Effects of blended NPS fertilizer rates on yield and yield components of potato (*Solanum tuberosum* L.) varieties at Dessie Zuria district, Northeast Ethiopia

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Abstract: In Ethiopia, the average yield of potato is far below the potential due to different problems like in low soil fertility. Hence, this research was done to evaluate the effects of blended NPS fertilizer rates on yield and yield components of potato. The study was conducted at Abaso Kotu, Dessie Zuria district, Ethiopia, during dry season of 2015. The experiment was consisted a factorial combination of two late maturing potato varieties (Belete and Local) and six NPS fertilizer rates (0:0 (T1), 111:89.7:16.52 (T3), 55:89.7:16.52 (T4), 111:44.85:8.26 (T5) and 55:44.85, 8.26 (T6)) kg ha⁻¹ and Randomized Complete Block Design with three replications was used. The highest potato plant height was recorded on 111:89.7:16.52 (T3) kg ha⁻¹ of NPS fertilizer rate. Belete variety supplied with 111:89.7:16.52 (T3) kg ha⁻¹ of NPS fertilizer rate recorded the maximum days (124.3) to maturity of potato. Similarly, Belete variety recorded the higher biomass than local...
variety. The 111:89.7:16.52 (T3) kg ha\(^{-1}\) and 55.5:89.7:16.52 (T4) kg ha\(^{-1}\) NPS fertilizer rates showed the highest above ground biomass and underground biomass of potato, respectively. The highest average tuber number per hill, tuber weight per hill, marketable, unmarketable and total tuber yield were recorded on potato which was applied with 55.5: 89.7:16.52 (T3) kg ha\(^{-1}\) of NPS fertilizer rate. It is concluded that 55.5:89.7:16.52 (T4) kg ha\(^{-1}\) NPS fertilizer rate application is recommended for the production of potato varieties at Abaso Kotu, Dessie Zuria District Ethiopia.

Subjects: Horticulture; Agriculture and Food; Agronomy

Keywords: days to maturity; tuber number; tuber weight; marketable yield; tuber yield; harvest index

1. Introduction

Potato (Solanum tuberosum L.) is the world’s most important root and tuber crop worldwide. It is grown in more than 125 countries and consumed almost daily by more than a billion people. Hundreds of millions of people in developing countries depend on potatoes for their survival (Food and Agriculture Organization of the United Nations [FAO], 2009). Its ability to produce high volume food per unit area and time (Israel et al., 2012) and its ease of cultivation and nutritive content have made it a valuable food security and cash crop for millions of farmers (FAO, 2009). The annual production of the world and Africa in the year of 2018 was about 368.2 and 26 million tons, respectively (FAOSTAT, 2020).

In Ethiopia, potato is one among the most economically important crops as a source of food and cash in the country (Adane et al., 2010). Annual potato production in Ethiopia has increased from 349,000 tons in 1993 to around 743, 153 tons in 2018 (FAOSTAT, 2020) and can potentially be grown on about 70% of arable land in the country (Central Statistical Agency of Ethiopia [CSA], 2008/2009; Gebremedhin et al., 2008). However, the average yields of potato in African are 6 to 12 tons per hectare (compared to 35–45 tons ha\(^{-1}\) in Europe and North America) (International Potato Centre [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). Inappropriate agronomic practices, shortage of seed tubers of improved potato varieties, soil nutrient depletion, moisture stresses, diseases and insect pests are the major constraints of potato production in Ethiopia (CIP, 2017; Kefelegn et al., 2012; Tekalign & Hammes, 2005).

The status of horticultural crops development including potato especially in the Northeast Ethiopia is negligible and mostly produced traditionally. However, with establishment and expansion of small scale irrigation schemes, the production of horticultural crops including potato is progressing, and yet the system of the production is constrained by various factors (Alemu, 2014). Depletion of soil nutrient resulted from continuous cropping and/or low inherent soil fertility status; limited application of organic and inorganic nutrient source fertilizers, leaching/erosion are some of the most important constraints limiting potato production in Eastern Africa including Ethiopia (Linus & Irungu, 2004). Ethiopian soils are very diverse in terms of inherent and dynamic soil quality. Low soil fertility is one of the limiting factors to sustain potato production and productivity in Ethiopia (Zelleke et al., 2010). Fertilizer recommendations made based on preliminary studies vary across diverse agro ecologies in the country. The fertilizer amount varies with soil type, fertility status, moisture amount, climatic variables, variety, crop rotation and crop management practices (Berihun & Woldegiorgis, 2012). In this regard, different reports have been made in determining the optimum N and P\(_2\)O\(_5\) fertilizer requirement of potato across the country (Ayichew et al., 2009; Ethiopian Institute of Agricultural Research [EIAR], 2000).

However, Ethiopian farmers rely on only two fertilizer types to supplement the nutrient requirement of the crops. Without considering the fertility status of the soil, the environment and the type
of varieties used, the Ethiopian agricultural Institution (EIAR) generally recommends farmers to use the blanket rate of 195 kg ha\(^{-1}\) of di-ammonium phosphate (DAP) and 165 kg ha\(^{-1}\) of urea, which sums up to account for 111 kg N ha\(^{-1}\) and 90 kg P\(_2\)O\(_5\) ha\(^{-1}\) to satisfy the phosphorous and nitrogen requirements of potato, respectively (Tewodros, 2014). But the Ethiopian soils lack most of the macronutrients (mainly Nitrogen, Phosphorus and Sulfur) and micronutrients (Cu, B and Zn) because of long years frequent cultivations of staple crops (Ethio SIS, 2014; Shiferaw, 2014) but that are required to sustain optimal growth and development of crops (Shiferaw, 2014). Thus, the majority of potato growers depend on P in the form of Di-ammonium phosphate (DAP) and N in the form of urea (Ethio SIS, 2014). Consequently, the yield and productivity of crops including potato in Ethiopia are much lower than in other countries.

To alleviate the problem, the Ministry of Agriculture of Ethiopia has introduced a new brand of NPS blended fertilizer which contains N, P and S with the proportion of 19% N, 38% P\(_2\)O\(_5\) and 7% S substituting DAP as source of P and S. This fertilizer has been currently distributed in Ethiopian crop production system (Ministry of Agriculture and Natural Resource [MoANR], 2013). However, the situation is challenging for the researchers and smallholder farmers to understand the effects and the optimum rates of the newly introduced blended NPS fertilizer that contains sulfur for production of crops including potato. Therefore, the objective of this study was to evaluate the effects of newly introduced blended NPS fertilizer rates on growth, yield and yield components of potato at Abaso Kotu, Dessie Zuria district, Northeast Ethiopia.

2. Materials and methods

2.1. Description of the study area
The experiment was conducted on farmers’ training center of Abaso Kotu peasant association, Dessie Zuria district, northeast Ethiopia during 2014/2015 dry season. The topography of the experimental site is located at 39°30'22.7" E, and 11°05'30.8" N with the average altitude of about 2270 meter above sea level. The site received an annual mean minimum and maximum temperatures are about 10°C and 25°C, respectively. The mean annual rainfall of the site ranges from 900 to 1100 mm with bimodal distribution and the soil of the site is belongs in well-drained cambisol group of soil with sandy loam textural class.

2.2. Soil sampling and analysis
Soil sample was taken randomly from five spots of the experimental area diagonally at the depth of 30 cm before planting and mixed to make one composite sample. The collected soil samples were taken to Dessie soil laboratory for analysis of physical and chemical properties. The collected soil samples were air-dried in plastic tray, grounded and sieved to pass through 2 mm sieve to exclude components other than soil. The pH of the soil was determined by diluting the soil with water in 1:2.5 ratios. After equilibrating the solution for 2–3 h, the suspension was filtered and the pH was measured by a glass electrode of pH meter. The salinity of the sample soils was measured as electrical conductivity (EC) and expressed in decisiemens (ds m\(^{-1}\)) (Rhoades et al., 2002). The organic carbon content of sampled soil was determined by oxidizing the organic carbon under standard conditions with potassium dichromate in sulfuric acid solution (Walkley & Black, 1934). The total nitrogen content of soil samples was determined using the Kjeldahl procedure (Horneck et al., 2011). Available phosphorous and Exchangeable bases (K and Na) were determined by Olsen et al. (1954) and Rowell (1994) methods, respectively. Particle size (soil texture) was determined by using hydrometer method of Bouyoucos (Day, 1965). Finally, the organic matter content of the soil sample was calculated by multiplying the organic carbon percentage by 1.724.

2.3. Experimental materials, treatments and design
The experiment consisted of a factorial combination of two potato varieties and six NPS fertilizer rates (Table 1). The two late maturing potato varieties used were improved variety (i.e. Belete) and farmer’s local variety. The blended NPS fertilizer is new for Ethiopian agriculture; it lacks baseline information about the levels of NPS fertilizer to be used in this study. Hence, these NPS rates were
taken on the basis of the N and P₂O₅ fertilizer application rate of blanket recommended 195 kg ha⁻¹ Diammonium Phosphate (DAP) and 165 kg ha⁻¹ urea for major potato producing areas of Ethiopia (EIAR, 2007). To determine the NPS fertilizer rates, 50% of the nutrients found in the blanket recommendations were added and subtracted and converted in terms of NPS fertilizer. NPS fertilizer was used mainly as the source of phosphorus and sulfur, while urea was used to compensate the N which was not covered by NPS fertilizer in the treatment.

The experimental plots were laid out as a randomized complete block design (RCBD) in factorial arrangements with three replications. Each experimental plot was 3 m wide and 3 m long (3x3) with 1 m and 1.5 m spacing between plots and blocks, respectively. Each plot accommodated four rows with 10 plants per row with the spacing of 0.75 and 0.3 between rows and plants, respectively, as recommended by EIAR (2007) and medium sized, healthy and well-sprouted potato tubers were planted.

2.4. Management of the experimental plots
The experimental area was prepared using draft animals and human labor. Based on the treatments, the total quantity of NPS fertilizer was applied at the time of planting. The quantity of nitrogen in NPS fertilizer was subtracted and remaining nitrogen was calculated from the blanket recommendation (165 kg ha⁻¹ urea) and applied in the form of urea at 45th days after planting for each treatment. Other cultural practices like weeding, irrigation intervals, cultivation and plant protection methods were done uniformly for all experimental plots as recommended by EIAR (2007).

2.5. Method of data collection, measurement and analysis
Both the growth and yield parameters were collected from plants in the net plot area (6.075 m²). The collected parameters were plant height (cm), number of stems per hill, days to 50% flowering, days to maturity, dry above ground biomass (g hill⁻¹), dry below ground biomass (g hill⁻¹), total dry biomass (g hill⁻³), tuber numbers per hill, average tuber weight (kg hill⁻¹), marketable tuber yield (t ha⁻¹), unmarketable tuber yield (t ha⁻¹) and tuber yield (t ha⁻¹).

Plant height (cm):- was taken from randomly selected 10 plants height from net plot area and measured from the soil surface to the top-most growth point of plants at physiological maturity time and the mean value was used for analysis.

Number of stem hill⁻¹:- data on this parameter were recorded as the average stem number counted on 10 hills from net plot area and counted at 50% flowering. Only stems that had directly grown from the mother tuber and acted as an independent plant above the soil were considered as stems. Stems branching from other stems above the soil were not considered as main stems (Lung’aho et al., 2007).

Days to flowering:- was recorded when 50% of the plant populations in each plot bloomed.

| Treatment name | Fertilizer rate (N:P₂O₅:S kg ha⁻¹) |
|---------------|-----------------------------------|
| T₁            | 0:0                               |
| T₂            | 111: 89.7: 0                      |
| T₃            | 111: 89.7:16.52                   |
| T₄            | 55.5: 89.7:16.52                  |
| T₅            | 111: 44.85:8.26                   |
| T₆            | 55.5: 44.85:8.26                  |
Days to maturity: - were recorded when the haulms (vines) of 70% of the plant population per plot turned yellowish or showed senescence.

Dry above ground biomass (g hill$^{-1}$): - was recorded by taking the average above ground biomass of 10 randomly selected plants from net plot area at the time of harvesting. Samples were air dried for 72 hours and then oven dried at 70°C for 48 hours.

Dry below ground biomass (g hill$^{-1}$): - was recorded by taking the average below ground biomass of 10 randomly selected plants from net plot area at the time of harvesting. Samples were air dried for 72 hours and then oven dried at 70°C for 48 hours.

Total dry biomass (g hill$^{-1}$): - was calculated as the sum of the dry weights of above ground biomass (g hill$^{-1}$) and below ground biomass (g hill$^{-1}$) from the net plot area at the time of harvesting.

Tuber number per hill: - was recorded as the actual number of tubers collected from randomly selected 10 plants in net plot area at the time of harvesting and calculated as an average tuber number.

Tuber weight (kg hill$^{-1}$): - was recorded from randomly selected 10 plants of net plot area and determined by dividing the total fresh tuber yield to their respective total hill number.

Harvest index percentage: - was determined as the ratio of dry weight of the tubers to the dry weight of the total plant biomass by measured from 10 randomly taken plants in the net plot area at the time of harvesting and multiplied by 100.

Marketable tuber yield (t ha$^{-1}$): - was done by weighing all the tubers which were free from defects, disease, crack, and other physiological disorders and not underweight per net plot area and converting into ton per hectare (Tesfaye et al., 2013).

Unmarketable tuber yield (t ha$^{-1}$): - was done by weighing all the tubers other than marketable from each net plot area and converting into ton per hectare (Tesfaye et al., 2013).

Total tuber yield (t ha$^{-1}$): - was calculated as the sum of the weights of marketable and unmarketable tubers from the net plot area and transformed into ton per hectare.

The collected data were subjected to the analysis of variance (ANOVA) by using SAS (Statistical Analysis System) version 9.2. The least significant difference (LSD) test at 5% probability was used for mean separation of the treatments.

3. Results

3.1. Soil properties before planting

The plant available nutrients content on the soil is a prerequisite for crop growth, yields and quality. The physical and chemical properties of the soil of the experimental field are indicated in Table 2. The soil textural class of the experimental site is sandy loam. According to the rating of Hazleton and Murphy (2007), the soil of experimental field is slightly acidic in pH (6.8), slightly saline in electrical conductivity (4.45 ds m$^{-1}$), very low in organic sulfur (0.0114%), high organic carbon (1.326%), very high organic matter (2.286%), low in total N (0.1143%), extremely low in available phosphorus (11.18 ppm) and high in exchangeable K (1.242 meq 100 g$^{-1}$) ions in arable soils of Ethiopia (Table 2). When the exchangeable K content was higher than 0.50 Cmol (+) kg$^{-1}$ plants’ response to potassium fertilizer application is unlikely (Landon, 1991). Therefore, application of potassium as a treatment to the soils of experimental sites was not required. From the results of soil analysis, it can be depicted all sulfur, nitrogen and phosphorus may be yield limiting factor for potato production in the area.
3.2. Phenological and Growth components of potato

3.2.1. Plant height and stem number per hill
Plant heights of potato were highly significantly affected by NPS application rates but not affected by varieties and their interaction at (p ≤ 0.05). On the other hand, both the interaction and the main effect of variety and NPS fertilizer rates showed non-significant difference in stem number per hill (p ≤ 0.05) (Table 3). Accordingly, the longest plant height of potato (87.60 cm) was recorded on potato supplied with 111: 89.7:16.52 (T3) kg ha\(^{-1}\) of NPS fertilizer rate. While the shortest plant height (62.27 cm) was recorded on control but not significant difference with potato plants treated with 111:44.85:8.26 (T5) and 111:89.7:0 (T2) rates. Application of 111: 89.7:16.52 (T3) kg ha\(^{-1}\) of NPS fertilizer rate increased the plant height by 40.7% compared to the corresponding control potato plants.

3.2.2. Days to flowering and maturity
Days to flowering of potato were highly significantly affected by varieties but not affected by NPS fertilizer rates and their interaction at (p ≤ 0.05) (Table 3). On the other hand, days to maturity highly significantly affected by both the main and interaction effect of variety and NPS fertilizer rates at (p ≤ 0.05) (Table 4). The longer (59.17) days to 50% flowering of potato were recorded on Belete variety and prolong flowering time by 4 days compared to local variety.

The longest days (124.3) to physiological maturity of potato were recorded on Belete variety supplied with 111: 89.7:16.52 (T3) kg ha\(^{-1}\) of NPS fertilizer rate. The shortest days to physiological maturity (111) were recorded on Belete variety in the absence of NPS fertilizer application but not significant difference with Belete variety supplied with 111:89.7:0 (T2) kg ha\(^{-1}\) fertilizer rate and local variety supplied with 55.5: 44.85:8.26 (T6) kg ha\(^{-1}\), 111:44.85:8.26 (T5) kg ha\(^{-1}\) fertilizer rates and control (Table 4). Application of 111: 89.7:16.52 (T3) kg ha\(^{-1}\) of NPS fertilizer on Belete and Local variety prolonged maturity by 13.33 and 6 days, respectively, compared to the respective control plants without NPS fertilizer application. Generally, increasing NPS fertilizer rates prolonged days of potato maturity compared to the corresponding NPS fertilizer rates applied.

| Soil texture | Content | Textural class |
|--------------|---------|----------------|
| Sand (%)     | 72      | Sandy loam     |
| Silt (%)     | 16      | Sandy loam     |
| Clay (%)     | 12      | Sandy loam     |

| Chemical properties | Rating   |
|---------------------|----------|
| pH                  | 6.8      | Slightly acidic|
| Electrical Conductivity (ds/m) | 4.45 | Slightly saline |
| Organic Sulfur (%)  | 0.0114   | Very Low       |
| Organic carbon (%)  | 1.326    | High           |
| Organic Matter (%)  | 2.286    | Very High      |
| Total Nitrogen (%)  | 0.1143   | Low            |
| Available Phosphorus (ppm) | 11.18 | Extremely low |
| Exchangeable Cations (meq/100 g) | |
| Na\(^+\)           | 0.391    | |
| K\(^+\)            | 1.242    | High           |
3.3. Yield and yield components of potato

3.3.1. Above ground, below ground and total biomass

The dry biomass contents of all above ground, below ground and total biomass were highly significantly affected by the main effects of NPS rate and potato variety but their interaction effect did not show difference. The higher above ground dry biomass (91.8 g hill\(^{-1}\)) underground dry biomass (261.2 g hill\(^{-1}\)) and total dry biomass (352.9 g hill\(^{-1}\)) were recorded on Belete variety (Figure 1). In the case of NPS fertilizer rates, the highest above ground dry biomass (103.24 g hill\(^{-1}\)) was recorded on potato plants which were supplied with 111:89.7:16.52 (T\(_3\)) kg ha\(^{-1}\) of NPS fertilizer (Figure 2). Application of 111:89.7:16.52 (T\(_3\)) kg ha\(^{-1}\) of NPS fertilizer on potato varieties increased above ground dry biomass by 126.4% as compared to the control potato plant.

On the other hand, the highest underground biomass of potato (290.9 g hill\(^{-1}\)) was recorded on potato supplied with 55.5:89.7:16.52 (T\(_4\)) kg ha\(^{-1}\) NPS fertilizer rate, but not

![Table 3. The effect of variety and NPS fertilizer rates on plant height (cm), stem number per hill and flowering days of potato at Abaso Kotu, Dessie Zuria district, Northeast Ethiopia](image)

| Variety  | Plant height (cm) | Number of stem hill\(^{-1}\) | Days to flowering |
|----------|-------------------|-----------------------------|------------------|
| Local    | 71.47             | 6.78                        | 55.17            |
| Belete   | 75.52             | 6.22                        | 59.17            |

| NPS fertilizer rate (N:P\(_2\)O\(_5\):S) | 0:0 | 111: 89.7: 0 | 111: 89.7:16.52 | 55.5: 89.7:16.52 | 111: 44.85:8.26 | 55.5: 44.85:8.26 |
|----------------------------------------|-----|--------------|-----------------|-----------------|----------------|-----------------|
|                                        | 62.27\(^{c}\) | 69.40\(^{a}\)  | 87.60\(^{a}\)  | 76.73\(^{a}\)   | 70.10\(^{bc}\) | 74.87\(^{a}\)   |
|                                        | 5.17 | 5.67         | 7.17            | 7.17            | 7.00           | 6.83            |
|                                        | 56.50| 58.33        | 55.17           | 56.17           | 58.83          | 58.00           |

| LSD (5%) | 12.78 | ns | ns | 1.74 |
|          | 10.27 | 23.92 | 4.4 |

Means in columns with the same letter are not significantly different from each other at P ≤ 0.05.

![Table 4. Interaction effect of variety and NPS fertilizer rates on days to maturity of potato at Abaso Kotu, Dessie Zuria district, Northeast Ethiopia](image)

| Fertilizer rate (N:P\(_2\)O\(_5\):S) | Variety  | Local | Belete | Days to maturity |
|------------------------------------|----------|-------|--------|-----------------|
| 0:0:0                              | 113.33\(^{de}\) | 111.00\(^{e}\) |
| 111: 89.7: 0                      | 114.67\(^{d}\) | 114.00\(^{de}\) |
| 111: 89.7:16.52                   | 119.33\(^{bc}\) | 124.33\(^{a}\) |
| 55.5: 89.7:16.52                  | 116.33\(^{cd}\) | 120.00\(^{a}\) |
| 111: 44.85:8.26                   | 114.00\(^{de}\) | 120.00\(^{a}\) |
| 55.5: 44.85:8.26                  | 114.33\(^{de}\) | 118.67\(^{bc}\) |

| LSD (5%) | 3.428 | 1.74 |

Means with the same letter are not significantly different from each other at P ≤ 0.05.
significant difference with potato supplied with 111:89.7:0 (T₂), 111:89.7:16.52 (T₃) and 55.5:44.85:8.26 (T₆) kg ha⁻¹ of NPS fertilizer rates (Figure 2). However, application of 55.5:89.7:16.52 (T₄) kg ha⁻¹ of NPS fertilizer on potato varieties increased below ground dry biomass by 70% as compared to the control potato plant. Similarly, the highest total biomass (378.8 g hill⁻¹) was recorded on potato plants which were supplied with 55.5:89.7:16.52 (T₄) kg ha⁻¹ of NPS but not significant difference with potato supplied with 111:89.7:16.52 (T₃) kg ha⁻¹ of NPS fertilizer rate (Figure 2). Application of 55.5:89.7:16.52 (T₄) kg ha⁻¹ of NPS fertilizer on potato varieties increased total dry biomass by 74.8% as compared to the control potato plant.
3.3.2. Average tuber number per hill
The analysis of variance revealed that there was no significant difference between varieties in their average tuber number per hill (Figure 1). However, the NPS fertilizer rates affected the tuber number significantly. The highest average tuber number per hill (15.67) was recorded on potato which was applied with 55.5: 89.7:16.52 (T₄ kg ha⁻¹ of NPS but not significantly different with all NPS fertilizer rates applied to potato plants while the unfertilized with NPS fertilizer potato plants recorded the lowest tuber number per hill (Figure 2).

3.3.3. Average tuber fresh weight per hill
The analysis of variance revealed that both variety and NPS fertilizer rates significantly affected the tuber fresh weight per hill of potato (Table 5). The higher average tuber fresh weight per hill (1.61 kg) was recorded on Belete variety which was higher by 15% as compared to Local variety. Moreover, Belete variety produced much bigger tubers than the local varieties. On the other hand, potato which was supplied with 55.5: 89.7:16.52 (T₄) kg ha⁻¹ NPS fertilizer rate scored the highest (1.82 kg hill⁻¹) average tuber fresh weight per hill but not significant difference with 111:44.85:8.26 (T₃) and 55.5:44.85:8.26 (T₄) kg ha⁻¹ of NPS fertilizer rates. The lowest average fresh tuber weight per hill (1.12 kg hill⁻¹) was recorded on unfertilized potato, but it was not significant difference with potato supplied with 111:89.7:0 (T₂) kg ha⁻¹ NPS rate which is the blanket recommendation of NP (Table 5).

3.3.4. Tuber yield of potato
The variety and NPS fertilizer rates showed highly significance difference (p ≤ 0.05) on marketable, unmarketable and total tuber yield of potato. All the higher marketable (48.11 t ha⁻¹), unmarketable (0.50 t ha⁻¹) and total (48.60 t ha⁻¹) tuber yield of potato were obtained from Belete variety. This variety was higher in marketable, unmarketable and total tuber yield by 16%, 19% and 16%, respectively as compared to the local variety.

Similarly, the highest marketable (53.61 t ha⁻¹), unmarketable (0.54 t ha⁻¹) and total (54.15 t ha⁻¹) tuber yield were obtained from potato which were supplied with 55.5: 89.7:16.52 (T₄) kg ha⁻¹ of NPS fertilizer rate but not significant difference with potato supplied with 111: 89.7:0 (T₂), 111: 89.7:16.52 (T₃) and 55.5:44.85:8.26 (T₄) kg ha⁻¹ of NPS fertilizer rates. While the lowest marketable (31.50 t ha⁻¹), unmarketable (0.36 t ha⁻¹) and total (31.85 t ha⁻¹) tuber yields of potato were obtained from potato which were not supplied by NPS fertilizer (Table 5). Increasing of NPS fertilizer application rates generally increased marketable, unmarketable and total yields of the tested potato varieties. Application of 55.5:89.7:16.52 (T₄) kg ha⁻¹ NPS fertilizer increased marketable, unmarketable and total yields by 70.2%, 50% and 70% respectively, compared to the respective unfertilized control potato plants.

3.3.5. Harvest index (%)
The analysis of variance of harvest index showed highly significant (p < 0.05) differences due to the effect of variety and NPS fertilizer rates. The harvest index of local variety was higher by 7% as compared to Belete variety. The highest harvest index (78.97%) was recorded from potato plant which was not supplied with NPS fertilizer rate (control) but statistically not significance difference with all NPS fertilizer rates except 111:89.7:16.52 (T₃) kg ha⁻¹ (Table 5). The control potato plant was higher in harvest index by 9% as compared to potato plant that supplied with the maximum NPS fertilizer rate (i.e. 111:89.7:16.52 (T₃)).

4. Discussion

4.1. Plant height and stem number per hill
The potato plant height was significantly affected by NPS fertilizer rates which correlate with the finding of Alemayehu and Jemberie (2018). When all the maximum NPS level of fertilization applied, highest plant height was obtained, but when N decreased by half while PS remained highest rate plant height decreased. The increased potato plant height by application of NPS may be attributed by
Table 5. The effect of variety and NPS fertilizer rates on average tuber weight, marketable yield, unmarketable yield and total tuber yield of potato at Abaso Kotu, Dessie Zuria district, Northeast Ethiopia

| Variety    | Average tuber weight (kg hill\(^{-1}\)) | Marketable yield (t ha\(^{-1}\)) | Unmarketable yield (t ha\(^{-1}\)) | Total tuber (t ha\(^{-1}\)) | Harvest index (%) |
|------------|----------------------------------------|---------------------------------|-----------------------------------|-----------------------------|-------------------|
| Local      | 1.40\(^{b}\)                           | 41.46\(^{b}\)                  | 0.42\(^{b}\)                     | 41.90\(^{b}\)             | 79.55\(^{b}\)    |
| Belete     | 1.61\(^{a}\)                           | 48.11\(^{a}\)                  | 0.50\(^{a}\)                     | 48.60\(^{a}\)             | 74.21\(^{b}\)    |
| LSD (5%)   | 0.16                                   | 5.02                            | 0.05                              | 5.07                        | 2.31              |
| NPS fertilizer rate (N:P\(_2\)O\(_5\):S) |                                   |                                 |                                   |                             |                   |
| 0.0:0      | 1.12\(^{d}\)                           | 31.50\(^{c}\)                  | 0.36\(^{c}\)                     | 31.85\(^{c}\)             | 78.97\(^{b}\)    |
| 111: 89.7:0 | 1.33\(^{cd}\)                          | 45.19\(^{ef}\)                 | 0.46\(^{de}\)                    | 45.65\(^{de}\)            | 77.31\(^{a}\)    |
| 111: 89.7:16.52 | 1.46\(^{c}\)                         | 48.78\(^{de}\)                 | 0.49\(^{de}\)                    | 49.27\(^{de}\)            | 72.40\(^{a}\)    |
| 55.5: 89.7:16.52 | 1.82\(^{a}\)                         | 53.61\(^{a}\)                  | 0.54\(^{a}\)                     | 54.15\(^{a}\)             | 77.23\(^{a}\)    |
| 111: 44.85:8.26 | 1.57\(^{bce}\)                      | 43.36\(^{a}\)                  | 0.44\(^{b}\)                     | 43.80\(^{a}\)             | 77.20\(^{a}\)    |
| 55.5: 44.85:8.26 | 1.71\(^{cd}\)                        | 46.26\(^{a}\)                  | 0.48\(^{cd}\)                    | 46.73\(^{a}\)             | 78.15\(^{a}\)    |
| LSD        | 0.28                                   | 8.69                            | 0.09                              | 8.78                        | 5.67              |
| CV         | 15.7                                   | 16.2                            | 16.4                              | 16.2                        | 4.4               |

Means in columns with the same letter are not significantly different from each other at P ≤ 0.05.
physiological stem elongation effect of N which is also observed by other authors (Lamessa & Zewdu, 2016; Sriom et al., 2017). When PS fertilizer amount decreased by half, the plant height decreased and statistically not significantly different with the control which conform the results in the application of S alone or S containing fertilizers (Choudhary et al., 2013; Sharma et al., 2015) up to certain level. The increase in plant height with the increased application of S and P might be due to its role in the growth and physiological functioning of plants (Sanchez, 2007; Haneklaus et al., 2007). Also, the increase in growth parameters under S application might be due to improved S availability, which in turn enhanced the plant metabolism and photosynthetic activity (Jat et al., 2013) and P enhanced the development of roots for nutrient uptake (Fantaw et al., 2019) resulting into better growth. The longest plant heights observed in the present study can be associated with the complementary effects of nutrients in NPS fertilizer and the relatively high amount of organic matter content presented in the soil as indicated in Table 2. This result correlates with other reports where the increased plant heights have been reported on wheat and garlic by application of NPS fertilizer on different agro-ecologies (Tagesse et al., 2018; Yayeh et al., 2017).

Despite the fact that stem density is one of the most important yield components in potato (Firman & Allen, 2007), the results of the present study showed that the influences of variety and fertilizer rates on stem number were not significant difference. It could also be due to the case that this trait was not influenced much by the mineral nutrition, as the stem number is the reflection of storage condition of tubers, number of viable sprouts at planting, sprout damage at the time of planting and growing conditions (Firman & Allen, 2007), physiological age of the seed tuber (Asiedu et al., 2003) and tuber size (Park et al., 2009).

4.2. Days to flowering and maturity
The effects of NPS fertilizer rates were not significant difference on days to 50% flowering which is not in line with the findings of Alemayehu and Jemberie (2018) who observed an excessive vegetative growth and thus delayed flowering of potato with high level of nitrogen fertilizer. Nitrogen fertilizer increased the leaf area which increases the amount of solar radiation intercepted and consequently, increases days to flowering, days to physiological maturity, plant height and dry matter production of different plant parts (Krishnippa, 1989). In contrast to N effect, P was reported to lead to earlier and shorten the growing period of potato (White et al., 2007). Also, S has role in promoting growth (Sanchez, 2007; El-Shafe & El-Gamaily, 2002) and better partitioning of the photosynthates in the shoot and tubers (Sud & Sharma, 2002). Hence, the reason for non-significance difference on days to flowering between fertilizer rates in this study might be due to counteract the P on the effect of N and S.

The days to physiological maturity were recorded on Belete variety supplied with the maximum NPS fertilizer rate while the shortest days to maturity was recorded on the control of same variety where the differences among the varieties are most probably associated with genetic makeup of the varieties. The maximum NPS fertilizer rate shows long maturity days may be due to luxury consumption of N and S elements (Gómez et al., 2018). The S and N stimulate the enzymatic actions as well as chlorophyll formation that increases the amount of solar radiation intercepted, which promote the growth and development of plants (Sanchez, 2007; El-Shafe & El-Gamaily, 2002) and consequently increase days to flowering and physiological maturity (Krishnippa, 1989). But, P was reported to lead to earlier and shorten the growing period (White et al., 2007). The finding of this study is generally supported by the findings of different researchers where increasing fertilizer rates, including NPS prolonged days to maturity in different agro-ecologies (Tagesse et al., 2018; Alemayehu & Jemberie, 2018; Ayichew et al., 2009).

4.3. Above ground, below ground and total dry biomass
The difference of varieties in all dry biomass yields is associated with the difference in the genetic makeup of the potato varieties. The dry biomass yields were increased as the rates of NPS fertilizer increases. When PS amount decreased by half while the N remained maximum rate, the aboveground dry biomass yield decreased but the underground and the total dry biomass yields were scored the
maximum yield. The result of this study shows that the N highly contributes for the development above ground biomass yield than PS, while PS more contribute for the development of the potato tuber than N. This result conformed to the findings of the White et al. (2007) who reported a significant increment in canopy dry matter yield of potato as N application increased. In general, biomass yield increment in response to N, P and S fertilization indicates that all nutrients could exert a significant influence on biomass production and partitioning to the different parts of potato plant.

The balanced supplement of N and P contributed to increased cell division, expansion of cell wall, meristematic activity, chlorophyll concentration, photosynthetic efficiency and the leaf expansion, the total number of leaves and the dry matter accumulation (Najm et al., 2010). Similarly, the increased S application contributes to increasing the dry matter contents of the tubers might be due to its role in the growth and physiological functioning of plants (Sanchez, 2007). 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.

4.4. Average tuber number per hill
In this finding, the varieties showed non-significant difference on tuber number per hill which confront the findings of other researchers where the varietal difference had significant influence on number of tuber per potato plant (Sharma et al., 2015). The average tuber numbers per hill recorded from potato supplied with NPS fertilizer rates were higher than control. In line with this finding, different investigators regarding the effect of mineral nutrition on the number of tubers set per plant. The application of N, P and S significantly increased the number of tubers set per unit area (Sharma et al., 2015). The N and P are important in tuber initiation and tuber enlargement. The application of P fertilizer results in increased ground cover at tuber initiation and throughout the season. Because yield is dependent on photo assimilate and radiation absorption during the period of tuber initiation is one of the factors influencing the number of tubers found at harvest, and this answered by the application of both P and N. Thus, tuber number increased with increase in N and P application (Powon et al., 2006; Rosen & Bierman, 2008; White et al., 2007). Also, Singh et al. (2016) and Alemayehu and Jemberie (2018) reported that nitrogen with sulfur fertilizer resulted in a significant and maximum number of stem per plant which correlates with the finding of this study.

4.5. Average tuber weight per hill
Different genetic makeup might have resulted in varied potential for sprouting as well as photosynthesis, which resulted in more food material accumulation and ultimately high fresh weight of potato tuber. In agreement with the result of the present study, Sharma et al. (2015), reported that there were significant differences between varieties for average tuber weight of potato. Saluzzo et al. (1999) also suggested that variety with higher average tuber weight in addition to its late maturity might also be more efficient in dry matter partitioning to tubers than variety with lower average tuber weight.

When the N amount decreased by half, while the PS remained maximum rate, the average tuber fresh weight was maximum which implies that PS highly contribute for potato tuberization than N. In control potato plant average tuber fresh weight was lowest, which is statistically non-significance difference with the blanket recommendation of NP. This result indicates that S contributes for average tuber fresh weight of potato. The current result is in conformity with the work of Israel et al. (2012) who reported an increase in phosphorous fertilizer revealed significant contribution to increase in total tuber yield and advanced to get larger average tuber weight and size. Similarly, sulfur fertilizer contributed to a significant increment of potato tuber yield through enlarging tuber weight per plant (Barczak et al., 2013; Sharma et al., 2011, 2015). The higher N rate triggers the vegetative growth for more photo-assimilate production while phosphorous enhanced the development of roots for nutrient uptake (Fantaw et al., 2019). In this study, when the NPS rate was maximum the average tuber weight was lower, this could be due to luxury consumption of N and S elements (Gómez et al., 2018) that could be due to their role in the vegetative growth (Sanchez, 2007) that led to a lower growth of tubers resulting from the low transport of assimilates to organs including tuber (Gómez et al., 2018) resulted with lower tuber weight.
4.6. Tuber yield

The variations in marketable, unmarketable and total tuber yield across varieties could be due to the variations in genetic makeup. Similarly, Alemayehu and Jemberie (2018), Sharma et al. (2015), and Sharma et al. (2011) also reported significant variation in tuber yield of different potato varieties which correlates with this finding.

The higher marketable, unmarketable and total tuber yields were obtained from potato which was supplied with all NPS fertilizer rates as compared with control. When N fertilizer amount decreased by half while PS fertilizer rate remains higher, all unmarketable, marketable and total tuber yields were increased. Also, when the amounts of PS were decreased by half while N remained higher rate, all unmarketable, marketable and total tuber yields were decreased but above the control. This indicates that the application of PS highly contributes for tuber number and size leads to have higher yield as compared with the application of N. Although P had shown a positive effect on tuber yield, the percentage of yield increment due to P was smaller than the yield increment due to N. This could probably be explained, at least in part, by a smaller increase in leaf area index due to P compared with the response to N. Moreover, P was reported to lead to earlier ground cover and shorten the growing period (White et al., 2007). Furthermore, S and N stimulate the enzymatic actions as well as chlorophyll formation, both of which promote the growth and development of plants and improve the yielding performance (El-Shafe & El-Gamaily, 2002).

In line with this finding, increasing NPS application rates in generally increased marketable, unmarketable and total tuber yields of the tested potato varieties (Alemayehu & Jemberie, 2018). Similarly, S levels showed significant influence on grade wise tuber yield (Juszczuk & Ostaszewska, 2011; Sharma et al., 2011, 2015). The increase in tuber yield with increasing S levels may be due to its role in synthesis of sulfur containing amino acids, proteins, energy transformation and activation of enzymes which in turn enhances carbohydrate metabolism and photosynthetic activity of plant with increased chlorophyll synthesis (Juszczuk & Ostaszewska, 2011) and partitioning of the photosynthates in the shoot and tubers (Sud & Sharma, 2002). Application of sulfur containing fertilizers like NPS improves availability of plant nutrients like P, Fe, Mn and Zn, by amending the soil pH (Marschner, 1995) that may in turn increase yields of vegetable crops including potato. Generally, the present study results revealed that application of NPS fertilizer increased tuber yields of potato in agreement with the findings of different researchers who reported positive response of potato for tuber yields with increasing levels of NPS fertilizer rates at different agro-ecologies (Abewa & Agumas, 2012; Alemayehu & Jemberie, 2018; Ayichew et al., 2009; Boke, 2014; Israel et al., 2012; Jemberie, 2017; Yayeh et al., 2017).

4.7. Harvest index

In this study, the potato plant supplied with the maximum NPS fertilizer rate was lower than the control. When the NPS fertilizer rate was increased the harvest index was decreased this may be due to the soil physical properties of the study area that helped to enhancing nutrients use efficiency and increased tuber size and number than above ground part and/or the summation effect of N and S on enhanced plant metabolism and photosynthetic activity resulting into better vegetative growth (Sanchez, 2007; Fantaw et al., 2019; Jat et al., 2013) than the tuber. This result confronts with the results of Shiferaw et al. (2015) where the increase in the rate of N, P and S led to higher harvest indices. The low physiological efficiency of N in the tubers with excesses of N might suggest a luxury consumption of these elements that could be due to a lower growth of tubers resulting from the low transport of assimilates to organs associated with low harvest index (Gómez et al., 2018).

Also, this confronts with the findings of other researchers’ findings that non-significant difference in harvest index of potato due to nitrogen application. The yield increment in response to nitrogen application might be cultivars may possibly able to produce high carbon assimilates and maintain active growth later in the season 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.,
When the N level increased, the dry matter percentage decreased, which in turn reduced tuber dry matter percentage by increasing tuber water content (Ezzat et al., 2011) leads to reduce harvest index. But these findings are correlated with the non-significant different NPS fertilizer rates including control for harvest index in this study.

5. Conclusion
In the present study, most growth, yield and yield components of potato varieties were increased with increased application rates of NPS fertilizer and their responses were significantly different. The findings also showed that the responses of potato varieties to applied NPS fertilizer were different with the rates of application. Accordingly, the highest plant height of potato (87.60 cm) was recorded on fertilizer rate of 111: 89.7:16.52 (T4) kg ha\(^{-1}\)of NPS fertilizer. The maximum days (124.3) to maturity of potato were recorded on Belete variety supplied with 111:89.7:16.52 (T4) kg ha\(^{-1}\) of NPS fertilizer rate. The higher total biomass, marketable, unmarketable and total tuber yield of potato was obtained from Belete variety. In the case of fertilizer rates, the highest total biomass tuber number per hill, tuber weight per hill, marketable, unmarketable and total tuber yield were recorded on potato which was applied with 55:5: 89.7:16.52 (T4) kg ha\(^{-1}\)of NPS fertilizer rate. Based on these results; application of 55:5:89.7:16.52 (T4) kg ha\(^{-1}\) NPS fertilizer rate is recommended for the production of Belete and Local varieties on soil with low content of phosphorous and Sulfur at Abaso Kotu, Dessie Zuria District.

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Data availability
All data are included in the manuscript, but we can provide any inquiry up on request.

Authors’ contribution
Mekides Mekashaw: Initiated the research, wrote the research proposal, conducted the research, did data entry and analysis and wrote the manuscript. Melkamu Alemayehu and Amare Haileslassie: Initiated the research, wrote the research proposal, reviewing and editing of research proposal and Manuscript. Getachew Shumye: did data entry and analysis and writing the manuscript. All are equally contributed.

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The authors consent to manuscript publication.

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