
165 N+ 135P_2O_5	5063.0^{ab}	89.03	13.21^{ab}	10.67^{ab}	7.04^{ab}
110 N+90P_2O_5+ 69 K_2O	6314.0^{a}	88.30	15.76^{a}	13.94^{a}	10.73^{a}
100% NPSB+ 91.9 N	4411.0^{bc}	130.43	9.77^{bcd}	9.02^{bdc}	7.03^{ab}
200% NPSB + 128.8N	5050.0^{ab}	125.53	12.58^{abc}	10.03^{abc}	6.81^{b}
100% NPSZnB + 93.1N	3354.3^{bc}	72.79	7.75^{bcd}	5.85^{bc}	4.33^{bc}
200% NPSZnB + 131.2 N	2698.3^{c}	51.41	7.08^{cde}	5.43^{de}	4.38^{bc}
LSD 5%	1784.8	Ns	5.55	4.19	3.73
CV %	26.48	44.93	34.29	30.46	37.15

Means followed by the same letter within a column are not significantly different at 5% level of significance; Ns = Not Significant; LSD = least significant difference; and CV= Coefficient of Variation; TDW=tuber Dry Weight.

4.7. Potato Nutrient Use Efficiency

4.7.1. Agronomic efficiency

Blended and non-blended fertilizer types and rates was significantly ($P<0.05$) influenced agronomic efficiency of potato (Appendix Table 7). The lowest agronomic efficiency (32.53) was obtained from application of 200% NPSZnB with adjusted N kg ha^{-1} while the highest agronomic efficiency (78.11) was obtained from treatment that received 100% NPSB with adjusted N of blended fertilizer. This might be due to the increased nutrient uptake through application of blended macronutrients with micronutrients in appropriate form of fertilizer to nutrient deficient soil which resulted in increased the nutrient use efficiency of potato and increased its potato tuber productivity. This result is in line with Fayera *et al*. (2014) who indicated that matching appropriate essential macronutrients and micronutrients with crop nutrient uptake could optimize nutrient use efficiency and crop yield.

Increasing rates of nitrogen and phosphorus from 55 kg N and 45 kg P_2O_5 ha^{-1} to 165 kg N and 135 kg P_2O_5 ha^{-1} decreased agronomic efficiency of potato crop by about 25%. This is due to the opposite relationship between increasing nutrient supply and yield production (Salam *et al.,* 2014). But, application of combined potassium, nitrogen and phosphorus resulted in improved agronomic efficiency (72.12) of potato. In general, increasing the rates of blended fertilizers decreased agronomic efficiency of potato crop. This is due to the fact that input-output relationship which follows the law of diminishing returns between N and yield (Das *et al.,* 2015). This result is in line with the finding of Tsegaye (2017) who reported that increasing phosphorus from organic and inorganic sources decreased agronomic efficiency of potato. According to Fageria *et al.* (2015), an efficient plant is one that produces higher economic yield with a limited quantity of applied or absorbed nutrient.

4.7.2. N and P tuber apparent recovery efficiency (ARE)

Analysis of variance revealed that N ARE was not significantly (P>0.05) affected by blended and non bended fertilizer types and rates (Appendix Table 9). The highest (98.38%) ARE of N was recorded from application of 100% NPSB with adjusted N kg ha^{-1} while the lowest (17.7%) ARE of N was observed from application of 200% NPSZnB with adjusted N kg ha^{-1}. This result is confirm the finding of Darwish *et al.* (2006) who found that decreasing N application to 125 kg ha^{-1}, (against 250, 375 and 500 kg N ha^{-1}) significantly led to higher N recovery. This might be resulted due to the potato highly efficient in utilizing nutrients from soil reserves and from low input fertilizers. Ruza *et al*. (2013) stated that tuber and foliage nitrogen apparent recovery efficiency was recorded 77 up to 151%.

Similarly, according to Kołodziejczyk (2014) reported that nitrogen recovery efficiency ranged from 49.6 to 78.0%. In this study NARE was ranged from 17.7% to 98.38%. This might also indicate that at higher supply of N, the nutrient availability in the soil might be low affecting the nutrient recover efficiency of plants. This result in line with the finding of Tsegaye (2017) who reported that high application of nutrients had low N recovery whereas low N application gave high recovery.

Analysis of variance revealed that P ARE not significantly affected by blended and non blended fertilizer types and rates (Appendix Table 9). The highest (22.3%) ARE of P was observed at application of 110 N+90P_2O_5+ 69 K_2O kg ha^{-1} while the lowest (7.92%) ARE of P was observed at application of 200%NPSZnB with adjusted N kg ha^{-1}. This might be due to antagonistic effects of phosphorus and zinc at high levels. According to Trehan *et al*. (2008) stated that potato phosphorus apparent recovery efficient was ranged from 10 to 15%. In case of this study tuber phosphorus apparent recovery efficient was ranged from 7.92 to 22.30%. This indicate that potato tuber where efficiently utilized low phosphorus fertilizer.

Table 9. Effects of blended and non-blended fertilizer types and rates on AE and NARE and PARE of potato at Assosa , western Ethiopia.

Applied fertilizers (kg/ha)	Nutrient Use Efficiency		
	N ARE (%)	P ARE (%)	AE(kg/kg)
Control	-	-	-
55N +45 P_2O_5	83.72	11.01	53.62^{ab}
110 N+90 P_2O_5	64.98	8.74	45.74^{ab}
165 N+ 135P_2O_5	40.5	8.51	40.02^{abc}
110 N+90P_2O_5+ 69 K_2O	60.08	15.59	72.13^{ab}
100% NPSB+ 91.9 N	98.38	22.3	78.11^{a}
200% NPSB + 128.8N	62.62	15.04	49.07^{ab}
100% NPSZnB + 93.1N	45.58	17.83	37.76^{abc}
200% NPSZnB + 131.2 N	17.7	7.92	32.55^{bc}
LSD 5%	Ns	Ns	41.87

TTY = Total Tuber Yield, AE= Agronomic Efficiency, NARE= Nitrogen Apparent Recovery Efficiency, PARE = Phosphorus Apparent Recovery Efficiency.

4.8. Correlation of Dry Total Tuber Yield with N, P, K, S Concentration and Uptake of Tuber

The analysis of simple correlation revealed that in tuber nutrients concentrations were not significantly ($P>0.05$) correlated with dry total tuber yield. Some nutrients such as nitrogen and phosphorus were N ($r= -0.1$) and P ($r= -0.17$) correlated with dry total tuber yield, whereas other nutrients such as K ($r= 0.12$) and S ($r=0.16$) positively correlated with dry total tuber yield. This might be due to the dilution effect of nitrogen concentration in potato dry total tuber yield i.e the treatment that had higher dry matter accumulation was low in nitrogen concentration and vice versa. This result is in contrast to the finding of Habtam (2012) who reported that concentration of potassium in tuber was highly significantly ($P<0.01$) correlated with tuber dry yield of potato.

The analysis of simple correlation revealed that (N, P, K and S) uptakes by tubers were positively and strongly significantly ($P<0.01$) correlated with dry total tuber yield. Uptakes nutrients such as N (r=0.61**), P (r= 0.65*), K (r= 0.96**), and S (r= 0.93**) were positively and strongly significantly ($P<0.01$) correlated with dry total tuber yield, indicating the improvement in growth and production due to fertilization with plant nutrients (Kirsten, 2014). This result is in line with the finding of Tsegaye (2017) who reported that NPK uptake exhibited positively and highly significantly ($P<0.01$) correlate with dry total tuber yield.

Table10. Dry total tuber yield as influenced by Nitrogen, Phosphorus, Potassium ,Sulfur and Zinc tuber uptake and concentration.

	DTTY	NC	PC	K C	SC	NU	PU	KU	SU
DTTY	1								
NC	-0.1ns	1							
PC	-0.17ns	-0.13ns	1						
K C	0.12ns	0.01ns	-0.14ns	1					
SC	0.16ns	0.013ns	-0.32ns	0.53**	1				
NU	0.61**	0.65ns	-0.2ns	0.12	0.074ns	1			
PU	0.65**	-0.15ns	0.62**	0.012	-0.15ns	0.34ns	1		
KU	0.96**	-0.07ns	-0.2ns	0.41*	0.27ns	0.62**	0.59**	1	
SU	0.93**	-0.10ns	-0.27ns	0.33	0.50**	0.55**	0.50**	0.93**	1

NC= Nitrogen Concentration, PC= Phosphorus Concentration, KC=potassium Concentration, SC= Sulfur Concentration, NU= Nitrogen uptake, PU =Phosphorus Uptake, KU= Potassium Uptake, TTDY= Dry Total Tuber Yield.

4.9. Partial Budget Analysis

When the new technology surpassed the conventional practice, it is said to be undominated (CIMMYT, 1988). Marginal rate of return measures the increase in the net income and is unnecessary when the new technology costs less than the existing farmers, technology. When the new technology yield lower benefit, then the technology is said to be dominated. The net benefit estimates for 9 treatments are presented (Table 11). For every 1.00 Birr invested at application of potassium combined with NP, farmers can expect to recover the 1.00 Birr, and obtain an additional 42.46 Birr ha^{-1} by applying recommended NPK (110 kg N ,90 kg P_2O_5, 69 kg K_2O ha^{-1}).The results of the partial budget analysis revealed that the highest net benefit of Birr 156262.8 ha^{-1} was recorded in the treatment that received nitrogen, phosphorus and potassium (110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1}) fertilizers whereas the lowest net benefit of Birr 55260 was obtained from control treatment. Based on partial budget analysis, it is advisable to apply full recommended NPK to get optimum yield of potato for Assosa area. Maximum yield and minimum cost evidently leads to high income.

4.9.1 Dominance analysis and net benefit curve

The dominant analysis revealed that the net benefit of some treatments were un-dominated. Thus, unfertilized plot, half of recommended 55 kg N + 45 kg P_2O_5 ha^{-1}, two rates of blended fertilizers 100% NPSB +91.9 kg N ha^{-1} , 200% NPSB +128.8 kg N ha^{-1} and full recommended 110 kg N,90 kg P_2O_5,69 kg K_2O ha^{-1} (Table 11). This result indicated that the net benefit increased a with increasing the total cost that varies. So, farmers' select un-dominated treatments compared to dominated treatments.

Table 11. Dominance analysis of blended and non-blended fertilizers types and rates application on potato production

Fertilizers (kg ha^{-1})	AVMTY kg ha^{-1}	10%Ad.MTY kg ha^{-1}	GB	TCV	NB	B:C
Control	10230	9210	55260	0	55260	-
55 N , 45 P_2O_5	17000	15301	91806	2502.91	89303.09	35.68
100%NPSB, 91.9N	20810	18728	112368	3063.19	109304.8	35.68
100% NPSZnB , 93.1 N	17120	15411	92466	3152.69	89313.31D	28.33
110N,90 P_2O_5	19350	17412	104472	4824.97	99647.03D	20.65
200%NPSB , 128.8 N	22250	20028	120168	4903.59	115264.4	23.51
100% NPSZnB , 93.1 N	18740	16863	101178	5095.21	96082.79D	18.86
110N,90 P_2O_5,69 K_2O	30030	27022	162132	5869.17	156262.8	26.62
165N,135P_2O_5	21880	19695	118170	7147.48	111022.52D	15.53

AVMTY kgha^{-1} = Average Marketable Tuber Yield kg ha^{-1}, 10%Ad.MTY= Adjusted Marketable Total Yield; GB= Gross Benefit, TVC= Total Cost that Vary; NB = Net Benefit; D = Dominance

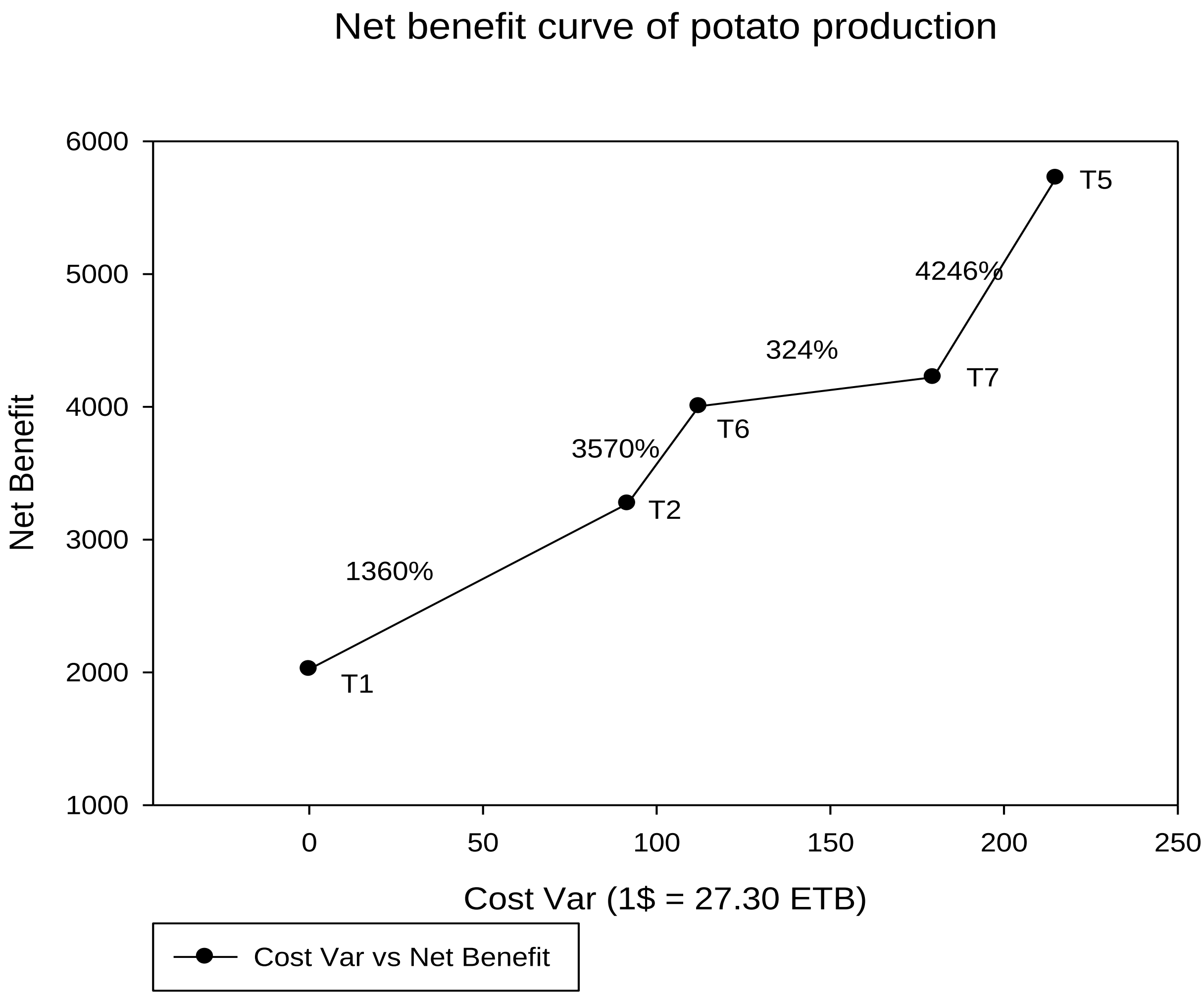

Figure 3. Net benefit curve and marginal rate of return of potato as influenced by blended and non-blended types and rates at Assosa area Western, Ethiopia

T1 = Control, T2= Half of recommended NP, T5= Full recommended of NPK, T6= 100% NPSB+91.9N kgha^{-1}, T7= 200%NPSB +128.8kg N ha^{-1}, the exchange rate of 1 $ is 27.30 Ethiopian Birr.

4.9.2 Marginal rate of return

The process of calculating the marginal rates of return of alternative treatments, proceeding in steps from the least costly treatment to the most costly, and deciding if they are acceptable to farmers, which is called marginal analysis (CIMMYT, 1988). The analysis indicated that all un-dominated treatments were above minimum acceptable rate of return for farmers' recommendation. It is important to note that the acceptable minimum rate of return to farmers' recommendation is 50%-100% (CIMMYT, 1988). However, in this study application of full recommended NPK (110 kg N, 90 kg P_2O_5 and 69kg K_2O ha^{-1}) showed highest net benefit and marginal rate of return. So, application of 110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1} is advisable for farmers at Assosa area. The best recommendation for treatments subjected to marginal rate of return is not (necessarily) based on the highest marginal rate of return, rather based on the minimum acceptable marginal rate of return and the treatment with the highest net benefit together with an acceptable MRR becomes the tentative recommendation (CIMMYT, 1988).

Table 12. Marginal rate of return of un-dominated treatments as influenced by blended and non blended fertilizers types and rates on yield and yield components in 2017.

Applied fertilizers kg/ha	TCV	MC	NB	MB	MRR%
0	0	-	55260	-	-
55N , 45 P_2O_5	2502.91	2502.91	89303.09	34043.09	1360
100%NPSB ,91.9N	3063.19	560.28	109304.8	20001.71	3570
200%NPSB , 128.8 N	4903.59	1840.4	115264.4	5959.6	324
110N,90 P_2O_5,69 K_2O	5869.17	965.58	156262.8	40998.4	4246

TCV=Total Cost that Vary, MC=Marginal cost, MB = Marginal Benefit NB=Net benefit, MRR= Marginal rate of return

5. SUMMARY AND RECCOMENDATIONS

The productivity of any crop depends on its genetic potential, cultural practices including soil fertility, and climatic variables. Under specific agro-climatic conditions, yield and quality of a crop mainly depend on balanced nutrition. Most soils in Assosa area are poor in fertility due to nutrient depletion, soil erosion, as well as some adverse soil conditions such as acidity, which reduce the efficiency of uptake of nutrients by plants. An experiment was conducted to investigate the effect of different rates of blended fertilizers and the recommended blanket fertilizer on yield and yield components of potato. The experimental soil was analyzed for texture, pH, OC, total N, available P, exchangeable K, S, B, and CEC. The results of soil analyses revealed that the soil of the experimental site was strongly acidic in pH, clay loam in texture, medium in OC and CEC, low in total N, available P and boron whereas very low in exchangeable K and sulfur.

The field experiment was conducted to evaluate the effects of blended and non-blended fertilizer types and rates on yield and yield components of potato (*Solanum tuberosum* L.) at Assosa, western Ethiopia. The results showed that increasing recommended the rates of N and P by 150% delayed 50% flowering by 4 days as compared to the control treatment. Although blended and unblended fertilizers application significantly ($P<0.05$) influenced shoot elongation, applying K (69 kg K_2O_5) with NP (110 N +90 P_2O_5 kg ha^{-1}) fertilizers increased potato height by about 39% as compared to control. Leaf area index was highly significantly influenced by application of blended and non blended fertilizers types and rates. Application of 200% NPSB with adjusted N improved leaf area index by about 89% as compared to control treatment. Increasing application of blended and non blended fertilizer types and rates no significant difference ($P>0.05$) on parameters such as number of main stem, above ground dry biomass, total tuber number per hill and unmarketable tuber yield. However, increasing application of blended and non blended fertilizers types and rates revealed significant difference ($P<0.05$) on parameters such as underground dry biomass yield, total tuber yield, marketable tuber yield and mean tuber weight.

Application of blended and non blended fertilizers types and rates did not significantly ($P>0.05$) influence on tuber specific gravity and tuber size distribution (small size tuber and medium size tuber) whereas tuber dry matter content and large size tuber yield significantly ($P<0.05$) affected. However, application of potassium (69 kg K_2O ha^{-1}) with the combination of NP (110 kg N and 90 kg P_2O_5 ha^{-1}) fertilizers gave highest tuber dry matter content and large tuber size as compared other treatments. Nutrient concentrations of leaf plus petiole and tuber were not significantly ($P>0.05$) influenced by application of blended and non blended fertilizers. Application of 200% NPSB with adjusted N improved tuber N uptake as compared to other treatments whereas application of NPK (110 kg N, 90 kg P_2O_5, and 69 kg K_2O ha^{-1}) improved tuber P uptake as compared to other treatments. On others hand , application of 100% NPSB with adjusted N improved agronomic efficiency and, N and P tuber apparent recovery efficiency as compared to others treatments. Dry total tuber yield was positively and highly significantly correlated to N, P, K, and S uptake.

Applications of 50%NP, 100% NPK, 100% NPSB with adjusted N and 200%NPSB with adjusted N fertilizers resulted in higher net benefits with the acceptable marginal rate of return (above 100%). The partial budget analysis revealed that application of 110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1} resulted in the highest net benefit and marginal rate of returns. Generally, on the basis of the marketable tuber yield, net benefit, and MRR, we made tentative recommendation of 110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1} fertilizers for potato production at Assosa area. However, it is not enough to draw a sound recommendation since the study was done for only one year and at one location. Further researches should be undertaken to give conclusive recommendation.

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7. APPENDICES

Appendix table 1. Amount of rainfall, relative humidity, average maximum and minimum temperatures of the site during the experimentation (2017).

Month	Rainfall (mm)	Relative Humidity %	Temperature ˚C		
			Min temp.	Max temp.	Mean temp.
January	0	19.1	11.2	32.5	21.85
February	0	25.4	13.2	29.8	21.5
March	18.2	20.6	13.8	33.2	23.5
April	50	43.2	14.2	29.5	21.85
May	131.9	60.1	14.4	23.5	18.95
June	270.4	71.4	13.3	23.5	18.4
July	178.8	76.8	15.9	23.9	19.9
August	241.6	76.9	15.8	23.7	19.75
September	333.8	72.3	15.5	25.5	20.5
October	154.7	65.6	15.5	25.9	20.7
November	1.6	53.5	12.6	27.5	20.05

December	0	45.2	12.3	30.5	21.4
Mean			13.97	27.42	20.69
Total	1381				

Source: AsARC Metrology Station (2017)

Appendix table 2. Critical levels used for classifying soil fertility parameters analysis result.

Soil parameters	Status	Critical Levels	Soil parameters	Status	Critical Levels
Soil pH	Strongly acidic	<5.5	Available P (mg kg^{-1})	low	<5
	Moderately acidic	5.6-6.5		Optimum	5-10
	Neutral	6.6-7.3		High	>10
	Moderately alkaline	7.3-8.4			
	Strongly alkaline	>8.4			
Total Nitrogen %	Very Low	<0.1	Exchangeable K (ppm)	Very Low	<90
	Low	0.1-0.15		Low	90-190
	Optimum	0.15-0.3		Optimum	190-600
	High	0.3-0.5		High	600-900
	Very high	>0.5		Very high	>900
OC%	Very Low	<0.5	Available Sulfur (ppm)	Very Low	<10
	Low	0.5-1.5		Low	10-20
	Optimum	1.5-3.0		Optimum	20-80
	High	>3.0		High	80-100
				Very high	>100
	Very Low	<1.0			
Zinc (ppm)	Low	1-1.5			

Optimum	1.5-10
High	10-20
Very high	>20

Sources: EthioSIS team analysis (2014), Olsen *et al*.(1954) and Tekalign (1991).

Appendix table 3.Mean squares of potato phonological and growth parameters as influenced by blended and non blended application types and rates.

Sources of variation		Phonology	Growth parameters			
	Df	DF	PH	LAI	AGDB	UGDB
Rep	2	5.444*	21.84ns	0.758ns	0.751	4.128*
Treatments	8	5.083**	100.5*	1.117 **	0.928	7.914**
Error	16	0.944	26.93	0.278	0.392	1.063

Where; **, * = indicate significant differences at 1% and 5% level of significance, respectively; Ns = Non-significant at 5% level of significance; Df = degree of freedom; DF= Date to Flowering, PH = Plant Height; LAI = Leaf Area Index; AGDB = Above Ground Dry Biomass; UGDB = Under-Ground Dry Biomass

Appendix table 4 . Mean squares of potato yield and yield component as influenced by blended and non blended fertilizer types and rates

Sources of variation	DF	Mark	Unmark	Total yield	MTW	NMS	TTNH
Rep	2	44.91ns	1.416ns	52.53ns	0.51 ns	0.099ns	0.508ns
Trt	8	83.9*	2.06ns	90.48**	7.57*	0.601ns	7.57ns

Error	16	22.81	1.187	20.96	4.01	0.428	4

Where; **, * = indicate significant differences at 1% and 5% level of significance, respectively; Ns - non-significant at 5% level of significance; d.f = degree of freedom; Mark = Marketable yield; Unmark= Unmarketable yield; MTW = Mean tuber weight; NMS =Number main stem; TTNH =Total Tuber Number Per Hill.

Appendix table 5. Mean squares of potato tuber quality as influenced by blended and non blended application types and rates

Sources of variation	DF	TDMC	SPG	Small size	Medium size	Large Size
Rep	2	1.83ns	0.003ns	9.308*	9.31 *	0.67
Treatment	8	8.13*	0.001ns	3.454ns	3.45ns	0.709*
Error	16	2.95	0.003	2.38	2.39	3.81

Where; * = indicate significant differences at 5% level of significance, respectively; Ns -non-significant at 5% level of significance; D.F = degree of freedom; Rep= Replication; TDMC=Tuber Dry Matter Content ;SPG=Specific Gravity.

Appendix Table 6 . Mean squares of leaf and petiole concentration as influenced by blended and non blended application rates and types

		Mean Square of leaf petiole Concentration				
Sources of variation	DF	N	P	K	S	Zn
Rep	2	0.1328ns	0.00070ns	0.2953**	0.00043ns	2.0459×10^{-6}ns
Trt	8	0.2772ns	0.00089ns	0.0525ns	0.00022ns	1.0534×10^{-6}ns
Error	16	0.1328	0.00102	0.0271	0.00025	0.00000060

Where; **, * = indicate significant differences at 1% and 5% level of significance, respectively; Ns - non-significant at 5% level of significance; Trt = Treatment; Rep = Replication; N= Nitrogen ; P= Phosphorus K= Potassium; S = Sulfur; Zn = Zinc D.F = degree of freedom.

Appendix Table 7. Mean squares of nutrients concentration in tuber and AE as influenced by blended and non blended fertilizer types and rates

SV	DF	N	P	K	S	Zn	AE
Rep	2	2.98*	0.072**	0.0028**	0.0079**	$2.7 \times 10^{-6*}$	7212.51**
Trt	8	0.53ns	0.004ns	0.00039ns	0.00089ns	5.13×10^{-7}ns	1567.22*
Error	16	0.68	0.0068	0.0006	0.0007	0.0000006	9362.22

Where; **, * = indicate significant differences at 1% and 5% level of significance, respectively; Ns - non-significant at 5% level of significance; Trt = Treatment; N= Nitrogen ; P= Phosphorus K= Potassium; S = Sulfur; Zn = Zinc, Trt=Treatment, Rep =Replication, D.F = degree of freedom; AE= Agronomic Efficiency, SV=Sources of Variation.

Appendix Table 8 . Zn concentration in leaf plus petiole and tuber as influenced by blended and non blended fertilizer types and rates.

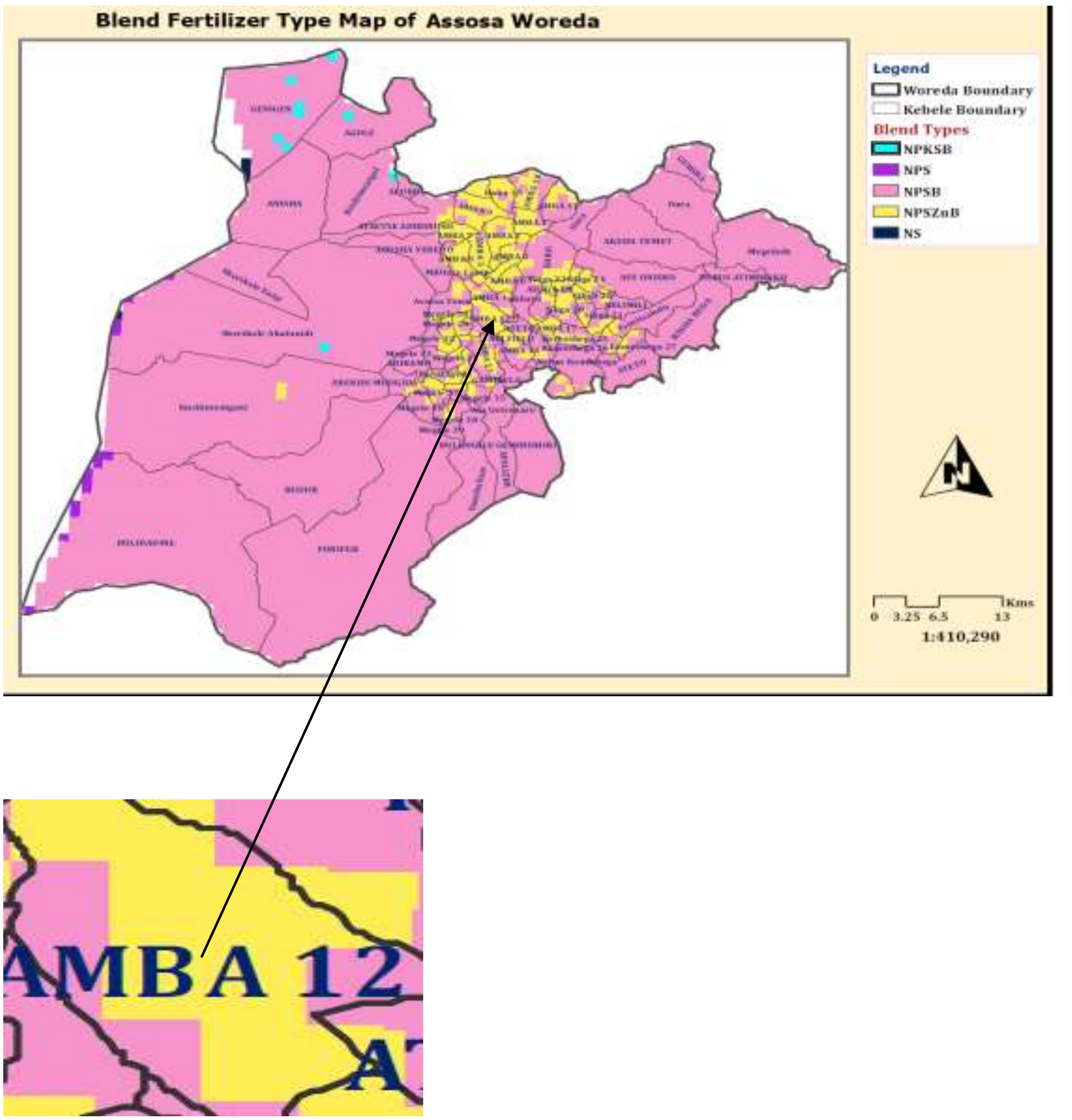
Treatments (kg ha^{-1})	Zn concentration in petiole plus leaf (ppm)	Zn concentration in tuber (ppm)

Control	27	20
55N +45 P_2O_5	13	13
110 N+90 P_2O_5	13	17
165 N+ 135P_2O_5	10	13
110 N+90P_2O_5+ 69 K_2O	7	17
100% NPSB+ 91.9 N	17	20
200% NPSB + 128.8N	10	20
100% NPSZnB + 93.1N	13	27
200% NPSZnB + 131.2 N	20	20

Appendix Table 9. Mean squares of tuber uptakes, N ARE and P ARE as influenced by blended and non blended application types and rates

SV	DF	N	P	K	S	N ARE	P ARE
Rep	2	6888.53*	16.52ns	29.19*	45.11**	92.59ns	705.26ns
Trt	8	3468.082ns	52.37**	40.32**	20.81**	80.48ns	1908.69ns
Error	16	1371.39	10.28	5.87	4.65	51.12	1521.77
CV%		44.93	34.28	30.46	37.14	53.48	65.23

Where; **, * = indicate significant differences at 1% and 5% level of significance, respectively; Ns - non-significant at 5% level of significance, SV =Source of Variation, Trt =Treatment, Rep= Replication, NARE = Nitrogen Apparent recovery Efficiency ,PARE = Phosphorus Apparent recovery Efficiency.



Source EthioSIS (2013).

Appendix Figure 1. Recommended fertilizers map for Assosa woreda and kebeles according to EthioSIS (2013).

BIOGRAPHICAL SKETCH

The author, Desta Bekele, was born on 19 April 1990 in Jardaga Jarte Woreda , Horro Guduru Wellega Zone, Oromia National Regional State. When he reached school age, he enrolled at Sute Elementary School (Grade 1-6). After completing elementary education in the subsequent years, he enrolled at Jarmat Primary and Secondary School (Grade 7-8) at Jarmat town. He enrolled to Alibo Secondary and Preparatory School at Alibo town. After successful completion of high school, he joined Hawassa University in 2008/09 and obtained the Degree of Bachelor of Science in Agriculture (Horticulture) in 2011.

Upon graduation, he was recruited by Upper Awash Agro Industry Enterprise as an expert of Horticulture where he worked for two years and two months. Then, he joined Ethiopian Institute of Agricultural Research as a horticulturist junior researcher at Assosa Research Center in 2014. After serving as junior researcher for 2 years, he enrolled to the School of Graduate Studies of Hawassa University in 2016 to pursue a study leading to the Degree of Master of Science in Horticulture.