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Ensuring Food Security of Smallholder Farmers through Improving Productivity and Nutrition of Potato

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Abstract

In a time of extremely high population growth, loss of arable land and climate change effects, food security issue is becoming more and more important. Thus, improving the food security of smallholder farmer is a major concern particularly in developing country. In this regard potato is one of the important cash crops which contributes for food security and reduce poverty among smallholder farmers in the developing countries like Ethiopia. However, the productivity of the crops is constrained by the limitation of soil macronutrient. Therefore, this research was conducted with the aim to improve potato productivity through intensive and economical uses of soil macronutrients. A factorial combination of four soil macro nutrients and three potato varieties were used in a Randomized Complete Block Design with three replications. The result revealed that soil macronutrients and potato variety had significantly influenced on phenology and growth components. Interaction effects of soil macro-nutrients and variety had also significantly affected total and marketable tuber yield of potato. The marginal rate of return of 7,370% was obtained from the Wabi variety with the application of 200 kg ha $^{-1}$ soil macro-nutrients (NPS fertilizer). Therefore, growing the Wabi variety of potato at 200 kg/ha of soil macro-nutrients resulted in a high productivity and economic returns of the crop.

Introduction

Potato (*Solanum tuberosum* L.) is one of the most productive food crops in terms of yields of edible energy and good quality protein per unit area per unit time (Jessie, 2017). It is regarded as a high potential food security crop because of its ability to produce high yield and quality product per unit input with a shorter crop cycle (mostly < 120 days) than major cereal crops (maize) (Adane et al., 2010; Israel et al., 2012).

The annual world and African production of potato during 2018 was about 368.2 and 26 million tons, respectively (FAOSTAT, 2020). Ethiopia is endowed with great potential for potato production majorly due to the good climatic and edaphic conditions for its production and productivity (Endale et al., 2008). In Ethiopia, about 9.245 million tons of potato is produced from 70,362 ha during 2019/20 cropping season (FAOSTAT, 2020) and can potentially be grown on about 70% of arable land (CSA, 2010). However, its average yield in African is very low (6 to 12 t ha^{-1}) compared to Europe and North America (35–45 t ha^{-1}) (CIP, 2017) and specifically in Ethiopia, it is 7.97 tons ha^{-1} (CSA, 2016) which is far below the potential of the crop (CIP, 2017).

As it was reported by Samuel (2017), the low production and productivity of potato in Ethiopia is due to the use of substandard agronomic practices including suboptimal amount and types of fertilizers, and use of substandard quality tubers, and shortage of improved and adaptable cultivars. CIP (2017) and Kefelegn et al. (2012) also reported that inappropriate agronomic practices, shortage of seed tubers of improved potato varieties, depletion of soil nutrient, moisture stresses, diseases and insect pests are the major constraints of potato production in Ethiopia. Thus, the low productivity of potato in Ethiopia is majorly due to the low soil fertility and varietal difference (Mekides et al., 2020).

Potato demands high levels of macro and micro soil nutrients due to its poorly developed and shallow root system (Dechassa et al., 2003). Potatoes have relatively shallow root zones and lower tolerance for water stress compared to other crops, therefore irrigation may be required where rainfall is limited (Makani et al., 2013). It is also characterized as a strict requirement of balanced soil nutrient (Ahmed et al., 2015).The crop produces much more dry matter by taking large amounts of nutrients per unit time, which generally most of the soils are not able to supply (Islam et al., 2013). Thus, low soil fertility is one of the limiting factors to sustain potato production and productivity in Ethiopia (Zelleke et al., 2010).

Ethiopian farmers have been relying only on blanket recommendations of 165 kg ha^{-1} of urea and 195 kg ha^{-1} DAP without considering the fertility status of the soil, the environment and the type of varieties used (Tewodros, 2014). However, Ethiopian soils lack most of the macro (NPS) and micro (Cu, B and Zn) nutrients (EthioSIS, 2014). Thus, the Ethiopian government has distributed blended NPS fertilizer in the crop production system since 2013 (MoANR, 2013).

Mekides et al. (2020) reported the significant improvement of Belete and Local potato varieties with 55.5: 89.7:16.52 kg ha^{-1} of NPS fertilizer rate. Similarly, Alemayehu and Jemberie (2018) reported that, application of 272 kg ha^{-1} NPS fertilizer on Belete variety recorded the longest plant height (64.8 cm) and the highest (9.3) stem numbers per hill. Gebremeskel (2016) and Yayeh et al. (2017) have also observed an increasing trends in growth of cabbage, onion and garlic by application of NPS fertilizer. Positive results on potato productivity were also reported by Alemayehu and Jemberie (2018) with increasing levels of soil macronutrients (NPS).

The positive influence of soil macronutrients have been also reported on various vegetable crops (Yayeh et al., 2017). Thus, to increase the productivity of potato, introducing the high yielding varieties with intensive and economical soil macronutrients is very important.

Materials And Methods

Description of the Study Area

The experiment was conducted at Agarfa, ATVET College during 2021. The area is located at 7° 16' 0" N to 7° 22' 30" N Latitude and 39° 51' 0" E to 39° 57' 0" E Longitude with altitude 2330 m above sea level and 455 km away from Addis Ababa in the south eastern part of the country. The experimental area is characterized as a sub-humid type of tropical climate. The average annual rainfall of the area based on the 21 years meteorological data is 829.4 mm. The site has a bimodal rainfall distribution hence; the area has two growing seasons as short rainy season and main rainy season. The short rainy season starts in January and ends in April. Main rainy season starts in mid-June and extends to late October. The mean annual temperature is 15.2^{o}C and the mean maximum and mean minimum temperature of the area are 24.75^{o}C and 7.1^{o}C, respectively.

Experimental Materials, Treatments and Design

Three improved potato varieties (Belete, Gudane and Wabi) were used as experimental material in the study area. Those varieties were released by different Agricultural Research Centers. Two factors of (fertilizer and potato varieties) with three replications were used in the experiment where the field was laid out factorialy in Randomized Complete Block Design (RCBD). Macro nutrients of 0, 100, 150 and 200 kg ha^{-1} with three potato varieties (Belete, Gudane and Wabi). The experiment has 12 treatments with three replications and each replication consists of 12 plots corresponding to the 12 treatment combinations. Each treatment combination was assigned randomly to the experimental units within a block. A uniform plot size of 3m x 3 m (9 m^2) was used for each unit with a total experimental area of 564 m^2. The space between each plot was 1m and the blocks were separated by 1.5 m.

Experimental Procedures and Field Managements

Uniform size, diseased free and uniformly sprouted tubers of three potato (Belete, Gudene and Wabi) varieties were collected from Sinana Agricultural Research Center. Land was plowed four times by oxen. Following the usual tillage practice the experimental field was conventionally prepared before planting on April, 2021 and it took three to four months to complete the research work till its final harvesting date August 28/2021. Ridges were made at a recommended spacing of 75 by 30 cm uniformly throughout the experimental plot. The experiment had four ridges per plot with 10 plants per row. Planting was done at 5 cm depth. Plot size was 3 m X 3 m= (9 m^2).   There were a total of 36 plots. NPS fertilizer treatment was applied based on the treatment-wise level and the recommended level of nitrogen (138 kg/ha) was applied uniformly for all plots to satisfy the nitrogen deficiency in NPS fertilizer. Recommended earthling up and other agronomic practices were done accordingly at the appropriate time and level. Disease was protected by chemical fungicide application for early blight and late blight (Ridomil MZ 63.5% WP at the rate of 2 Kg/ha and Mancozeb at the rate 3 kg/ha) (EARO, 2004).

Physico-chemical Properties of the Experimental Site soil

Soil sample was taken at a depth of 0-30 cm from randomly selected spots in a W-shaped pattern across the experimental field before planting using auger. The collected soil sample was composited and prepared for analysis to determine the physicochemical properties of experimental site soil. The soil samples were analyzed at an appropriate soil laboratory for soil texture, total nitrogen, pH, organic matter, available phosphorus, and cation exchange capacity (CEC). Total nitrogen was determined according to Tekalign et al. (1991) classification; the soil pH was measured using Olson II methods (Olsen et al., 1954); organic carbon was determined by the method of (Booker, 1991) classification and the available phosphorus was measured using Olson II methods (Olsen et al., 1954); Cation exchange capacity (CEC) was determined by Landon (1991) method.

Table 3. Physico-Chemical properties of the experimental site soil

Parameter	Values	Rating	References
Sand %	20.96		
Silt %	36.28		
Clay %	42.76		
Textural Class	Clay loam		
Available phosphorus (mg kg^{-1})	22.23	Medium	
Available Sulfur (mg kg^{-1})	14.5	Low	
Total N	0.15	Low	
OC %	1.82	Low	
pH	6.04	Slightly acidic	
OM %	2.96	Medium	
EC (ds/m)	0.19	Low	
CEC [Cmol (+) kg^{-1} soil]	21.7	Medium	

Where N=Nitrogen, OC%=Percent of Organic carbon, pH=Power of hydrogen, EC = Electrical conductivity, OM%=percent of organic matter, CEC=Cation exchange capacity, Cmol = Centimole

Data Collection

Phenological Data

Days to emergence, flowering and maturity were recorded when 50 % of planted tubers emerged and produced flowers and when 90 % of the plants of different treatments (each plot) were ready for harvest, respectively. The days were counted from emergence to maturity of the crop or 50% above ground is failed to the ground and color change.

Growth and physiological parameters

Plant height (cm) was measured from the five randomly selected plants in each plots at 50% flowering. Number of leaves per hill was measured by counting from the five randomly selected plants in each hill. Leaf area (cm^2) was determined by the product of leaves width and leaf length from five randomly selected plants and multiplied by a constant value of 0.674. Whereas, leaf area (LA) was measured according to Sakllova (1979) cited by Djilani and Senoussi (2013). The five randomly selected plants in central rows that arose from the ground was counted and converted as number of stems per hill and biomass was measured at physiological maturity.

Yield and yield components

Marketable tuber yield (t ha^{-1}) was measured by selecting average weight of tubers which were free from diseases, insect pests and above 20 g tubers from five randomly taken plants and the rest was recorded as unmarketable tuber yield (t ha^{-1}). Whereas, total tuber yield/ha was recorded by adding the weights of marketable and unmarketable tubers. The number of tubers which were free from diseases, insect pests, and tubers of having above 20 g from five plants in the three middle rows was computed as marketable tuber number /hill and the rest were measured as unmarketable tuber number / hill. Whereas, total tuber number $hill^{-1}$ was determined by adding up the number of marketable and unmarketable tubers per hill. Harvest index was determined as the ratio of dry weight of tubers to the total dry biomass.

Quality parameters

The proportional number of tubers size categories was measured according to Lung'aho et al. (2007) and recorded as tuber size distribution. Whereas, tuber dry matter content (%) and specific gravity as measured based on the methods developed by CIP (2007).

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

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

Partial Budget Analysis

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

Data Analysis

The parameters considered in this study were subjected to analysis of variance using General Linear Model of GenStat 16th edition (GenStat, 2016) and mean separation was made based on least significance difference at 5% probability level.

Results And Discussion

Phenological parameters of potato

Days to 50% emergence

The overall range of number of days to emergency was 12 – 15 days; this was statistically significant at $p \leq 0.01$. NPS rates of 200 kg/ha delayed the days to emergency (14.22 days) and it was statistically similar with 150 kg/ha of NPS rates, whereas control treatment (0 NPS) produced early emergency (12.89 days) of potato plants (Table 4). These could be due to the interaction of the mineral fertilizer and temperature/storage conditions.

According to Struik (2007), higher temperatures increased gibberellic acid production (GA), in addition to mineral fertilizer, particularly nitrogen which also promotes gibberellic acid and thus increased the rate of emergence. Morena et al. (1994) also reported that the emergence of potato tubers was affected by storage conditions and physiological age of the seed tubers rather than being disciplined by the fertility status of the land.

Guadane (13.16) and Wabi (13.42) took shorter days to emerge and it was delayed in Belete variety (14.08) (Table 4). Variation in emergency might be governed by the genetic factors of the plant through its nutrient supply. This suggestion was supported by Degam (2016) who reported a significant difference between Gudanie, Belete and Jalenie varieties for days to 50% emergence of potato plants. Different cultivars had different capacity to store food and to provide an optimal supply of carbohydrate for the emerging seedling of embryo. The result is in agreement with the findings of Abubaker et al. (2011) who reported that the genetic variation could be attributed to the emergency difference among varieties. Lung'aho et al. (2007) stated that younger tubers took longer times to emerge from the soil.

Days to 50% flowering

The maximum NPS fertilizer rates (200 kg/ha) took 56.67 days and it was followed by NPS rates of 150 kg/ha. The control and 100 kg/ha NPS fertilizer rates treatment took 54.44 days to flowering (Table 4). The significant difference among the treatments might be attributed to the characteristics of nitrogen and phosphorus nutrients which enhanced vegetative growth of the crop and prolonged days required to attain 50% of flowering. In line with this, Alemayehu et al. (2015) and Biruk (2018) have also reported that increasing nitrogen and phosphorus fertilization levels significantly delayed days required reaching flowering in potatoes. The higher rates of N from higher rates of NPS fertilizer might have a positive effect to stimulate growth and prolonged vegetative phase thus, delaying the reproductive phase of plants (Tisdale et al., 2003). Similarly, Israel et al. (2012) reported that increased phosphorus application prolonged the days to 50% flowering.

The maximum days required to reach 50% flowering (56.75 days) was recorded from the Belete variety. The shortest day to 50% flowering (54.25 days) was recorded from the Gudane variety and it was statistically similar with Wabi (Table 4). This might be due to the difference in environmental adaptability among varieties and the indicators of the traits that are mostly controlled by genetic factors. The result supported by Arega et al. (2007) who reported that day to flowering is highly dependent on gene factors and governed by many environmental factors, mainly temperature and light. Early flowering of varieties may indicate the beginning of tuberization at an early stage (Carrie et al., 2014). Bradshaw (2007) also reported that a genetic difference is the cause for difference in flowering among the difference in variety. The number of days required for flowering is one of the important parameters for potato farmers due to the fact that it enables the grower to forecast its harvesting scheme and marketing plan (Khalafalla, 2001).

Table 4
Effects of NPS fertilizer rates and potato variety on days to emergence, days to flowering and day's maturity

NPS (kg ha^{-1})	Days 50% emergence	Days to 50% flowering	Days 90% maturity
0	12.89^{c}	54.44^{b}	94.78^{c}
100	13.33^{bc}	54.44^{b}	96.22^{b}
150	13.78^{ab}	56^{ab}	97.44^{a}
200	14.22^{a}	56.67^{a}	98^{a}
LSD (5%)	**0.51**	**1.60**	**1.2**
Variety			
Belete	14.08^{a}	56.75^{a}	104.83^{a}
Gudane	13.17^{b}	54.25^{b}	82.83^{c}
Wabi	13.42^{b}	55.17^{b}	102.17^{b}
LSD (5%)	**0.44**	**1.39**	**1.04**
CV (%)	**3.83**	**2.96**	**1.27**

Means followed by the same letters in the same across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

Days to 90% maturity

A day to maturity for potatoes is defined as the number of days from emergence to when 90% of the plants reached harvest accompanied with senescence of the haulms. The maximum days to attain days to 90% maturity (98 days) was recorded from application of 200 kg ha^{-1} NPS fertilizer rates and it was statistically similar with 150 kg/ha NPS fertilizer rates. The shortest days (94.778 days) to maturity was recorded from the control treatment (Table 4). Increased rate of nitrogen stimulated haulm growth prolonged the growing period and delayed tuber formation (crop maturity). Therefore, a crop with more nitrogen will mature later in the season than a crop with less nitrogen because late growth (maturity) is related to excessive haulm development while early tuber growth (maturity) is related to less abundant haulm growth (Mulubrhan, 2004). The delayed maturity of plants in response to the application of the blended NPS fertilizer at higher rates might be due to the effect of nitrogen contained in the fertilizer which may have stimulated plant growth, enlarged leaves and tubers but delayed flowering and maturity. This suggestion is in agreement with Tantowijoyo and Van de Fliert (2006) who reported that the application of nitrogen fertilizer at higher rates enhances vegetative growth by helping the plant to absorb sunlight and produce carbohydrates but delayed the production of reproductive part and thereby delayed maturity. The results of the present study are generally in agreement with the findings of various researchers where increasing fertilizer rates, including NPS prolonged days to flowering and maturity of different vegetable crops including potato in different agro-ecologies (Gebremeskel, 2016; Mekashaw, 2016).

Variety days to maturity was delayed 104.83 days) in Belete variety and the earliest was recorded from Gudane (82.83 days), whereas Wabi is matured in between the two (Table 4). The result is supported by the findings of Getachew et al. (2016) who reported early maturation of Gudane compared to Belete varieties. This result is also supported by the findings of Abera et al. (2018), and Alemayehu and Jemberie (2018).

Growth parameters of potato

Plant height (cm)

The longest plant height (80.06 cm) was recorded by the application of 200 kg ha^{-1} NPS fertilizer and it was followed by 150 kg/ha NPS fertilizer rates. The shortest plant height (65.15 cm) was recorded from the control treatment (unfertilized plot). Increasing the rate of NPS fertilizer rates enhanced plant height of potato (Table 5). The result revealed that application of 200 kg ha^{-1} NPS fertilizer rates significantly influenced plant height of potato. The significant increase in plant height in NPS fertilizer could be due to the fact that nitrogen is considered as one of the major limiting nutrients in plant growth and promotes the formation of chlorophyll which in turn resulted in higher photosynthetic activity, vigorous vegetative growth and taller plants. Phosphorus is also required in large quantities in shoot and root tips where metabolism is high and cell division is rapid. Sulfur promotes the formation of chlorophyll, higher photosynthetic activity, vigorous vegetative growth and taller plants. The current investigation is also consistent with the findings of Alemayehu et al. (2015) and Biruk (2018) who indicated that plant height increased with increasing amounts of nitrogen fertilizer in potatoes. Gezahegn (2011) has also reported that plant height increased in response to increased application rate of N and P fertilizers, which could be related to the role of nitrogen in promoting vegetative growth and that of phosphate in favoring leaf expansion and stem elongation. Similarly, Israel et al. (2012) have found that increasing application of nitrogen and phosphorus significantly increased plant height.

The longest (79.74 cm) and shortest (65.71 cm) plant height was recorded from the Belete and Gudane varieties, respectively. The Wabi (75.79 cm) variety was shorter than Belete and taller than Gudane (Table 5). The differences between varieties for plant heights might be attributed by differences in genetic constitution of the varieties and quality of material used. The current investigation is also consistent with the findings of Eaton et al. (2017) who indicated the variations in plant height among varieties were most probably due to plant genetics and quality of plant materials used. These results also agree with the finding of Bekele (2018) that variation among plant height was observed due to the ample food provided and/or due to varietal differences that could be associated with their canopy structure or other growth habit for varieties.

Leave number per hill

The maximum number of leaves per hill (445.48) was recorded from 200 kg ha^{-1} of NPS fertilizer rates and it was followed by 150 and 100 kg/ha of NPS rates. The smallest number of leaves per hill (399.78) was recorded from the control plot (Table 5). The increased leaf number per hill with increasing NPS fertilizer could be due to the contribution of NPS fertilizer for above-ground biomass (leaves). This result is inconsistent with the findings of Yayeh et al. (2017) who reported an increase in leaf number per hill as rates of NPS fertilizer application increased on vegetable crops. The combined application of NPS and compost resulted in higher photosynthetic activity and chlorophyll synthesis which seemed to have a favorable effect on the number of leaves per plant in Maize (Sisay and Adugnaw, 2020).

The maximum leaf number per hill (445.42) was recorded from the Belete variety and it was statistically similar with Wabi. The minimum leave number per hill was recorded (402.36) from the Gudane variety. This might be due to the genetic difference of plants which contributes to the production of many stems per hill and thereby produces significantly different leaf numbers among the potato variety. Similarly, Masarirambi et al. (2012) and Zebenay (2015) in their study in Zimbabwe and at central highlands of Ethiopia, respectively also reported that numbers of leaves were significantly influenced by plant density and seed size due to variety. Leaf number was significantly and positively correlated with days 50% emergence, days to 50% flowering, days to physiological maturity and plant height (Appendix Table 2). This might be due to the increasing level of NPS in favorable soil conditions for plants to increase the above-ground biomass (leaf number) which resulted in increase the number of branches and plant height consequently prolonged in days to 50% flowering and maturity.

Table 5
Effects of NPS fertilizer rates and potato variety on plant height, leaf number per hill, leaf area, leaf area index, stem number per hill and above ground dry biomass

NPS (kg/ha)	PH (cm)	LNH^{-1}	LA (cm^2)	LAI	SNPH	AGBM (g)
0	65.15^{c}	399.78^{b}	17.54^{c}	3.13^{c}	6.87^{c}	94.89^{d}
100	72.2^{b}	429.02^{ab}	18.18^{bc}	3.4^{c}	7.36^{c}	113.36^{c}
150	77.58^{a}	437.82^{a}	19.68^{b}	3.85^{b}	8.09^{b}	123.29^{b}
200	80.06^{a}	445.48^{a}	21.99^{a}	4.33^{a}	8.89^{a}	143.17^{a}
LSD (5%)	**4.50**	**31.05**	**1.79**	**0.44**	**0.54**	**6.55**
Variety						
Belete	79.74^{a}	445.42^{a}	22.51^{a}	4.44^{a}	8^{a}	138.04^{a}
Gudane	65.71^{c}	402.36^{b}	15.91^{c}	2.83^{c}	7.37^{b}	96.03^{c}
Wabi	75.79^{b}	429.02^{ab}	19.62^{b}	3.78^{b}	8.03^{a}	121.96^{b}
LSD (5%)	**3.90**	**26.87**	**1.55**	**0.38**	**0.47**	**5.68**
CV (%)	**6.25**	**7.46**	**9.48**	**12.1**	**7.12**	**5.65**

PH, LNH^{-1}, LA, LAI, SNPH, AGBM, LSD and CV stands for plant height, leaf number per hill, leaf area, leaf area index, stem number per hill and above ground dry biomass. Means across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

Leaf area

The highest (21.99 cm^2) and the lowest (17.54 cm^2) leaves area was recorded from 200 and 0 kg ha^{-1} of NPS fertilizer rates, respectively, while the other treatments were in between the two (Table 5). The result further indicated that, as the rates of NPS fertilizer increased up to optimal level, leaf area increased which plays a vital role in absorption of solar radiation thereby contributing for growth, yield and yield components of the crop. The result is in line with the findings of Assefa et al. (2015) who reported an increment of leaf area and leaf area duration with increased NP rates. Similarly, Tariku et al. (2018) also reported that the increased rate of NPS fertilizer application significantly increased leaf area in barley. According to Israel et al. (2012) and Mulubrhan, (2004), application of nitrogen fertilizer resulted in excessive development of haulm. Similarly, Zelalem et al. (2009) have found that increased application of nitrogen rate significantly increased leaf area of potato.

With regard to variety, significantly maximum leaf area (22.51 cm^2) were obtained from Belete variety and the minimum leaf area (15.91 cm^2) were obtained from Gudane variety (Table 5). This might be due to different genotypes having different genetic character and having different growth habits. According to

Paul (2007) the number of initially available (first order) stems have a role in increase in leaf number and position on the plant which is important for rate of leaf area increase.

Leaf area Index

The highest leaf area index (4.33) was recorded from 200 kg ha^{-1} NPS fertilizer rate. The lowest (3.13) leaf area index was recorded from control treatment and it was statistically similar with 100 kg/ha of NPS rates (Table 5). The increased leaf area index might be due to the improved soil property by NPS fertilizer resulting in expanded leaf size thereby planting covered large space which gives an increase in LAI. Increased leaf area could be attributed to the development of above ground biomass with the expanded leaves produced in response to nitrogen (Firew, 2014). Vaezzadeh and Naderidar (2012) also reported that organic and inorganic fertilizer expanded the leaf area index. This result is also in line with the findings of Bewket (2019) who reported that increasing the rate of organic and inorganic fertilizer increased leaf area index.

It is also evident from Table 5 that maximum (4.44) leaf area index at variety Belete was noted followed by Wabi variety (3.78), while the minimum (2.83) leaf area index was achieved at Gudene variety. The result of this study indicates that some of the cultivars differed in leaf area index possibly due to genetic differences, which was influenced by environment. This finding is corroborated by the results of a study conducted by Putz (1986). Allen et al. (1992) also reported that leaf area index can vary widely according to growing conditions and variety. Dhital et al. (2009) also found that young and fully expanded leaves led to better tuberization in potato cultivars than the very young or very old leaves with less leaf area index.

Stem number/hill

The highest stem number per hill (8.89) was attained at 200 kg ha^{-1} NPS rates and the lowest was (6.87) recorded from the control plot. Increasing the rates of NPS fertilizers, significantly increased stem number per hill (Table 5). This result is consistent with the findings of Jembrie et al. (2017) who reported that increasing application of NPS fertilizer rates increased the main stem number of potatoes. Singh et al. (2016) and Alemayehu and Jemberie (2018) reported that nitrogen with Sulfur fertilizer resulted in a significant and maximum number of stems per plant. This also conforms to that of Niguse (2016) who reported that application of P and K fertilizers significantly increased stem number per hill. However, Alemayehu and Jembere (2018) pointed out that, application of 281.75 kg ha^{-1} NPS blended fertilizer which is more than this experiment.

The highest (8.03) stems number per hill was recorded from the Wabi variety and it was statistically similar with the Belete variety. The lowest (7.37) stems number per hill was recorded from the Gudene variety (Table 5). This difference could be due to the inherent variations in the number of buds per tuber of cultivars. The number of stems relate to numbers of branches and numbers of leaves which contributes to photosynthesis potential. An increase in absorption of solar radiation can ensure a higher photosynthesis potential and promote synthesis and accumulation of reserve carbohydrates in the potato tuber which has a positive effect on the final tuber yield (White et al., 2007). Different scholars reported that the stem number is the reflection of different factors, such as storage condition (Islam, 2006), physiological age of the seed of the variety and tuber size. The number of stems per plant had direct relation with the number of sprouts per tuber not on the treatment applied (Abebe et al., 2010) and the sprouts are the function of the number of eyes on tubers. The result is also in agreement with the findings of Frezgi (2007) who reported that the number of stems per hill was not influenced by plant density rather it is influenced by cultivar.

Above ground dry biomass

The highest above ground dry biomass (143.17 g) was attained at the rate of 200 kg ha^{-1} NPS and the lowest was (94.89 g) recorded from the control treatment (Table 5). Biomass yield increment in response to NPS treatment indicates that all nutrients could influence biomass production and partitioning to the different parts of the potato plant. This result conformed to the findings of the White et al. (2007) who reported a significant increment in dry matter yield of potato as N application increased. The increment of dry matter yield per plant was also more apparent in plants from the applied fertilizer which is probably due to less competition among the plants for nutrients. The findings of Millard and Marshall (1986) also noted that a significant increment in canopy dry matter yield of potato as N application increased supports the results obtained in this study. The results of the present study clearly indicated that application of NPS fertilizer increased biomass yield of potato varieties which are in line with the findings of various researchers (Sharma and Arora, 1987).

Table 5 clearly showed that Belete variety gave the highest above ground dry biomass (138.04 g) and it was followed by Wabi (121.96 g), whereas Gudene variety gave the smallest (4.23 cm) above ground dry biomass. The difference of varieties in all dry biomass yields is associated with the difference in the genetic makeup of the potato varieties. This type of result has also been observed by Mekides et al. (2020) who reported that dry biomass yields are associated with genetic make-up differences among potato varieties.

Yield and yield components of potato parameters

Total Tuber Number $hill^{-1}$

The highest total tuber number per hill (48.16) was recorded from the maximum NPS fertilizer rate (200 kg/ha) and it was followed by 150 and 100 kg/ha of NPS rates with the total tuber number per hill of 42.83 and 37.1, respectively, whereas the control treatment (0 NPS) gave smallest (27.84) tuber number per hill (Table 6). The increase in the total tuber number per hill with an increase in NPS rate could be due to the fact that N can trigger the vegetative growth for more photo-assimilate production, while P enhances the development of roots for nutrient uptake. In agreement with the present finding, the authors of Zamil et al. (2010) and Israel et al. (2012) have reported a significant marketable and total tuber number increment in response to N and P fertilizer application. In line with this Sharma (2015) reported that, application of N, P and S significantly increased the number of tubers set per unit area. Singh et al.

(2016) and Alemayehu and Jemberie (2018) also reported that nitrogen with sulfur fertilizer produced a significant and maximum number of stems per plant. According to Ababiya (2018), increasing the rate of the blended NPS application from nil to 200 kg ha^{-1} significantly increased the average tuber number per hill by about 28.57%.

The maximum total tuber number per hill (40.86) was recorded at Belete variety. However, it was statistically at par with the Wabi variety with a result of 39.53, whereas the lowest total tuber number per hill was recorded from the Gudene variety (36.56). The variation may be attributed to the difference in genetic potential among potato varieties (Table 6). Stolen and tuberilization processes are affected by genetic makeup and environmental factors (Bekele, 2018). Similarly, Sharma et al. (2015) and Alemayehu and Jemberie (2018) also reported significant variation in tuber yield of different potato varieties. Getachew et al. (2016) reported significant differences among potato genotypes in their number of tubers per plant due to genetic variation.

Marketable tuber number /hill

The highest marketable tuber number per hill (43.96) was recorded from 200 kg/ha of NPS fertilizer rates followed by 150 and 100 kg/ha of NPS rates. The lowest marketable tuber number per hill was recorded from control treatment. Marketable tuber number per hill increased from control plot to maximum NPS rate (200 kg ha^{-1}) accordingly. In this experiment, NPS fertilizer rate increases marketable tuber size by 16.12% (Table 6). This might be due to different rates of fertilizer applications having different marketable yields. Increase in marketable tuber numbers per hill was due to the application of nitrogen, sulfur and phosphorus was associated with a decrease in number of the small-sized tubers and increase in the weight of individual tubers. The application of 180 kg N along with 50 kg S increased the number of marketable tubers by 43% (Singh et al., 2016). From the findings of Daniel et al. (2008) the possible reason for increased marketable tuber number per hill might be due to the application of organic and inorganic fertilizer. This result is in agreement with the findings of Israel et al. (2012) and Alemayehu et al. (2015) who reported that application of nitrogen and phosphorus significantly increased marketable tuber and total tuber number. Similarly, Zelealem et al. (2009) also reported that increases in the rates of NPS and urea fertilizers significantly increased tuber number per potato plant.

The Belete variety had recorded the highest marketable tuber number per hill (35.96) and the lowest marketable tuber number per hill (32.08) was recorded from the Gudane variety (Table 6). This variation is due to genetic differences among varieties. According to Fikre, (2012) genetic differences among potato varieties play a role in their ability to produce high solids. The variation in total yield of potato genotypes may be due to differences in response to the growing environmental factors. This is in agreement with findings of other authors, who reported that tuber yield differences among genotypes were attributed both to the inherent potential of genotypes and growing environment as well as to the interaction of genotype x environment (Habtamu et al., 2016).

Unmarketable tuber number / hill

The maximum unmarketable tuber number per hill (5.44) was recorded from the control plot. The lowest unmarketable tuber number per hill (4.21) was recorded from the maximum (200 kg/ha) NPS fertilizer treatment and it was statistically similar with 150 and 100 kg/ha of NPS fertilizer treatment. The result further explained that with increased NPS rates from 0 to 200 kg/ha, unmarketable tuber number per hill was decreased (Table 6). This result is in line with the findings of Biruk (2018) who reported the lowest unmarketable tuber numbers per hill from the highest NPS fertilizer rate. Similar result was also reported by Solomon et al. (2019) who reported that the increased application rate of NPS fertilizer results in lower numbers of unmarketable tuber numbers as compared to unfertilized treatment.

Harvest index

The maximum harvest index (0.33 g) was recorded from the highest fertilizer treatment (200 kg ha^{-1}) and it was statistically similar with 150 kg/ha of NPS fertilizer rates. The lowest harvest index (0.21 g) was recorded from an unfertilized plot (Table 6). The possible reason could be due to the effect of phosphorus in increasing tuber production of the potato than the vegetative part. This result was agreed with the findings of Shiferaw et al. (2015) who reported that increase in the rate of N, P and S led to higher harvest indices. Similarly, Israel et al. (2012) found that, increasing application of N and P rate increased harvest index of potato. This result is confronted with the findings of Ezzat et al. (2011) who reported that as N level increases, the dry matter percentage decreased, which in turn reduced tuber dry matter percentage by increasing tuber water content which leads to reduced harvest index. The yield increment in response to nitrogen application might be due to the production of high carbon assimilates thereby giving high yield in spite of harvest index value and also might be due to proportional increment of total tuber and biomass yields (Israel et al., 2012).

Maximum harvest index (0.29 g) was recorded from Belete and Wabi potato varieties, while the minimum harvest index (0.26 g) was obtained from Gudene variety (Table 6). It probably could be attributed to the increase in leaf area coverage of the soil surface until sufficient light became trapped for optimally enhanced productions of photo assimilation. Ronald (2005) who revealed that the highest density increased leaf area index, possibly indicating potential partitioning of assimilates for vegetative growth. Leaf area index indicates the level of photosynthesis and accumulation of starch for partitioning to tuber at the end of the growing season. Leaf area index can vary widely according to growing conditions and variety which is in agreement with the report of Allen et al. (1992).

Table 6
Effects of NPS fertilizer rates and potato variety on total tuber number hill^{-1}, marketable tuber number hill^{-1}, unmarketable tuber number hill^{-1} and harvest index

NPS(kgha^{-1})	TTNH^{-1}	MTNH^{-1}	UNMTNH^{-1}	Harvest index
0	27.84^{d}	22.4^{d}	5.44^{a}	0.21^{c}
100	37.1^{c}	32.44^{c}	4.66^{b}	0.27^{b}
150	42.83^{b}	38.22^{b}	4.61^{b}	0.30^{ab}
200	48.16^{a}	43.96^{a}	4.21^{b}	0.33^{a}
LSD (5%)	**1.97**	**1.95**	**0.48**	**0.03**
Variety				
Belete	40.86^{a}	35.96^{a}	4.91	0.29^{a}
Gudane	36.56^{b}	32.08^{b}	4.56	0.26^{b}
Wabi	39.53^{a}	34.73^{a}	4.72	0.29^{a}
LSD (5%)	**1.71**	**1.69**	**NS**	**0.03**
CV (%)	**5.17**	**5.82**	**10.34**	**12.28**

Means across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

Total tuber yield (t/ha)

Increasing the rate of NPS fertilizer from nil to 200 kg ha^{-1} increased total tuber yield significantly. Higher total tuber yield per hectare (41.7) was scored from Belete at 200 kg ha^{-1} of NPS fertilizer and lower total tuber (23.1) per hectare was scored from Gudane variety which was unfertilized plot. Total tuber yield of Belete was increased by 17.1%, Gudane was increased by 14.57% and Wabi was increased by 15.85% from unfertilized plot to fertilizer application up to 200 kg ha^{-1} (Table 7).

The higher total tuber yields were obtained from potato which was supplied with all NPS fertilizer rates as compared with control. This variation might be due to the increasing rate of fertilizers the tuber yields. The probable reason for increased tuber yield with increasing sulfur levels might be attributed to its role in better partitioning of the photo-assimilates in the shoot and tubers (Sud and Sharma, 2002). According to the report of Mahmoodabad et al. (2010) and Sharma and Arora (1987), increment of nitrogen fertilizer rate resulted in more tuber yield but excessive rate of nitrogen (250 kg ha^{-1}) and decreased the total number of tubers per unit area and yield, since high amount of nitrogen encourage vegetative growth more than tuber growth. Increasing in total tuber yield with increasing rates of blended NPSZnB fertilizer was due to the positive effect of both nitrogen and phosphorus on total tuber weight (Israel et al., 2012). This is probably attributed to the improvement in conditions that enhanced vegetative growth of the aerial parts and, hence, translocation of photosynthate into the storage parts (Alemayehu et al., 2015).

This variation might be due to storage of photosynthetically matter in the tubers and also may be due to the cultivar having inherent genetic variation on tuber bulking among potato varieties.

This result also agrees with the work of Levy and Veilleux (2007), who suggested that the duration and rate of tuber bulking vary, among varieties and depends on environmental conditions. These results were similar with other researchers who reported that total tuber yield was significantly varied by variety (Kumar et al., 2007). Similarly, Sharma (2015), Sharma et al. (2011) and Alemayehu and Jemberie (2018) reported significant variation in tuber yield of different potato varieties. In addition to the genetic makeup of the varieties, differences in tuber size, plant spacing and others could have contributed to the observed yield variations among-varieties and environments (Masarirambi et al., 2012).

Table 7
Interaction effects of NPS fertilizer rates and potato variety on total tuber yield

Variety	**NPS kg ha^{-1} 0**	**100**	**150**	**200**
Belete	24.6^{fg}	30.12^{cd}	37.52^{b}	41.7^{a}
Guadne	23.1^{g}	27.03^{ef}	31.09^{c}	37.67^{b}
Wabi	24.78^{fg}	27.91^{de}	36.13^{b}	40.63^{a}
LSD (5%)	**2.77**			
CV (%)	**5.01**			

Means across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

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

Plants grown without fertilizer application produced the lowest marketable (18.76 t ha^{-1}) from Gudane variety and the highest marketable (36.74 t ha^{-1}) tuber yields were produced from Belete variety by application of 200 kg ha^{-1} (Table 8). Wabi was recorded (34.67 t ha^{-1}) at 200 kg ha^{-1} NPS fertilizer rate application which was statically similar with the Belete variety. This variation might be due to application of different rates of fertilizers. Increasing the rate of blended NPS fertilizer from zero to 200 kg ha^{-1} increased marketable tuber yield significantly. The result shows that marketable tuber yields increased significantly when the blended NPS rate was increased. This result is consistent also with those of Jemberie et al. (2017) and Alemayehu et al. (2018) who reported that the application of NPS fertilizer at the rate of 272 kg ha^{-1} resulted in the production of the highest marketable tuber yield (47.02 t ha^{-1}) of potato. The result is also in line with that of Getachew et al. (2016) who reported that the maximum marketable yield was obtained in response to the application of 100 kg ha^{-1} blended NPKSZ and the lowest recorded from unfertilized plots. Similarly, Ababiya (2018) and Bewket (2019) have reported that higher marketable tuber yield of potato crop was obtained from application of blended fertilizers at increased rates.

Solomon et al. (2019) reported that the lowest unmarketable tuber yield was obtained from potato plants that received a higher rate of blended fertilizer that contains sulfur, while the highest value was recorded for plots that did not receive fertilizers. Zelalem et al. (2009) and Israel et al. (2012) also reported that N and P fertilization significantly influenced productivity of potato measured in terms of marketable and total tuber yields. Similarly, total tuber yield and marketable tuber yield increased significantly as the rate of sulfur increased, probably due to sulfur’s role in the synthesis of sulfur containing amino acids, proteins, energy transformation, activation of enzymes which in turn enhances carbohydrate metabolism and photosynthetic activity of plant with increased chlorophyll synthesis Israel et al. (2012).

This variation might be due to genotype variation among varieties. In agreement with the present findings, a significant difference in total and marketable tuber yield among potato varieties was reported by Berhanu and Tewodros (2016) and Habtamu et al. (2016). These results were in line with other researchers who reported that marketable tuber yield was significantly varied by variety (Kumar et al., 2007). Accordingly Habtamu et al. (2016) reported a significant variation was observed between potato varieties for their total tuber number per hill, marketable, unmarketable and total tuber yield in t ha^{-1}.

Marketable tuber yield increment was found to be strongly and positively associated with days to 50% emergence, days to 50% flowering, days to physiological maturity (leaf number, plant leaf area, and leaf area index, above ground biomass, Stem number, plant height, total tuber number, marketable tuber number, harvest index and total tuber yield.

Table 8
Interaction effects of NPS fertilizer rates and potato variety on marketable tuber yield

Variety	**NPS kg ha^{-1} 0**	**100**	**150**	**200**
Belete	19.68^{de}	25.21^{c}	30.8^{b}	36.74^{a}
Guadne	18.76^{e}	21.38^{d}	26.83^{c}	32.75^{b}
Wabi	19.05^{de}	21.37^{d}	27.2^{c}	34.67^{ab}
LSD (5%)	**2.60**			
CV (%)	**5.25**			

Means across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

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

Table 9 explained that maximum unmarketable tuber yield (4.1 t ha^{-1}) was recorded from the unfertilized plot (0 kg/ha NPS). The minimum unmarketable tuber yield (2.83 t ha^{-1}) was recorded from the maximum NPS fertilizer rates (200 kg/ha) and it was statistically similar (3.09 t ha^{-1}) with 150 kg/ha of NPS rates.

Unmarketable tuber yield was decreased by 1.27% when the NPS fertilizer rates application increased from 0 to 200 kg ha^{-1} fertilizer rates. The decrease in the level of phosphorus might have decreased the growth of above ground biomass, tuber growth which leads to reduced tuber size and thereby contributes to the high unmarketable tuber yield. The increase in unmarketable tuber yields of potato plants was also observed with decreasing fertilizer rates as indicated by the findings of Zelealem et al. (2009) which is in line with the findings of the present study. Similarly, highly and positively association results were reported between the proportions of small sized tuber yield with unmarketable tuber yield (Helen, 2011). Bekele (2018) showed that variation among genotypes of non-marketable yield could be attributed to their genetic make-up. Zelealem et al. (2009) also pointed out that genotype differences significantly contributed to unmarketable tuber yield.

Table 9
Effects of NPS fertilizer rates and potato variety on unmarketable tuber yield

NPS kg ha^{-1}	Unmarketable tuber yield (tha^{-1})
0	4.1^{a}
100	3.36^{b}
150	$3.09b^{c}$
200	2.83^{c}
LSD (5%)	**0.5**
Variety	
Belete	3.12
Gudane	3.46
Wabi	3.46
LSD (5%)	Ns
CV (%)	**14.91**

Ns stand for non-significant at 5% level of significance. Means across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

Potato Quality Parameters

Specific gravity

The highest specific gravity (1.076) was recorded at the maximum NPS fertilizer (200 kg ha^{-1}) and the lowest specific gravity was (1.025) recorded from unfertilized plots (Table 10). This could probably be due to its association with the increased stored assimilates in potato tubers with higher rates of NPS fertilizer. Silva et al. (2014) described that specific gravity is an important trait, because it is directly related to the dry matter content of the tubers. Higher specific gravity provides higher processing yield, less fat absorption, better texture without affecting the taste of the final product.

The result further explained that with increasing NPS fertilizer rates from 0 to 200 kg/ha the specific gravity increased by 5%. The result is in agreement with the findings of Zelealem et al. (2009) and Tesfaye et al. (2013) who reported significantly increased specific gravity of potato tubers with the increased fertilizer rates. Similarly Ahmed et al. (2015) also reported that growth and quality of potato were affected by the combination of both sources of fertilizers. In contrast to the current findings Bewket (2019) reported that application of the maximum dose of inorganic and organic fertilizer resulted in lowest tuber specific gravity. According to Bekele (2018), the specific gravity of tubers was significantly affected by blended NPSZnB fertilizer and highly significantly affected by cattle manure.

Dry matter contents

The maximum dry matter content of potato (27.51%) was recorded from the maximum NPS fertilizer treatment (200 kg/ha) and the minimum dry matter content (21.54%) was obtained from the controlled treatment (unfertilized plot), whereas the other treatments were in between the two (Table 10). This is probably associated with the influence of N on gibberellin biosynthesis and other phyto-hormonal activities which have direct influence on plant growth and dry matter accumulation. This might be attributed to high NPS dose which results in high NPS use efficiency and dry matter accumulation in tubers (Gawronska et al., 1984). The highest dry matter and starch content were accumulated in potato tubers fertilized with mineral not organic fertilizers (Strimumar and Ockerman, 1990). Another study indicated that, increase in NP fertilizer might have enhanced growth components by promoting the dry matter accumulation Najm et al. (2010).

On the data, Belete variety produced the highest dry matter content (25.85%) and Gudane variety recorded the lowest with a value of 24.21%, whereas Wabi recorded in between the two (Table 10). Higher dry matter percentage recorded at cultivar that had maximum LAI, it might be the capacity to prepare more photosynthesis and able to produce more assimilates and it is the channeled to sinks and also the inherent genetic differences among the potato varieties in the production of dry matter (total solids) contents of tubers. Dry matter is a varietal character; however, growing location, season, climatic conditions and cultural practices greatly affect the accumulation of dry matter in tubers, a dry matter content of more than 20% is considered ideal for making chips (Saran and Chhabra, 2014). The present result is in concur with the finding of Tekalign and Hammes (2005) who reported that significant variation among potato cultivars with respect to total dry matter content was observed. Dry matter of potato tubers is genetically controlled and influenced by environmental conditions during growing season and storage temperature (Saran and Chhabra, 2014). Bekele (2018) showed that Variation among genotypes of non-marketable yield, marketable and quality could be attributed to genetic make-up.

Table 10
Effects of NPS fertilizer rates and potato variety on specific gravity and dry matter contents of potato

NPS kg^{-1}	SG	DMC (%)
0	1.025^{d}	21.54^{d}
100	1.05^{c}	24.74^{c}
150	1.06^{b}	26.38^{b}
200	1.08^{a}	27.51^{a}
LSD (5%)	**0.01**	**1.19**
Variety		
Belete	1.050	25.85^{a}
Gudane	1.056	24.21^{c}
Wabi	1.051	25.07^{b}
LSD (5%)	**Ns**	**0.93**
CV (%)	**1.28**	**3.63**

Ns, SG and DMC stand for non-significant, specific gravity and dry matter content. Means across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

Potato tuber size distribution

As the rate of blended NPS rates increased, large tuber size increased by 35.06%, medium tuber size increased by 26.26% but small tuber size decreased by 35.55% at highest rates of 200 kg ha^{-1} application (Table 11). This indicates that phosphorus is a critical nutrient in determining tuber size of potato varieties. This could be due to the interaction of the mineral fertilizers and re-absorption of stored food from tubers because of fast growth of aboveground biomass due to nitrogen fertilizer. This is due to the presence of relatively better nutrient supply which results in production of large and medium tuber production. This could be due to supply of nutrients to potato crop resulting in luxuriant growth, more canopies and leaf area for a function of photosynthesis which helped in producing larger tubers, hence resulting in higher yields Mulubrhan (2004) and Israel et al. (2012). This result also agrees with the results reported by Kumar et al. (2007) that the production of large sized tubers and medium sized tubers increased due to less competition for nutrients and moisture. This may be attributed to the enhanced metabolic role the nutrient plays in tuber cell growth and development (Marschner, 1995). Alemayehu et al. (2015) and Frezgi (2007) have also noted that nitrogen application increased the quantity of larger size tubers and total yield.

Gudane had the highest small tuber size (32.25%) but Belete had the lowest small size (26.04%) as compared to both Gudane and Wabi varieties. Wabi had the highest medium tuber size (52.71%) but Gudane had the lowest medium tuber size (43.64%). Belete had the highest large tuber size (50.15%) but Wabi had the lowest large tuber size (35.8%) but it had statically the same with Gudane variety. This may be due to the higher number of tubers as well as characteristics of variety adaptability or establishment effects of the other growth attributes and variations among varieties might be due to the inherent characteristics of the cultivars used. This result was in line with this study, Berhanu and Tewodros (2016) and Habtamu et al. (2016) reported that tuber size distribution varied with varieties. Also, in confirmation with the findings of Patel et al. (2008) and Kumar et al. (2007) who reported that maximum yield of small size tubers may be due to higher number of tubers as well as varietal character, adaptability or establishment effects of the other growth attributes.

Table 11
Effects of NPS fertilizer rates and potato variety on tuber size distribution

	Tuber size distribution		
Fertilizer rates	Small	Medium	Large
0	49.43[a]	35.1[d]	21.71[d]
100	31.88[b]	48.37[c]	38.49[c]
150	20.32[c]	52.42[b]	47.6[b]
200	14.37[d]	61.36[a]	58.26[a]
LSD (5%)	**4.49**	**3.92**	**4.43**
Variety	Small	Medium	Large
Belete	26.04[b]	51.65[a]	50.15[a]
Gudane	32.25[a]	43.64[b]	38.59[b]
Wabi	28.71[ab]	52.71[a]	35.8[b]
LSD (5%)	**3.89**	**3.4**	**3.83**
CV (%)	**15.84**	**8.14**	**10.92**

Means across all rows and columns followed by the same letter (s) are not significantly different at 5% level of significance (LSD)

Partial Budget Analysis

Partial budget is a method of organizing experimental data and information about the costs and benefits of various alternative treatments (CIMMYT, 1988). Therefore, partial budget analysis was made to find out the exact rate of return that the farmers gain to their investment with changing the existing cultural practices by the new alternative practices. The non-dominated treatments were shown through their dominance over others in the sense that the treatment combinations showed higher net benefits with the same or lower level of variable costs.

Marginal rate of return of the three non-dominated combinations of NPS and potato varieties (Wx200, Bx200 and Gx200) was carried out to find out the relative profitability of the promising treatment combinations. Accordingly, the MRR attained at a combination of Bx200, Wx200 and Gx200 were 7370%, 5840% and 5820%, respectively (Table 6). The maximum MRR of 7370% was obtained when the treatment combination was shifted from Gx200 to Wx200 and the highest (308430 ETB ha^{-1}) net field benefit was also recorded on this treatment combination (Wx200). Moreover, the treatments combination of Wx200 gave the maximum marketable tuber yield of potato (Table 12).

The highest marginal rate of return (MRR) of 7370% followed by 5840 were obtained from Wabi and Belete varieties received with 200 kg ha^{-1} NPS fertilizer, respectively (Table 6). The results indicated that the farmers could obtain a minimum and maximum of 12.1 and 73.7 Birr, respectively from Gudane and Wabi varieties when farmers cost 1 Birr for purchasing fertilizer. As per, CIMMYT (1988) the minimum acceptable MRR for farmers is 100%. Thus, the MRR obtained at Bx10, Bx150, Bx200, Wx100, Wx150 and Wx200 combinations was above the minimum acceptable marginal rate of returns. Therefore, the combination of Wabi variety with 200 kg/ha NPS fertilizer had the highest marketable tuber yield (34.67 t/ha) and the highest net benefit (308430 ETB ha^{-1}) together with an acceptable MRR might be taken as profitable and can be temporarily recommended for the test area.

Table 12
Partial budget analysis for quality tuber production of potato varieties as affected by NPS fertilizer rates

Treatments	MTY(kg ha^{-1})	Adj.MTY(kg ha^{-1})	GB(ETB)	TVC(ETB)	NB	MRR%
Bx0	19068	17161.2	171612	0	171612	-
Bx100	25210	22689	226890	1800	225090	2971
Bx150	30800	27720	277200	2700	274500	5490
Bx200	36740	33066	330660	3600	327060	5840
Wx0	19051	17145.5	171459	0	171459	D
Wx100	21370	19233	192330	1800	190530	1060
Wx150	27200	24480	244800	2700	242100	5730
Wx200	34670	31203	312030	3600	308430	7370
Gx0	18760	16884	168840	0	168840	D
Gx100	21380	19242	192420	1800	190620	1210
Gx150	26830	24147	241470	2700	238770	5350
Gx200	32750	29475	294750	3600	291150	5820

Where, Blended NPS cost = 18 Birr kg^{-1}, Field price of potato during harvesting = Birr 10 birr kg^{-1}, MTY = Marketable tuber yield, Adj.MTY = Adjusted Marketable tuber yield, GB = Growth Benefit, TVC = Total variable cost, NB = Net benefit, MRR (%) = Marginal rate of return and D = Dominated treatment, Belete,G = Gudane, W = Wabi

Summary And Conclusion

Potato is one of the most productive food crops in terms of yields of edible energy and good quality protein per unit area per unit time. Productivity of potato demands high levels of macro and micro nutrients due to its poorly developed and shallow root system. Therefore, this research was conducted to determine the effect of blended NPS fertilizer rates on growth, yield and quality of potato varieties at Agarfa, Bale Zone, and South Eastern Ethiopia. Three potato varieties, namely Belete, Gudane and Wabi were used in this experiment in the 2021 cropping season as experimental material. Four rates of blended NPS fertilizer (0, 100, 150 and 200 kg ha^{-1}) were used. The experiment was tested in factorial arrangement in randomized block design with three replications. Belete and Gudane varieties are well adaptable to varying climatic conditions and have yield variation across the region also resistant to late blight diseases at their optimum agro ecological conditions. Wabi is a newly released variety, high yield and well resistant to late blight diseases.

The main effects of NPS fertilizer rates and potato varieties revealed significant differences on days to 50% emergence, days to 50% maturity, plant height, leaf area, leaf area index, stem number, total tuber number per hill, marketable tuber number per hill, Unmarketable tuber number, harvest index, specific gravity, dry matter content, tuber size distributions.

The interaction effects of NPS fertilizer rates and potato varieties were significant on total tuber yield and marketable tuber yield. Highest total tuber yield per hectare (41.7) was recorded from Belete at 200 kg ha^{-1} of NPS fertilizer and lower total tuber (23.1**)** per hectare was scored from Gudane variety which was unfertilized plot. Total tuber yield of Belete was increased by 17.1%, Gudane was increased by 14.57 % and Wabi was increased by 15.85% from unfertilized plot to fertilizer application up to 200 kg ha^{-1}. The highest marketable (36.74 t ha^{-1}) tuber yields were produced from Belete variety by application of 200 kg ha^{-1}. Wabi was recorded (34.67 t ha^{-1}) at 200 kg ha^{-1} NPS fertilizer rate application which was statically similar with the Belete variety.

Partial budget analysis of the present study revealed that the combination of Wabi variety with 200 kg/ha NPS fertilizer resulted in a higher net field benefit of 308430 Ethiopian birr ha^{-1} which was obtained from an acceptable MRR of 7370%. These findings have to be confirmed through further research across more locations and years to ascertain the consistency of the recommendation.

Declarations

- **Ethics approval and consent to participate**: Not applicable
- **Consent for publication**: Not applicable
- **Availability of data and materials**: Not applicable and somebody needs the corresponding author will handle it

- **Conflict of Interest**: "The authors declared that they have no conflict of interest"
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- **Authors' contributions:**

GM: Data collected, analyzed data and drafted the manuscript. AH: Research conceptualization, supervision, manuscript preparation and review.

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References

Ababiya, A. 2018. Integrated use of NPS blended fertilizer and cattle manure on growth, yield and quality of potato (*Solanum tuberosum* L.) under Dabo Ghibe Kebele, Seka Werada of Jimma Zone, Southwest Ethiopia (Doctoral dissertation, Jimma University).

Abebe, G.K., Bijman, J., Ruben, R., Omta, S.W.F. and Tsegaye, A. 2010. The role of agricultural POsin improving quality and reducing transaction costs in the Ethiopian potato chain. In *Proceedings of the 9th Wageningen International Conference on Chain and Network Management, Wageningen, Netherlands,* pp. 16-26.

Abera, T., Belete, K. and Tana, T. 2018. Effect of Blended NPS Fertilizer Supplemented with Nitrogen on Yield Components and Yield of Bread Wheat (*Triticumaestivum* L.). *Journal of Natural Sciences Research*, 8 (11): 90-96.

Abubaker, S., AbuRayyan, A., Amre, A., Alzu`bi1, Y. and Hadidi, N. 2011. Impact of Cultivar and Growing Season on Potato (*Solanum tuberosum* L.), Under Center Pivot Irrigation System. *World Journal of Agricultural Sciences*, *7*(6), pp.718-721.

Adane, H., Meuwissen, M.P.M., Tesfaye, A., Lommen, W.J.M., Lansink, A.O., Tsegaye, A. and Struik, P.C. 2010. Analysis of Seed Potato Systems in Ethiopia. *American Potato Research Journal,* 87: 537-552.

Ahmed, A., Zaki, M., Shafeek, M., Helmy, Y., Abd, E. and Baky, M. 2015. "Integrated Use of Farmyard Manure and Inorganic Nitrogen Fertilizer on Growth, Yield and Quality of Potato." *International Journal of Current Microbiology and Applied Science,* 4(10): 325–349.

Alemayehu, G., Shibabaw, A., Adgo, E., Asch, F. and Freyer, B. 2018. Effects of organic manure and crop rotation system on potato (*Solanum tuberosum* L.) tuber yield in the highlands of Awi Zone. *Ethiopian Journal of Science and Technology*, *11*(1): 1-18.

Alemayehu, M. and Jemberie, M. 2018. Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern Ethiopia. *Cogent Food* *and Agriculture*, 4 (1):63.

Alemayehu, T.G., Nigussie, D. and Tamado, T. 2015. Response of potato (*Solanum tuberosum* L.) yield and yield components to nitrogen fertilizer and planting density at Haramaya, Eastern Ethiopia. *Journal of Plant Sciences*, 3(6): 320-328.

Allen, E.J., Wurr, D.C.E. and Fellows, J.R. 1992. Determination of optimum tuber planting density in the potato varieties, Pent land Squire, Cara, Estima, Maris Piper and King Edward. *The Journal of Agricultural Science*, 119 (1):35-44.

Arega, D.A, Manyoung, V.M., Omanya, G., Mignouna, H.D., Bakanga, M. and Odhiambo, G.D. 2007. Smallholder Marketed surplus and Input NSE under transactions costs: Maize supply and fertilizer Demand in Kenya AAAE *Conference Proceedings*, 125-130.

Assefa, M., Johnson, Semoka, M.R., Nyambilila, A. and Tekalign, M. 2015. Wheat Response to Applied Nitrogen, Sulfur and Phosphorous in three Representative Areas of the Central Highlands of Ethiopia. *International Journal of Plant and Soil Science*, 8 (5): 1–11.

Bekele, T. 2018. Adaptability study of improved potato (*Solanum tuberosum* L.) varieties at Shebench district, south-western Ethiopia. *Academia Journal of Agricultural Research*, 6(10): 333-338.

Berhanu, B. and Tewodros, M. 2016. Performance evaluation of released and farmers' potato (*Solanum tuberosum* L.) varieties in eastern Ethiopia. *Sky Journal of Agricultural Research*, 5(2): 34 - 41.

Berihun, B. and Woldegiogis, G. 2012. Potato research and development in Ethiopia: Achievements and trends. *Proceedings of the national workshop on seed potato tuber production and dissemination*. pp. 35–44. Bahir Dar, Ethiopia.

Bewket, G. 2019. Effect of blended (NPSZnB) fertilizer and cattle Manure Rates of Growth, Yield and Quality of Potato (*Solanum tuberosum* L.) at Banja District, Awi Zone, and North Western Ethiopia. *International Journal of Research Studies in Agricultural Sciences* (IJRSAS), 5: 27-36.

Biruk N. 2018. Effects on rates of blended NPSB and nitrogen fertilizers on yield and yield components of potato (*Solanum tuberosum* L.) in East Badawacho district, southern Ethiopia. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.56P.

Booker, T.L.1991. Tropical soil manual a hand book for soil survey and Agricultural land.

Bradshaw, J.E. 2007. Potato-Breeding Strategy. In: Potato Biology and Biotechnology: Advances and Perspectives, (eds). Vreugdenhil D, Bradshaw J, Gebhardt C, Govers F, Mackerron DKL, Taylor MA and Ross HA. Elsevier Ltd., Amsterdam, Netherlands pp. 157-178.

Carrie, H., Wohleb, N., Richard, K. and Mark, J.P. 2014. Plant growth and development. In: R. Navarre, and J. P. Mark (eds.), pp. 64-82. The Potato: Botany, production and uses. CABI International, Wallingford, UK.

CIMMYT (International Maize and Wheat Improvement Center). 1988. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. Mexico. D.F. ISBN 968-61 27-18-6.

CIP (International Potato Center). 2007. *Procedures for standard evaluation trials of advanced potato clones. An international cooperator's guide*.

CIP (International Potato Centre). 2017*. Harnessing potato and sweet potato's power for food security, nutrition and climate resilience international, annual report*. International Potato Centre.

CSA (Central Statistical Agency of Ethiopia). 2010. Agricultural sample survey: Report on area and production of crops, Addis Abeba, Ethiopia, p 126.

CSA (Central Statistical Agency of Ethiopia). 2016. Agricultural sample survey. Report on area and production of major crops. In S. Bulletin Ed., *Agricultural sample survey*. 125p. Addis Ababa: Central Statistical Agency.

Daniel, M., Pant, L.M. and Nigussie, D. 2008. Effect of integrated nutrient management on yield of potato and soil nutrient status of Bako, West Shewa, Ethiopian. *Journal of Natural Resources,* 10: 85-101.

Dechassa, N., Schenk, M. K., Claassen, N. and Steingrobe, B. 2003. Phosphorus efficiency of cabbage (*Brassica oleraceae* L. var. capitata), carrot (*Daucus carota* L.) and potato (*Solanum tuberosum* L). *Plant and Soil*, 250: 215–224.

Dhital, A., Prasad, S., Phil, S., Choi, A. and Lim, H.T. 2009. Effect of leaf age, leaf area, plant growth regulator and genotypes on the production of potato mini tubers. *Biotechnology Journal*, 26: 67-87.

Djilani, G. A and Senoussi, M.M., 2013. The Effect of natural organic manure on the growth and productivity ofpotato (solanum tuberosum Z var spunta) in a Sahara desert region.

EARO (Ethiopian Agricultural Research Organization). 2004. Directory of released crop varieties and their recommended cultural practices. Ethiopian Agricultural Research Organization, Ethiopia, pp. 36.

Eaton, T.E., Azad, A.K., Kabir, H. and Siddiq, A.B. 2017. Evaluation of Six Modern Varieties of Potatoes for Yield, Plant Growth Parameters and Resistance to Insects and Diseases. *Agricultural Sciences*, 8 (11):1315–26.

Endale, G., Gebremedhin, W., Bekele, K. and Lemaga, B. 2008. Postharvest management in root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga.pp.22-30. Ethiopian Institute of Agricultural Research, Addis Ababa Ethiopia.

EthioSIS. 2014. *Soil fertility and fertilizer tentative recommendation oromia region*. Ministry of Agriculture (MoA) and Agricultural Transformation Agency (ATA).

Ezzat, A.E.-B.S., El-Awady, A.A. and Ahmed, H.M.I. 2011. Improving nitrogen utilization efficiency by potato (*Solanum tuberosum* L.). *Nature and Science*, 9: 34–42.

FAOSTAT (Food and Agriculture Organization). 2020. Agricultural in the world top country of potato producer area and production of major tables of Central Statistical Agency, Available online accessed at www.potato.org.

Fikre, D. 2012. Influence of Nitrogen Supply on Yield and Yield Components of Potato Cultivars (*Solanum tuberosum* L.) and Nitrogen use Efficiency of the Cultivars at Debark District, North Western Ethiopia MSc Thesis, Haramaya University, Haramaya, Ethiopia. 60p.

Firew, G. 2014. Response of potato (*solanum tuberosum* L.) to nitrogen and phosphorus application under irrigation in Dire Dawa, eastern Ethiopia. A thesis submitted to the School of Graduate Studies, School of Plant Sciences, Haramaya University, Ethiopia. 57p.

Frezgi, A. 2007. Effect of Planting Density and Nitrogen Application on Yield and Yield Components of Potato (*Solanum tuberosum* L.) at Enderta, Southern Tigray, Ethiopia. MSc. Thesis submitted to school of plant sciences, Haramaya, University, Ethiopia. 62p.

Gawronska, H., Dwelle, R.B., Pavek, J.J. and Rowe, P., 1984. Partitioning of Photo assimilates by Four Potato Clones. *Crop science*, 24 (6): 1031-1036.

Gebremedhin, W., Endale, G. and Kiflu, B. 2013. National potato research program report. pp. 125. Ethiopian Agricultural Research Organization, Holetta Agricultural Research Center.

Gebremedhin, W., Endale, G. and Lemaga, B. 2008. Potato variety development. In Root and tuber crops: The untapped resources, ed. W. Gebremedhin, G. Endale, and B. Lemaga, 15– 32. Addis Abeba: Ethiopian Institute of Agricultural Research.

Gebremeskel, D. K. 2016. Assessment of production practices and effect of N: P2 O5: S rates on yield and yield components of head cabbage (Brassica oleracea var. capitata) under irrigation conditions in Lay Armachio District, Amhara Region, Ethiopia. (MSc Thesis). Bahir Dar University, Ethiopia. 63p.

GenStat. 2016. Gen Stat Procuduers Library Release. 16th Edition VSN International Ltd.

Getachew, A., Wassu, M. and Tesfaye, A. 2016. Genetic variability studies in potato (*Solanum tuberosum* L.) genotypes in Bale highlands, South Eastern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 6(3): 117- 119.

Gezahegn W. 2011. Response of Potato (*Solanum tuberosum* l.) to Application of Nitrogen, Phosphorus, and Farmyard Manure at Debark, Northwestern Ethiopia. M.Sc. Thesis,

Gusha, S. 2014. From Potato Fields to Potato Sacks. Pastorial Response. Anglical Diocese of Harare, Zimbabwe.64p.

Habtamu, G., Wassu, M. and Beneberu, Shi. 2016. Evaluation of Potato (*Solanum tuberosum* L.) Varieties for Yield and Yield Components in Eastern Ethiopia. *Journal of Biology, Agriculture and Health care*, 6:5.

Havlin, J.L., Beaton, J.D., Tisdale, S.L. and Nilson, W.L. 1999. Soil fertility and Fertilizer: An introduction to nutrient management. 6th ed. Prentice Hall. Upper Saddle River, New Jersey.

Helen, T. 2011. Evaluation on Growth Performance of Improved and Local Potato (*solanum tuberosum* L.) Cultivars Grown in Eastern Ethiopia. *Advances in Life Science and Technology*, 23:29-35.

Hirpa, A., Meuwissen, M.P.M., Tesfaye Abebe., Lommen, W.J.M., Lansink, A.O., Tsegaye, A. and Struik, P.C. 2010. Analysis of seed potato systems in Ethiopia. *AmericanJournal of Potato Research*, 87: 537-552.

Islam, Md.M, Akhter, S., Majid, N.M., Ferdous, J. and Alma, M.S. 2013. Integrated nutrient management for potato (*Solanum tuberosum* L) in grey terrace soil (Aric Albaquipt). *Australian Journal of Crop Science*, 7(9): 1235-1241.

Islam, S. 2006. "Sweet potato Leaf: Its Potential Effect on Human Health and Nutrition," *J. Food Sci.* 71:R13R21.

Israel, Z., Ali, M. and Solomon, T. 2012. Effect of different rate of nitrogen and phosphorus on yield and yield components of potato (*Solanum tuberosum* L.) at Masha District, South western Ethiopia. *International Journal Soil Science,* 7(4):146- 156.

Jemberie, M. 2017. Effects of NPS fertilizer rate and irrigation frequency determination method on the growth and tuber yield of potato (*Solanum tuberosum* L) in Koga Irrigation Scheme, Northwestern Ethiopia (M.Sc. Thesis). Bahir Dar University, Ethiopia.

Jessie, S. 2017. Potatoes: Health Benefits, Risks and Nutrition Facts: Live Science.

Kefelegn, H., Chala, A., Kassa, B. and Tiwari, P. K. 2012. Evaluation of different potato variety and fungicide combinations for the management of potato late blight (*Phytophthora infestans*) in Southern Ethiopia. *International Journal of Life Sciences*, 1(1): 8–15.

Khalafalla, A.M. 2001. Effect of plant density and seed size on growth and yield of potato (*Solanum tuberosum* L) in Khartoum state, Sudan. *Journal of African Crop Science, 8(3):28-31.*

Kumar, S., Khade, D., Dhokane, S., Bethere, G. and Sharma, A. 2007. Irradiation in combination with higher storage temperatures maintains chip-making quality of potato. *Journal of Food Science,* 72(6):402-406.

Landon, J.R. 1991. Booker Tropical Soil Manual: A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. (Eds.) John Wiley & Sons Inc., New York.

Levy and Veilleux, R.E. 2007. Adaptation of potato to high temperatures and Salinity. A review. *American Journal of potato Research*, 84: 487-506.

Lung'aho, C., Lemaga, B., Nyongesa,M, Gildemacher, P., Kinyale, P., Demo, P. and Kabira, J. 2007. Commercial seed potato production in eastern and central Africa. Kenya Agricultural Institute, Kenya. 140p.

Mahmoodabad, R., Jamaati, S., Khayatnezhad, M. and Gholamin, R. 2010. Quantitative and qualitative yield of Potato tuber by use of nitrogen fertilizer and plant density. *American-Eurasian Journal of Agriculture and Environmental Sciences,* 9(3): 310-318.

Makani, J., Ofori-Acquah, Nnodu, O., Wonkam, A. and Ohene- Frempong. 2013. Sickle cell diseases: New Opportunity and challenges in Africa. Muhimbili university of Health and Allied science. Dar es salaam, Tanzania.

Marschner, H. 1995. Mineral nutrition of higher plants 2nd (Eds.). London, New York: Academic Press.

Masarirambi, M.T., Mandisodza, F.C., Mashingaidze, A.B. and Bhebhe, E. 2012. Influence of plant population and seed tuber size on growth and yield components of potato (*Solanum tuberosum L*) .*International Journal of Agriculture and Biology* 14: 545–9.

Mekashaw, M. 2016. Assessment of farmer's production practices and effects of different rates of NPS fertilizer on yield and yield components of potato (*Solanum tuberosum* L) variety under irrigated farming system in Dessie Zuria District, Amhara Region, Ethiopia (MSc Thesis). Bahir Dar University, Ethiopia.

Mekides, M., Melkamu, A., Getachew, S.H. and Amare, H. 2020. Effects of blended NPS fertilizer rates on yield and yield components of potato (*Solanum tuberosum* L.) varieties at Dessie Zuria district, Northeast Ethiopia, *Cogent Food and Agriculture*, 6 (1): 78.

Millard, P. and Marshall, B. 1986. Growth, nitrogen uptake and partitioning within the potato (*Solanum tuberosum* L.) crop, in relation to nitrogen application. *The Journal of Agricultural Science,* 107: 429.

MoANR (Ministry of Agriculture and Natural Resource). 2013. *Ethiopia is transitioning into the implementation of soil test based fertilizer use system*.

MoARD (Ministry of Agriculture and Rural Development). 2009. Crop Variety Register Book, Addis Ababa, Ethiopia.

Morena, D.L., Guillen, I.A. and Garcia, L.F. 1994. Yield development in potato as influenced by cultivars and the timing and level of nitrogen fertilizer. *American Journal of Potato Research,* 71:165-171.

Mulubrhan, H. 2004. The effects of nitrogen, phosphorus and potassium fertilization on the yield and yield components of potato (*Solanum tuberosum* L.), grown on vertisols of Mekelle area Ethiopia. MSc. Thesis, School of Graduate Study Alemaya University, Ethiopia, Pages: 83

Najm, A.A., Hadi, M.R.H.S., Fazeli, F., Taghi Darzi, M. and Shamorady, R. 2010. Effect of utilization of organic and inorganic nitrogen source on the potato shoots dry matter, leaf area index and plant height, during middle stage of growth. *International Journal of Agricultural and Biological Sciences, 1: 26-29.*

Niguse, A. 2016. Effect of Phosphorus and Potassium Fertilizer Rates on Yield and Yield Component of Potato (*Solanum tubersum* L.) at K/Awlaelo, Tigray, Ethiopia. Food Science and Quality Management Vol.48.

Olsen, S.R., C.V. Cole, Watanabe, F.S. and Dean, L.A. 1954 .Estimation of available phosphorus in soils by extraction with sodium bicarbonate.US. Dep. Agric., Circ.939, USA.

Patel, C.K., Patel, P.T. and Chaudhari, S.M. 2008. Effect of physiological age and seed size on seed production of potato in North Gujarat. *India Journal of Potato,* 35:85-87.

Paul, CS. 2007. Above-Ground and Below-Ground Plant Development. In: Potato Biology and Biotechnology: Advances and Perspectives, (eds). Vreugdenhil D, Bradshaw J, Gebhardt C, Govers F, Mackerron DKL, Taylor MA and Ross HA. Elsevier ltd, Amsterdam, Netherlands pp. 219-236.

Putz, B.1986. Kartoffeln. Pflanzenproduktion. Band 2: Produktionstechnik. Red J Oehmichen, Berlin und Hamburg. In German. pp. 431-462.

Samuel, S. 2017. Effect of Combined Application of Biochar and Inorganic Nutrients (N and P) on Yield and Yield Components of Potato (*Solanum tuberosum* L.) at Gecha, Andiracha District, South western Ethiopia. MSc thesis Submitted to School of Graduate studies, Jimma University, Jimma, Ethiopia.

Saran, V. P. and Chhabra, P. 2014. Studies on the parameters of potato processing. Int. *Interdisciplinary Research Journal*, 4: 320-33.

Sharma, A.K., Venkatasalam, E.P. and Singh, R.K. 2011. Micro-tuber production behaviour of some commercially important potato (*Solanum tuberosum*) cultivars. *Indian Journal of Agricultural Sciences*, 81(11): 1008-1013.

Sharma, C. U. and Arora, B. R. 1987. Effect of nitrogen, phosphorus and potassium application on yield of potato tubers (*Solanum tuberosum* L.).*The Journal of Agricultural Science*, 108 (2): 321-329.

Sharma, D. 2015. "Effect of Sulphur on Growth, Yield and Economic of Potato Cultivar." *Annals of Plant and Soil Research*, 17: 45-49.

Sharma, D.K., Kushwah, S.S., Nema, P.K. and Rathore, S.S. 2011. Effect of Sulphur on yield and quality of potato (*Solanium tubersoum* L.). *International Journal of Agricultural Research*, 6: (2) 143-148.

Shiferaw, D.G., Nigussie, D.R., Kebede, W., Getachew, T. and Sharma, J.J. 2015. Effect of nitrogen, phosphorus, and sulphur fertilizers on growth, yield, and economic returns of garlic (*Allium sativum* L.). *Science, Technology and Arts Research Journal*, 4(2): 10–22.

Silva, G.O., Pereira, A.S. and Carvalho, A.D.F. 2014. Seleção de clones de batata para fritura com base em índices de seleção. *Revista Ceres*, 61:941-947.

Singh, H., Madhu, S., Aakash, G. and Monika, B. 2016. Effect of Nitrogen and Sulphur on Growth and Yield Attributes of Potato (*Solanum tuberosum* L.). *International Journal of Plant and Soil Science,* 9(5):1-8.

Sisay, G. and Adugnaw, M. 2020. Effect of Combined Application of NPS Fertilizer and Compost on Phenology and Growth of Quality Protein Maize (Zea Mays L.) at Jimma, South Western Ethiopia. *International Journal of Research Studies in Science, Engineering and Technology, 7(1): 18-28.*

Solomon, F., Derajew, A. and Alemenew, T. 2019. Effect of blended chemical fertilizer (nitrogen, phosphorus and sulfur) on yield and yield components of potato (*Solanum tuberosum* L.) in the rainy season. *Journal of Horticulture and Forestry*, 11*:* 54-61.

Strimumar, T. S. and Ockerman, P. A. 1990. The effects of fertilization and manuring on the content of some nutrients in potato (var. Provita). *Food Chemistry*, 37: 47-60.

Struik, P. C. 2007. Above-ground and below-ground plant development. Pages 219-236 in D.Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D. K. L. Mackerron, M. A.

Sud, K.C. and Sharma, R.C. 2002. Sulphur needs of potato under rain fed conditions in Shimla hills, In: Paul SM, Khurana G, Shekhawat S, Pandey SK, Singh BS (eds.). Potato global research and development, *Indian Potato Association*, Shimla, India pp. 889-899.

Tantowijoyo, W. and Van de Fliert Fliert, E. 2006. All about potatoes: A handbook to the ecology and integrated potato crop management.

Tariku, B. Tolera, A. and Ermiyas, H. 2018. Effect of Integrated Nutrient Management on Growth and Yield of Food Barley (*Hordeum vulgare*) variety in Toke Kutaye District, West Showa Zone, Ethiopia. *Advance Crop science Technology*, 6:3-6.

Tekalign, M., Tekalign, T. and Aduayi, E. A. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant Science Division Working Document 13, ILCA, Addis Ababa, Ethiopia.

Tekalign, T. and Hammes, P. S. 2005. Growth and productivity of potato as influenced by cultivar and reproductive growth I, stomatal conductance, rate of transpiration, net photosynthesis and dry matter production and allocation. *Scientia Horticulture Journal*, 105(1): 13–27.

Tesfaye, A., Shermari, W. and Thunya, T. 2013. Evaluation of Specific Gravity of Potato Varieties in Ethiopia as Criterion for Determining Processing Quality. *Agriculture and Natural Resources*, 47(1), pp.30-41.

Tewodros, A. 2014. Analysis of seed potato (*Solanum tuberosum* L.) systems with special focus in Ethiopia: Review. *Asian Journal of Agricultural Research*, 8(3): 122–135.

Tisdale, S., Nelson, W., Beato, J. and Halvin, J. 2003. *Soil Fertility and Fertilizers. 5th ed. New York*: Macmillan Publishing Co. Inc., 109-229.

Vaezzadeh, M. and Naderidar, B.M. 2012. The result of various nitrogen fertilizers amounts on yield and nitrate accumulation in tubers of two potato cultivars in cold regions of Isfahan (Iran). *International Journal of Agriculture and Crop Sciences*. 4 (22): 1688-1691.

White, P. J., Wheatley, R. E., Hammond, J. P. and Zhang, K. 2007. Minerals, soils and roots in: *Potato biology and biotechnology*: Advances and perspectives. Elsevier B.V.

Yayeh, S. G., Alemayehu, M., Hailesilassie, A. and Yigzaw, D. 2017. Economic and agronomic optimum rates of NPS fertilizer for irrigated garlic (*Alliums sativum* L) production in the highlands of Ethiopia. *Cogent Food and Agriculture*, *3*(1):133.

Zamil, M., Rahman, M., Rabbani, M. G. and Khatun, T. 2010. “Combined effect of nitrogen and plant spacing on the growth and yield of potato with economic performance,” Bangladesh *Journal of Agricultural Research*, 3: 1062–1070.

Zebenay, D. 2015. Influence of Seed Tuber Size and Plant Spacing on Potato (*Solanum tuberosum* L.) Production in Wolmera District, Central Ethiopia. Msc. Thesis, Haramaya University, Haramaya, Ethiopia.69p.

Zelalem, A., Tekalign, T. and Nigussie, D. 2009. Response of potato (*Solanum tuberosum* L.) to different rates of nitrogen and phosphorus fertilization on vertisols at Debre Berhan, in the central highlands of Ethiopia. *African Journal of Plant Science,* 3(2): 20.

Zelleke, G., Agegnehu, G., Abera, D. and Rashid, S. 2010. *Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system*. International Food Policy Research Institute.

Tables And Appendix

Tables 1-2 and appendix not available with this version.