

A Review on Responses of Potato to Macro and Micro Fertilizers Application

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Abstract
Potato was considered as food security crop in Ethiopia because of its high yielding potential, high nutritional quality, short growing period and wider adaptability. In area coverage, it is second widely grown crop next to 'Enset' (Ensete ventricosum L.). Its production is affected by many factors. Among these factors, optimum fertilizer application is the main factor degrading the productivity of the crop. Achieving optimum fertilizer application depends on the climate, soil, variety and availability of the water. This review was aimed to access all available fertilizer trials to point out the types of fertilizers soil is deficient in relation to potato crop response and needed additional application during production cycles for boosting yield. Almost all soil of arable lands of Ethiopia was deficient in nitrogen (N), phosphorus (P), and sulfur(S). In addition, a larger part of arable land was deficient in N, P, S, and boron (B). Some lands' soils require addition of either of potassium or Zinc other time both. Potato is requiring both macro and micro elements for high yield and better quality product. It is concluded that, most reviewed sources indicate that there was less recommendation concerning micro and macro elements for potato in the country in relation to the variable ecology of the country owned.
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1. Introduction

Potato (*Solanum tuberosum L*) is classified under family *solanaceae,* genus *solanum,* and series Tuberosa (Van den Berg and Jacobs, 2007). It is originated in the Andes of South America and cultivated for the first time in the border of Peru and Bolivia (Horton, 1987). It was introduced to Ethiopia before 163 years ago by the German botanist Schimper (Pankhurst, 1964). Since then, its production grew gradually from high land garden lands to the field crop status in high land and mid land mainly in rain fed and in lesser land under irrigation production systems. Now, it is important food security crop in many parts of the country. On global scale, there was a production volume of 368 million metric tons annually from an estimated area of 17.58 million hectares (FAOSTAT, 2018). Potato has become an important crop in many parts of Ethiopia and it ranks first among root and tuber crops in volume produced and consumed followed by Cassava, Sweet potato and Yam (CSA, 2017). It was considered as food security crop in Ethiopia because of its high yielding potential, high nutritional quality, short growing period and wider adaptability (Tewodros *et al*., 2014 and Brasesco *et al*., 2019). In area coverage it is second widely grown crop next to 'Enset' (*Ensete ventricosum* L.)(Girma, 2001).

Potato has been highly recommended by the Food and Agriculture Organization (FAO) as a food security crop. Potato helped smallholder farmers by providing direct access to nutritious food, increasing household incomes and minimized their danger to face the food price instability (André *et al*., 2014). In Ethiopia, its meher season production area has reached about 70,362.22 ha, with total production of 924,528.361 cultivated by over 1.068 million households (CSA, 2019). On the other hand, the productivity of this crop in the country is very low (13.14 t ha^{-1}) compared to the world's average yield of 19 t ha^{-1} (CSA, 2019). According to Brasesco et al. (2019), model farmers those using full technology (good quality seeds and optimum fertilizer application accompanied with good agronomic practice) potato yield showed that a yield potential up to 50 t/ha. Balanced fertilization applications sustains optimal crop production, better quality product and ensues profitability of growers. Nutrients such as N, P, K, S, B, Zn and Fe are plant nutrients found deficient in Ethiopian cultivable land soil though there are variation among location types and included in new fertilizer formula of the Ethiopian soils. In area coverage most soils are deficient in N, P, S, and B followed by those location lacking N, P, and S (EthioSIS, 2016) and in general all cultivated land soils lack N, P and S. According to EthioSIS(2016), the soil content of different elements were said deficient whenever each of them was below 30, 190, 20, 0.5, 0.9, and 0.8 ppm foe P, K, S, Zn, Cu, and B, respectively based on the soil critical point concept. Fertilizers application based on crop needs and soil deficiency, reduce soil nutrient imbalance and satisfy crop needs, improve crop productivity and reduce poverty. Fertilizer rates determination and recommendation should base on climate, soil factors, and crop needs. In Ethiopia, research works carried earlier have been limited to the two common macronutrients (N and P) for long time that resulted in soil nutrient imbalance and degrade soil ecology which in turn greatly influence sustainable harvestable yield.

Based on the crop needs and soil shortages new fertilizing materials with secondary and micronutrients would be required to ensure balanced fertilizer use involving most of the nutrients required by crops (Bewketet al., 2018). That is why many fertilizer formula such as NPS, NPSB, NPSFeB, NPSFeZn, NPSFeBZn, NPSZn, NPSB, NPKSB, NPKSFeB, NPKSFeZn, NPKFeZnB, NPKSZn and NPKSZnB and soon are developed in the country based on soil shortage and crop needs (EthioSIS, 2015). Not only developing the formula but also the availability and cost of the fertilizers also play significant role in utilization of the developed technology and converting the opportunity for improving productivity and reducing poverty. One of the problems of our farmers facing now is a problem similar to these mentioned ones. There is developed formula but some of them are not available in the amount required and the available ones are high cost while some are available but there is less attention to utilize them. This review was conducted to collect available information about fertilizers effect on potato crop and indicate the gap for researchers and users.

1.1 Origin, Botany and Ecology of potato

The origins of potato can be traced backs to the highlands of the Peruvian Andes-mountains in South America on the border between Bolivia and Peru, 8,000 years ago. Research indicates that communities of hunters and gatherers, who had first entered the South America continent at least 7,000 years ago, before domesticating wild potato plants that, grew around the lake in abundance. It was in the central Andes that farmers succeeded in selecting and improving the first of what was to become, over the following millennia, a staggering range of tuber crops. In fact, what we know as "the potato" (*Solanum tuberosum* L) contains just a fragment of the genetic diversity found in the seven recognized potato species and 5,000 potato varieties still grown in the Andes. Potatoes have relatively shallow, fibrous root system with the majority of the roots in the surface 30cm. The root system develops rapidly during early growth and achieves maximum development by midseason. Thereafter, root length, density and root mass decrease as the plant matures. Rooting depths of 1.2m or more have been reported for potato under favorable soil conditions (Tanner *et al.,* 1982).

The main stem of the potato plant terminates in flower cluster. They bear white, pink, red, blue, or purple flowers with yellow stamens. Flower bud abortion may occur at a very early stage of development; but in any case apical growth of the main stem ceases with formation of the flower buds. The cessation of growth of the main shoot axis may not be obvious because sympodial growth of one or more axillary branches just below the apex permits further extension above the flower (Rending and Taylor, 1989.).

1.2 Climatic Requirements of Potato

Potato grows well and produces yields at an altitude of over 1000 meters above sea level, although recently produced cultivars perform well at low elevations ranging from 400 to 2000 meters above sea level in tropical highlands (Levy and Veilleux, 2007). In Ethiopia, the altitude between 1800 to 2500 meters above sea level is regarded as suitable for seed and potatoes production (Bezabih and Mengistu, 2011). Potato is grown in many different environments, but it is best adapted to temperate climates (Hijmans, 2003). Higher temperatures above 29 ^{O}C diminish tuberization, promote foliage growth and reduce partitioning of photosynthate and assimilate to the tubers (Levy and Veilleux, 2007). Potato is also frost sensitive and severe damage may occur when temperature drops below 0^{0}C (Hijmans, 2003). Short day length and low temperatures are principally important to enhance tuber initiation and the number of tubers formed (Levy and Veilleux, 2007).

Potato is basically a crop of temperate region, but there is a large variation in the gene pool with respect to its response to thermo periods. 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).). The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas a higher temperature favors 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). Farmers have also developed a frost resistant potato species that survives on the alpine tundra of the Puna zone at 4,300m.a.s.l (14,100ft.) (Gebremedhin *et al*., 2008). Better tuber yields have been obtained from potatoes grown at soil reaction ranging from pH 5.2 to 6.5 (Fageria *et al*., 2011). According to FAO (2000) report the pH range of most crops were 4-8 because of variable optimum pH requirement of different crops. Optimal soil pH for potato is indicated as 5 to 5.5(Ann *et al*., 2017).

1.3 Distribution of Potato in the World

The global distribution of potato is described using country-level statistics and a new geo-referenced data base. There are two main peaks in global potato distribution by latitude. The major peak is between 45^{0}N and 57^{0} N and represents potato production zones in the temperate climate where potato is a summer crop. The other peak is between 23^{0}N and 37^{0}N, and mainly presents production those in the subtropical lowlands, where the crop grows in winter crop. Between 1950 and 1998, potato production area increase at low latitudes and decreased at high latitudes, particularly around 53^{0}N (this zone includes parts of Belarus, Germany, Poland Russia, and

Ukraine). The northern limit of potato production coincides with the boundaries of agriculture and the presence of human population density (per area of land and per area of arable land). About 25% of the global potato area is in the highlands above 1000 m.a.s.l. (American Journal of Potato Research, 2001).

1.4 Major Potato Production Area in Ethiopia

In Ethiopia, potato is grown in four major areas: the Central, the Eastern, the North-Western and the Southern regions, which together constitute approximately 83% of the potato farmers in the country (CSA, 2008). In the Central area, potato production includes the highland areas surrounding the capital city of Ethiopia, Addis Ababa. In this area the major potato growing zones are West Shewa and North Shewa. About 10% of the potato farmers are located in this area (CSA, 2008). Average productivity of a potato crop ranges from 8 to 10 ton ha^{-1} which is higher than the productivity in the North-Western and Southern areas. This higher productivity might be due to the use of improved varieties and practices obtained from Holetta Agricultural Research Centre in the central area. In the central area potato is produced mainly 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). Because of the cool climate and access to improved varieties, farmers in this area of the country also produce seed potatoes which are sold to other farmers in the vicinity or to NGOs and agricultural bureaus to be disseminated to distant farmers. In the central area, farmers grow about seven local varieties, eight improved varieties and six clones i.e. genetic material which is not officially released (Adane *et al*., 2010).

1.5 Economic Importance of Potato

Potato serves as food and cash crop for small scale farmers and occupies the largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops (Tesfaye *et al.,* 2015). As a food crop, it has a great potential to supply high quality food within a relatively short period and is one of the cheapest sources of energy. Moreover, the protein from potato is of good composition with regard to essential amino acids in human nutrition (Hussain, 2016). Relatively high carbohydrate and low fat content of potato makes it an excellent energy source for human consumption. It is known to supply carbohydrate, high quality protein and a substantial amount of essential vitamins, minerals and trace elements (MoARD, 2011). The potato production area is rapidly expanding due to its high yield potential and suitability hence, it is estimated that potato is cultivated at about one hundred thousand hectares before 2001 (Endale and Gebremedhin, 2001) while it was more than 296 thousand hectors in 2016 production season(CSA, 2017).

1.6 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. The annual world potato production is estimated to 376 million tons (FAOSTAT, 2015). Among this, Asia and Europe are the major potato producing continents, 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 (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 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.*(2008), 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 capital 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.

1.7 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 to high temperatures and drought. The national average potato yield is very low as compared to the potential yield (50 t ha-1) obtained under research conditions and model farmer's situations. 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). On the other hand, not exploiting available water, limited the productivity of potato crop though the country is wealthy in its available irrigation water and irrigable land. Moreover, the crop is better performing under irrigation than the main cropping season due to disease influence exclusion and getting easy workable soil which favor the crop and management operations during cultivation and earthing up.

1.8 Opportunities of Potato production in Ethiopia

Ethiopia has suitable condition for potato production and potato can play an important role in improving food security and cash income of small hold of potato growers in Ethiopia. As a food crop, potato has a high potential to supply a cheap and quality food within a relatively short period. There is a high potential to expand the cultivation area of the potato crop in Ethiopia. Not only expanding cultivation land but also exploiting other system of production like irrigation is also crucial as the land is free of cropping off-season and potato is best performing due to escaping of highly devastating late blight diseases. While, national average yields are still far below attainable yields, ample opportunities exist to utilize this crop's potential for increasing food security and income generation in Ethiopia (Helen, 2016).

Agronomic practices in most of the potato growing areas of Ethiopia leave much to desire for improvement. The agro-ecologies where farmers thrive to grow potato are characterized by diverse conditions. They vary considerably in soil type, moisture and temperature regimes, fertility conditions, and in the on-set, intensity and duration of rain. Therefore, crop management operations have to take into account of these differences to ensure high yielding potential of cultivars. In general, several activities were conducted so far on various agronomic practices to improve the production and productivity of potato in different parts of the country. However, some of these research recommendations were obsolete and should be revised for enhancing the yield of the crop. Therefore, the research and development on agronomic practices of potato should be continued to improve the production and productivity of potato as a food security crop in the country (Abebe *et al*., 2016).

1.9 Effects of Mineral Nutrients on Growth and Yield of Potato

In the past years, mineral fertilizer was advocated for crop production to ameliorate low inherent fertility of soils in the tropics. However, currently it is well recognized that the use of mineral fertilizer has not been helpful in intensive agriculture because it is often associated with reduced crop yield, soil acidity and nutrient imbalance (Kumar *et al*., 2013). Appropriate mineral fertilizer application, especially nitrogen and phosphorus are required to correct the nutrient imbalance in infertile soils (Peter *et al*., 2015). Potatoes require high quantity of nutrients in order to form abundant vegetative mass and high quantity tubers per unit area (White *et al.,* 2007). Moreover, potatoes require high amounts of fertilizer due to the characteristics of shallow and inefficient rooting system (Dechassa *et al.,* 2003). Potatoes respond to an ample soil moisture supply with an increase in yield and quality (Dolores *et al.,*2009). A rainfall ranging between 500 and 750 mm with even distribution during the growing period is generally necessary for optimum growth (Stol *et al.,*1991). Potatoes have relatively shallow root zone and lower tolerance for water stress compared to other crops, therefore irrigation may be required where rainfall is limited (Makani *et al*., 2013). Fayera (2017) confirmed that increasing the rate of nitrogen increase total tuber yield/plot average tuber weight, marketable tuber weight, unmarketable tuber weight, total tuber number/ plant and small tuber size. In agreement with this, finding of Biruk (2018) reported increasing the rate of nitrogen from 0 to 92 Kg/ha linearly increased shoot dry biomass yield. Application of 165 kg N/ha increased shoot dry weight from 52.75 to 72.25 by 19.5 g/hill compared to control (Israel *et al*., 2012). Minwyelet (2017) report that the application of NPS fertilizer at the rate of 272 kg/ha produced the highest total tuber yield (47.53 t/ha), while potato plants without NPS fertilizer produced the lowest total tuber yield (17.32 t/ha). In agreement with this report, increasing NPS application rates significantly increased marketable tuber yield of potato (Melkamu and Miniweyilet, 2018).

1.9.1 Nitrogen

Agricultural crops have a considerable dependence on inorganic nitrogen and 85–90 million metric tons of nitrogenous fertilizers are added to the soil worldwide annually. Due to the cost associated with manufacture, nitrogen is one of the most expensive nutrients to supply and commercial fertilizers represent a major cost in potato crop production. Nitrogen is a key element in potato growing and required by the plant's roots and shoot throughout the growing season. Nitrogen gas makes up 80% of the earth's atmosphere, but this gaseous nitrogen is unavailable for plant growth. Bacteria play an essential role in making atmospheric N available for plant growth. Nitrogen is a very dynamic plant nutrient and inefficient utilization by plants that may result in environmental pollution (Moreno *et al*., 2003). It is an essential component of proteins, nucleic acids and enzymes. Along with magnesium, it is a major constituent of chlorophyll, the green colored compound that traps sunlight and utilizes the solar energy to manufacture the products required for growth and development. Pale green new leaves, yellowing of older leaves, slow growth and stunted growth, are likely symptoms of nitrogen deficiency (Foth and Ellis, 1997). Potato plants have a high requirement for nitrogen to produce the amount of protein required by the leaves, roots and tubers. Potato plant roots can take up several chemical forms of nitrogen. The most common are ammonium (NH_4^+), nitrate (NO_3^-) and urea ((NH_2)2CO). Natural processes in the soil can convert one form into another. The nitrogen in urea is completely water-soluble. Upon application, urea nitrogen changes rapidly to NH_3-N which is readily available to plants on application to the soil (Kolbe *et al*., 1997).

Urea is the most widely used dry nitrogen fertilizer in the world. After application to soils, urea is converted into ammonia, which can be held in the soil or converted into nitrate. Ammonia volatilization following fertilization with urea can be substantial, and if urea is applied to the surface of the land, without immediate incorporation into the soil, considerable loss of nitrogen can occur (Truog, 1946). Hydrolysis of urea by urease produces ammonium carbonate. With surface-applied urea, alkalinity of pH 9 or higher can develop under the urea granule or pellet, and ammonia will volatilize into the air. Volatilization occurs on bare ground, on debris, or on plant leaves. Urea is readily soluble in water, and rainfall or irrigation after its application will move it into the soil and lessens volatilization losses. Use of urease inhibitors has been suggested to lessen the volatilization losses of ammonia from surface-applied urea. Manufactured urea is identical to urea in animal urine. Currently there is considerable interest in the efficient use of N in agriculture (Wikipedia, 2016)).

An adequate supply of N is associated with vigorous vegetative growth and a dark green color while an unbalanced N and higher N rates are associated with more foliage, promoted photosynthetic action and translocation to tubers (Kumar *et al*., 2007). However, an excess of this nutrient in relation to other nutrients, such as P, K, and S leads to excessive stolen and leaf growth, delayed leaf maturation, tuber differentiation, extended tuber bulking period, and ultimately reduced yield and tuber dry matter (Goffart *et al*., 2008). Whereas shortage of N restricts the growth of all plant organs, roots, stems, leaves, flowers, stunted plant growth, yellowing leading to low fruits and seed yields (Barker and Bryson, 2007). Shortage of N also restricts tuber size due to reduced leaf area and early defoliation (Goffart *et al*., 2008).Nitrogen is very important nutrient in potato production as the value of the other inputs cannot be fully realized unless N is applied to the crop in an optimum amount (Ruža *et al*., 2013). Several N fertilization rates have been advised as optimal rate for potato production. In some European countries and the USA that have a potato growth cycle of 4-5 months, the recommended N fertilization rates vary from 70 to 330 kg ha-1, and the most economically efficient rates range from 147 to 201 kg ha-1 (Fontes *et al*., 2010). Researchers in the Czech Republic advice application of fertilizer rate of 140 kg ha-1 as the optimal to obtain tuber yield above 30 t ha-1 (Ruža *et al*., 2013).

Many factors and processes including initial amount of mineral N, net mineralization or immobilization, de-nitrification, leaching, and atmospheric deposition influence the relation between nitrogen supply and uptake (Ruža *et al*., 2013). Furthermore, according to Vos (1997), all factors that affect the depth of root penetration (density and texture of soil, pH, etc.) or its function (including pests, diseases, drought and water logging) also affect the relationships between supply and uptake. Potato is a crop that is highly responsive to N-fertilizer (Sincik *et al.*, 2008). Therefore, the nitrogen rate identification was difficult due to these mentioned problems and the sources applied to the soil. Now days, there are two nitrogen sources applied to soil in highlands used for potato growing (Urea and NPSB). The nitrogen needs of crops may vary when the source vary which necessitate the response assessment for different varieties of potato. In line with this, rate determinations for nitrogen should be done related to climate, time of application, the source, soil matrix and varietal reaction.

1.9.2 Phosphorus

1.9.2.1 Phosphorus in Soils and Plants

Plants absorb phosphorus in the form of $HPO_4^{-2}$and $H_2PO_4^-$ (Tisdale *et al.,* 1995). The physical and chemical properties of soils were reported to influence the solubility of phosphorus and its adsorption reactions in soils. These include the nature and amount of soil minerals, soil pH, cation effect, anion effect, extent of phosphorus saturation, reaction time and temperature, flooding and fertilizer management (Tisdale *et al.,* 1995). Moreover, availability of phosphorus from fertilizers may be affected by the soil reaction, the degree of soil phosphorus deficiency, rate and method of application, needs of the specific crops, certain soil differences. The maximum availability of phosphorus for plant utilization is known to occur at soil pH between 6.5 and 7.5.

The use of phosphorus fertilizers becomes imperative because the concentration of phosphorus in many soils is reported to be very low and it is also liable to different chemical reactions that make it unavailable to plants. Plants provided with adequate amount of phosphorus have been reported to form good root system, strong stem, mature early and give high yield. On the other hand, plants grown on phosphorus deficient soils show stunted growth, low shoot to root ratio, poor fruit and seed formation, purple colored leaves with reddish discoloration of the stem. Biochemically, phosphorus deficiency causes changes in functions of the plant including accumulation of sucrose and reducing sugars and sometimes of starch(Tisdale *et al.,* 1995).

1.9.2.2 The role of phosphorus in potato cropping

Agriculture and food production are dependent on a p supply to produce adequate food, fiber and fuel for society (Hopkins *et al.,* 2008; Syers *et al.,* 2008). Efficient use of P is also crucial in order to minimize losses of P from agro-ecosystems (Syers *et al.,* 2008; Hart *et al.,* 2004). The fact that p losses from agriculture contribute to eutrophication of aquatic ecosystems further emphasizes the importance of efficient agronomic P use (Syers *et al.,* 2008; Bergström *et al.,* 2007).

1.9.2.3 Phosphorus Requirements of Potato

The need for p is critical during the early stage of growth when normal meristem development and rapid vine growth are necessary for a high yield. Large amounts of p are needed for starch phosphorylation in potatoes. Tubers from 50-day-old plants contained only 23% of the total plant p; while tubers from plants 123 days old contained 83% of the total plant p (Houghland, 1960). On soils containing sub-optimum levels of available p, potato crops show economic responses to the application of P fertilizer (Johnston *et al.,* 1986) and, as a result, relatively large amounts are applied in commercial practice. Surprisingly, very few studies have attempted to analyze the mechanism by which this nutrient influences crop growth although some reports have suggested that adequate levels of P promote early leaf canopy growth but may advance senescence (Dyson and Watson, 1971). Such responses might be expected to influence the temporal patterns of radiation interception, and thereby dry matter accumulation under varying conditions of p supply.

Potato cultivars differ in the extent and duration of their canopy growth (Griffith *et al.,* 1984). Whilst adequate nutrient levels are necessary to maintain an active canopy for an extended period, the amounts required may vary between cultivars as a consequence of intrinsic variation in their capacity to generate leaf area. Consequently, the response to applied P fertilizer may vary if the principal effect of this nutrient is to influence canopy cover. Cultivars also vary in the depth and density of their root growth (Allen and Scott, 1992). Those with a more limited root system, a characteristic usually associated with earlier maturing cultivars, have a reduced capacity to explore the soil profile for nutrients. This is particularly important for those nutrients that are relatively immobile in soil, such as p, for which uptake is limited to depletion zones that are very close to the root surface (Wild, 1988). Factors other than cultivar influence rooting and, therefore, the likely response to fertilizer P seed sprout status as well-sprouted seed generally produce smaller leaf canopies (O'Brien *et al.,* 1983) and are likely also to have more shallow rooting systems, although substantial evidence to support this is lacking.

1.9.2.4 Phosphorus acquisition in potato

Phosphorus is taken up by the potato crop continuously over the growing season. However, the amount taken up per day varies depending on the phenological stage. Although P is crucial, the element is needed in relatively small amounts, 0.5 kg ton-1compared with 3 kg ton-1 for N and 4 kg ton-1 for K (Stark *et al.,* 2004; Dampney *et al.,* 2002; Bennett, 1993). The report of (Girma et al., 2017) indicated that increasing phosphorous rate increases marketable tubers, total tuber numbers, average tuber weight were highly increased due to high responsive of potato as compared to other tuber crops. As the recommended amount of P_2O_5 was 90 kg/ha for highland of Ethiopia regardless of the variety and soil components, it has to be checked again and again as it is related to cost and nutrient is depleting and depleting with time due to continues cropping and leaching as well as erosion. On the other hand, previous recommendation was done on DAP as p-source and due to soil nutrient change blended fertilizer which contain nitrogen, phosphorus, sulfur and Boron was recommended as p-source for some highland like Holetta; In different chemical formula which can vary the needs of crop. Therefore, it is important to evaluate the variety responses to the different rates of NPSB blended fertilizer and recommend economically optimum rate for production.

1.9.3 Role of Sulfur on the growth and yield of potato

Sulfur is classified as a secondary element, along with Magnesium and Calcium, but it is sometimes called "the 4th major nutrient. Some crops can take up as much P as S. Sulfur is one of the key secondary elements essential for optimal plant growth. It is taken up from the soil solution by the plant in the sulfate form (SO_4^{2-}). Sulfur is one of 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 much reaction in all living cell (Sud and Sharma, 2002) and sulfur deficient plant had poor utilization of nitrogen, phosphorus and potash and a significant reduction of catalyze activities at all age (Nasreen *et al.*, 2003). Effect of sulfur application on quality parameters of potato after harvesting was studied by many authors. Jaiswal *et al.,* (2008) and Ullah and Saikia (2008) reported differences in quality parameters among different varieties of potato. According to these authors, tuber yield per plant showed maximum values with 45 kg ha-1 Sulfur which was significantly superior over control, 15 and 30 kg ha-1sulfur application. Mani *et al.,*(2014) small size tuber yield (%) was the maximum under control followed by 15, 30, 60 and 45 kg ha-1 in descending order along with this medium and large size tuber yield (%) was maximum under 45 kg ha-1followed by 60, 30 and 15 kg ha-1 sulfur. Sud and Sharma (2002) reported that increase in tuber yield with increasing sulfur levels may be attributed to its role in better partitioning of the photosynthesis in the shoot and tubers. Significant effect on grade wise tuber yield and increase in bulking rate with sulfur application was reported by Lalitha *et al.,* (2002). Most soils of Ethiopia was found short of sulfur, so that blended fertilizer like NPSB and NPS was formulated for such soils and the need of crops grown for food on this soil has to be accessed on the base of yield and yield component traits. According to Bewket et al.,(2018), increasing the rates of sulfur resulted in to significant total tuber and marketable yield increased probably because of sulfur effect on the synthesis of sulfur containing amino acids, proteins, energy transformation, and activation of enzymes.

1.9.4 Boron

Boron is an essential micronutrient for plants, and plant requirements for this nutrient are lower than the requirements for all other nutrients except molybdenum and copper. It is the only non-metal among the micronutrients and also the only micronutrient present over a wide pH range as a neutral rather than an ion (Epstein and Bloom, 2005). Boron has been found to play a key role in reproductive processes affecting anthers development, pollen germination and pollen tube growth (Loomis and Durst, 1992). Besides, Kaisher *et al.* (2010) reported a synergistic effect while working on sulfur and boron with respect to yield and yield contributing characters in addition to quality of the crop yield. Boron deficiency can be confused with Ca deficiency, which also affects the growing points and leads to their 'dying off.' Ca deficiency also causes leaf necrosis, which is seen at the edge of the leaf and not between the veins as with boron deficiency. Potato has a relatively low requirement hence deficiency symptoms occurs mainly on soils with poor boron content (weathered sandy soils) or soils with a high fixing capacity (recently limed, peat soils, pH > 7) (Kolbe, 1997). Some of the symptoms of boron deficiency in potato appear as a chlorosis in the interveinal areas of new leaves, leaf and plant growth stunting, death of leaves and fall of the plant (Raskshya and Arjun, 2019).The primary role of boron is in the cell walls, where it provides cross links between polysaccharides to give structure to cell walls. Boron also plays roles in formation of sugar complexes for translocation within plants, and in the formation of proteins (Truog, 1946). Boron deficiency induces thickening of the young leaves also crinkled and bordered by light brown tissue, which extends to the intercoastal areas. The growing points and the shoot tips die off. In severe cases, the leaf margins are cupped upward (Kolbe, 1997). Deficiency symptoms are induced by sandy soils, alkaline soils and soils low in organic matter, high levels of nitrogen, and high levels of calcium, cold wet weather, and periods of drought. Boron is important for improved crop development and improved tuber quality. It reduces incidence of internal Rust Spot and incidence of internal browning (Truog, 1946). Due to these reasons, the micro nutrient blended form of fertilizer developed in the country when soil was found deficient in Boron and the need for the rate determination for Blended fertilizer that contain boron become one area of work for researchers in Ethiopia. Not only rate determination but also the variety effect evaluation in relation to their boron requirement is also basic information to be obtained. Boron application also significantly increased tuber yield probably due to its role in regulation of carbohydrate metabolism and its transport within the plant besides the synthesis of amino acids and proteins(Walter and Rao, 2015). Furthermore, crops differ in their micronutrient contents depending on species, variety and physiological features (Oury et al., 2006). Among the important factors regulating the crop nutrient supply, the root system temperature, fluctuations of plant physiological processes are consequently, control the plant nutrient supply (Baghour, 2002).

1.9.5 Potassium effect on potato

Potassium was found increasing both marketable and total tuber weight by increasing tuber sizes (Shunka *et al.*, 2016). On an average, potato removed about 91 kgK2O ha−1 at the yield of 29 Mg ha−1 (Moinuddin *et al.*, 2005). Duan *et al.* (2013) found that the average uptake of K by rain fed potato and irrigated potato in Inner Mongolia of China was 82.2 and 221.7 kgK2O ha−1 at the yield of 14.9 and 35.7 Mg ha−1, respectively. The positive effect of K fertilization is greater on tuber quality than on yield (Kavvadias *et al*., 2012). The commonly used methods for K recommendations for crops are based on soil testing and sometimes can be used effectively for guiding fertilizer applications (Hannan *et al*., 2011), but the critical level of soil test K should be determined. The alternative way is to make fertilizer recommendation based on yield response and agronomic efficiency, which was successfully used in fertilizer recommendation for wheat and maize (Chuan *et al*., 2013; Xu *et al*., 2014). Another method for K recommendation is based on K balance in soil plant systems and the recommended rate of K should be at least the amount of K removed by crop products (Shutian *et al*., 2015). Similarly, nutrient uptake by the potato crops also depends on the climatic condition, soil type and fertility status, variety cultivated and crop management practice (Sedera and Shetata, 1994)). Potassium (K) aids in maintaining osmotic potential which enhances water uptake and root permeability, control ionic balances, regulate plant stomata and activate enzymatic processes(Bishwoyog and Swarnima, 2016). According to Bishwoyog and Swarnima (2016) potassium (K) plays significant role in quality as well as yield attributes of potato such as reducing sugar, Vitamin C content, specific gravity, shelf life and total yield. Because of higher loss and low replacement of potassium, widespread deficiency of potassium have been reported in many of the intensively cultivated soil(Adhikary and Karki, 2006) and application of K fertilizers have responded satisfactorily (Regmi *et al*.,2002). Potassium is one of the most essential nutrients required for plant development. It plays vital role in several physiological processes such as photosynthesis, translocation of photosynthates, control of ionic balance, regulation of plant stomata and transpiration, activation of plant enzymes and many other processes (Thompson, 2010). The quality parameters such as dry matter, specific gravity, starch contents, vitamin-C and ash contents are affected with application of P and K (Khan *et al*., 2012). Application of Potassium is not only responsible to increase K concentration but also affects the concentration of N and P in potato tubers (Muhammad *et al*., 2015). According to Singh and Lal (2012) potassium significantly affect plant height, number of leaves per plant and marketable yield of potato tubers. Application of Potassium fertilizer plays vital role in yield of potato. Such increases in yield of potato tubers are either due to the formation of large size tubers or increasing of the number of tubers per plant or both. Westennann (2005) stated that insufficient K resulted in smaller-sized tubers. Potassium increases the size but not the total number of tubers (Trehan *et al*., 2001). Potassium helps to increase the content of carbohydrate significantly which ultimately helps to increase the tuber size (A-Moshileh & Errebi, 2004). Compared to other vegetables commonly found in grocery stores, potatoes are the largest and most affordable source of potassium (Drewnowski *et al*. 2013) with zero mg of sodium per serving, and 2 g of fiber. In human case, Accordding to Bethke and Jansky(2018),potassium control high blood pressure and decrease risk of strock when taken in high amount. The adequate intake of potassium for adult peoples was 4,700mg per day which is 100g boiled potato can supply 16% of this requirement.

1.9.6 Zinc effect on potato

According to the Food and Agriculture Organization (FAO), about 30% of the cultivable soils of the world contain low levels of plant available Zn (Hafeeze *et al*., 2013)]. Zinc is an important micro-nutrient needed for good growth and performance of potato (Raskshya and Arjun, 2019). Zinc exerts a great influence on basic plant life processes, such as: Nitrogen metabolism and uptake of nitrogen, photosynthesis and chlorophyll synthesis (Tahmorespour *et al*., 2013). Genotypes were variable in the concentration of mineral elements (copper, iron, manganese, zinc) in potato tubers (Subramanian *et al*., 2017 and Asrat *et al*., 2018). Potatoes are an excellent candidate for tackling malnourishment in developing countries and easily satisfying micronutrient needs of fast growing global population. According to Raskshya and Arjun (2019), folar application of Zn significantly affected the potato height, stem number, canopy coverage and tuber yield. The mineral composition of potato was improved by foliar application of Fe and Zn by Fe (+70%) and Zn (+27%) over the control (Anita *et al*., 2020) and they recommended 200 g serving of potatoes for one day dietary need of micro nutrient.

Fe and Zn facilitate the functioning of different enzymes, including DNA/RNA polymerases, N-metabolizing enzymes and numerous other enzymes involved in redox processes (Broadley *et al*., 2012). In sugar beet (Barłóg *et al*.,2016) there was Zn treatments significant impact on total uptake of N and significant positive correlation between tuber Zn and N concentration(White *et al*., 2012). According to Buono *et al*. (2009) potato tubers are source of vital minerals like potassium in higher amount and lesser amount of magnesium, phosphorus, manganese, zinc and iron. These essential elements are nutritionally important which play critical roles in various biological processes of both plants (Maathuis, 2009) and human beings (Martinez-Ballesta *et al*., 2010). In humans, the deficiencies cause metabolic disorders and organ damage, leading to acute and chronic diseases and even death (Dos *et al*., 2013). Its deficiency is worldwide common problem and the most important global challenges for human nutrition (Pinto *et al*., 2015). Over three billion people are currently malnourished, with the highest rates in developing countries where iron (Fe), zinc (Zn) and vitamin A are the most critical deficiencies (Gabriela *et al*., 2007). According to Renata *et al*. (2020), balanced micronutrient supply is the prerequisite to ensure normal plant growth no less than the supply of essential macronutrients. In the plant metabolism, the mutual proportions between the individual macro and micronutrients are of greater importance than the absolute element contents (Fageria *et al*., 2008). According to Renate *et al*. (2020), there was significant effect of zinc applied with sulfate potassium in the variety bred for crisps. Zinc effected 52% protein content (Zhang *et al*., 2008).

1.9.7 Iron effect on potato

Iron element is found to be increasing tuber yield from 40-45 % (Renata *et al*., 2020). According to Gabriela *et al*. (2007) application of Iron resulted in yield increases of potato though some research indicated that there is considerable variation among genotypes in the concentration of mineral elements (copper, iron, manganese, zinc) in potato tubers (Subramanian *et al*., 2017 and Asrat *et al*., 2018). In line with this, Gebriela *et al*. (2021), reported significantly different Iron concentration of potato with variety, location and variety interaction environment. Micronutrients fertilization improved mineral composition of raw potatoes (Anita *et al*., 2020). According to Broadley *et al*. (2012), Fe (Iron) involved as facilitator of different enzymes, including DNA/RNA polymerases, N-metabolizing enzymes and numerous other enzymes. Potato is a good source of vitamin C, vitamin B6 and iron (Buono *et al*., 2009). Food is the best means of getting Iron in human beings. More than three billion people are reported to be malnourished with the greater amount in developing countries especially iron (Fe) and vitamin A are the most critical deficiencies (Gabriela *et al*., 2007). Iron deficiency weaken physical growth, cognitive development, immunity and poor school performance in young children, while in pregnant women, it causes fetal growth retardation and is responsible for a large proportion of maternal deaths (Gabriela *et al*., 2007).

1.10 Concussion

Potato is responsive to both micro and macro element application. It is highly productive and a food security crop of the Ethiopian peoples. Achieving optimum fertilizer application is important agronomic activities that encourage the crop to provide the yield to its maximum potentials. Almost all Ethiopian soils is in generally deficient in macro element N, P, and S while some of the locations lack micro elements B , Zn as well as macro element P. It is concluded that, most reviewed sources indicate that there was less recommendation concerning micro and macro elements for potato in the country in relation to the variable ecology the country owned

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