Full Length Research Paper

Effects of chemical fertilizer types and rates on tuber yield and quality of potato (Solanum tuberosum L.) at Assosa, Western Ethiopia

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Received 2 November, 2019; Accepted 3 January, 2020

Potato tuber yield and quality is constrained by a number of biotic and abiotic factors, among which low soil fertility is the prime one. Thus, the objective of the study was to evaluate the effects of chemical fertilizer types and rates on tuber yield and quality of potato at Assosa, Western Ethiopia. The treatments consisted of control, three rates of NP combinations (55 kg N and 45 kg P₂O₅, 110 kg N and 90 kg P₂O₅, 165 kg N and 135 kg P₂O₅ kg ha⁻¹), one NPK combination (110 kg N, 90 kg P₂O₅ and 69 kg K₂O ha⁻¹), formula 2 (100 % NPSB + 91.9 N kg ha⁻¹ and 200% NPSB + 128.8 N kg ha⁻¹) and formula 4 (100 % NPSZnB + 93.1 N kg ha⁻¹ and 200% NPSZnB + 131.2 N kg ha⁻¹). It was observed that higher marketable tuber yield (30.03 t ha⁻¹) and total tuber yield (34.58 t ha⁻¹) were obtained with the application of NPK (110 kg N + 90 kg P₂O₅ + 69 kg K₂O ha⁻¹) implying that K is an important limiting nutrient besides N and P in the study area. Therefore, NPK fertilizer application is recommended for high yield and quality tuber production in Assosa area, western Ethiopia.

Key words: Chemical fertilizer, potato, tuber, yield.

INTRODUCTION

Potato is the fourth most important crop after rice, wheat, and maize, and has historically contributed to food and nutrition security in the world (FAOSTAT, 2015; FAO, 2015). The crop is also rich in several micronutrients and vitamins, especially vitamin C; a single medium sized potato of 150 g provides nearly half of the daily adult requirement (100 mg) (FAO, 2008). Potato is a versatile crop that can be cultivated in diverse environments and is currently grown in 100 different countries. Africa takes 10% of potato production in hectares from the world (FAOSTAT, 2015), while Kenya takes the highest potato production in Eastern Africa. Potato production in Kenya increased from 1,084,412 tons in 2004 to 2,192,885 tons in 2013 (FAOSTAT, 2015). Ethiopia has about 70% of the available agricultural land suitable for potato production (Gebremedhin et al., 2008a). Since the highlands are also home to 88% of Ethiopia’s population (Gebremedhin et al., 2008b) potato could play a key role in ensuring national food security. Potato is one of the tuber crops grown in Benishangul Gumuz region of Ethiopia, whereby the number of farmers growing potato is increasing from time to time in the region. The number of farmers growing potato in Benishangul Gumuz region was approximately

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Potato is one of the important tuber crops that have great contribution to food security and cash income for farm households in Ethiopia. Potatoes bulk higher tuber yield in shorter time. However, it requires higher nutrients since it has shallow root systems and shorter growing season (Nigussie, 2001). In addition to N and P, potato demands higher amounts of potassium fertilizer, since it is involved as an important regulator and quality nutrient that is supposed to regulate several enzymes for plant biochemical reactions in the plant cell. Potassium improves the quality of tuber size and dry matter content of potatoes. Thus, balanced application of mineral fertilizer maximizes potato yield and reduces N and P losses to the environment.

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

However, there is little information on the impact of different types of fertilizers on the growth and productivity of potato and their interaction on the availability of micro nutrients in Ethiopia. According to Bekabil et al. (2011), there is lack of knowledge and information with regard to balanced macro- and micro-nutrient types and rates in fertilizer blends as a major input to enhance crop productivity. According to EthioSIS (2013), Assosa area soils are deficient with N, P, S, Zn and B; and fertilizer application practices in the region have been mainly based on blanket recommendations, since limited studies were carried out. There is little information on the response of the crop to different fertilizer types and chemical fertilizers under the conditions in the Benishangul Gumuz region. Thus, this study was conducted with the objectives to evaluate the effect of chemical fertilizer types and rates on potato tuber yield, yield components and tuber quality and to determine economically optimum and agronomically efficient types and rate (s) for potato production at Assosa area, western Ethiopia.

MATERIALS AND METHODS

Description of the study site

The experiment was conducted at Asossa Agricultural Research Center (AsARC) in 2017 main cropping season under rain fed conditions at Benishangul Gumuz Regional State of Ethiopia. The AsARC is located from 10° 01' 25" to 10° 02' 50" N latitude and from 34° 33' 50" to 34° 34' 35" E longitude. The experimental site is located at an altitude of about 1553 m above sea level. Benishangul Gumuz Regional State is geographically located between 9° 30' to 11° 39' N latitude and 34° 20' to 36° 30' E longitude covering a total land area of 50,000 km². The experimental site is located between 10° 02' 05" N latitude and 34° 34' 09" E longitudes at 4 km east of Assossa town and at 660 km west of Addis Ababa.

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

Experimental procedures

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

Experimental materials

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

Nitrogen Phosphorus Sulphur and Boron (NPSB) (Formula 2) and Nitrogen Phosphorus Sulphur Zinc and Boron (NPSzNB; Formula 4) blended fertilizer rates, NPK and national blanket recommended N and P rates selected for Assosa area were used following the EthioSIS soil fertility map (EthioSIS, 2013). Nitrogen shortage in blended fertilizers was adjusted by Urea. Chemical fertilizer, potassium from KCl source and phosphorus from TSP (Triple Super Phosphate) source were basal applied at planting and nitrogen was applied twice. Half of nitrogen was applied at planting time, while the rest half was applied at 40 days after planting as side dressing.

Treatments and experimental design

The treatments consisted of control, two levels of formula 2: NPSB (100% and 200%) rates, two levels of formula 4:NPSzNB (100% and 200%) rates and three levels of recommended NP (50%, 100% and 150% NP) rates and recommended NPK. Half of recommended NP (55 kg N and 45kg P₂O₅ ha⁻¹), full of recommended NP 100% (110 kg N + 90 kg P₂O₅ ha⁻¹) and 150% recommended NP (165 kg N + 135 kg P₂O₅ ha⁻¹) and full recommended N and K (110 kg N + 90 kg P₂O₅ + 69 kg K₂O ha⁻¹)}
were used as treatments. Additional N was added to most of the chemical fertilizers to meet the N shortages in the chemical (Table 1). The experiment was carried out in a Randomized Complete Block Design (RCBD) with three replications. The nine treatments were assigned to each plot randomly. The total numbers of plots were 27 and each plot had a gross area of 11.25 m² with 3 m length and 3.75 m width. A spacing of 0.75 x 0.30 m was used in each plot having 50 plants where spacing between plots and adjacent blocks were 1 and 2 m, respectively.

### Soil sampling and analysis

Twelve surface soil samples (0-30 cm) were randomly collected following diagonal sampling technique from the entire experimental field before planting. The collected samples were bulked into one composite sample, then air dried and passed through a 2-mm sieve for analysis of selected physico-chemical properties, while organic carbon and total N was determined from soil samples sieved by 0.5-mm sieve. Bulk density was determined using soils sampled by core sampler.

Thus, soil samples were subjected for physico-chemical analysis (soil texture, organic carbon, soil pH, total N, available P, exchangeable K, S, Zn, B and CEC). The soil particle size distribution was determined using the hydrometer technique (Ryan and Rashid, 2001) while the soil textural class was identified from textural triangle (Motsara and Roy, 2008). The cation exchange capacity (CEC) was determined using 1N-neutral ammonium acetate method (Jackson, 1967). Soil pH was determined in a 1:2.5 soil to water ratio using a glass electrode attached to a digital pH meter (Page, 1982).

Organic carbon content of the soil was determined following the wet oxidation method of Walkley and Black (1934). Total nitrogen was determined according to the Kjeldahl method (Dewis and Freitas, 1984). Exchangeable potassium was extracted using 1N neutral ammonium acetate methods at pH 7 (Hesse, 1971) and determined with a flame photometer. Available phosphorus was determined by the Olsen method (Olsen et al., 1954). Sulfur was determined by aqua regia digest–turbidimetric method, while Zn was determined by ash extract–flame atomic absorption.

### Data collection and measurements

Data were collected from the three middle rows, leaving aside plants in the border rows in order to avoid edge effects. Data were recorded on different phonological and growth parameters, including yield and yield components, and tuber quality parameters.
and greater than or equal to 25 g in weight, was recorded as marketable tuber yield.

Unmarketable tuber yield (ton ha⁻¹): the weight of diseased and/or rotting and small-sized (less than 25 g in weight) tubers was recorded.

Total tuber yield (ton ha⁻¹)
The total weight of both marketable and unmarketable tubers.

Tuber quality parameters

Tuber dry matter content (%)
Five fresh tubers were randomly selected from each plot and weighed. The tubers were sliced and dried in an oven at 70°C for 24 hours. The dry matter percent was calculated according to the following formula (Williams and Woodbury, 1968).

\[
\text{Tuber Dry matter Content} = \frac{\text{Weight of sample after drying (g)}}{\text{Initial weight of sample (g)}} \times 100
\]

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

Partial budget analysis
Partial budget analysis was performed following CIMMYT (1988) procedures. For economic evaluation, dominance analysis, cost and marginal rate of return (MRR) were calculated according to the procedures of CIMMYT (1988). The process of calculating the marginal rates of return of alternative treatments, proceeding in steps from the least costly treatment to the most costly, and deciding if they are acceptable to farmers, is called marginal analysis (CIMMYT, 1988). The field price (6 Birr kg⁻¹) for potato tuber yield at the time of harvest and Urea (8.24 Birr kg⁻¹), TSP (12.75 Birr kg⁻¹), potassium chloride (9.08 Birr kg⁻¹), NPSB (11.02 Birr kg⁻¹), and NPSZnB (11.70 Birr kg⁻¹) were used for partial budget analysis.

Statistical analysis
Data were subjected to analysis of variance (ANOVA) according to Proc Mixed SAS version 9.0 (SAS, 2004). The treatments mean value differences were separated by using Least Significant Difference at 5% level of significance.

RESULTS AND DISCUSSION

Selected physicochemical properties of the experimental soil
The physicochemical properties are presented in Table 2. The results revealed that the soil was clay loam in texture with strongly acidic in reaction (pH 5.5). According to Fageria et al. (2011) optimum growth of potato was found within the soil pH range of 5.2 to 6.5. Furthermore, the clay loamy soil texture was suitable for the production of potato and other major crops due to its good ability to retain nutrients and soil moisture (water). The experimental soil had medium CEC, 22.93 Cmol(+)_1 kg⁻¹ soil (Hazelton and Murphy, 2007), but low in total nitrogen, 0.15% (EthioSIS, 2014). The available phosphorus (4.52 mg kg⁻¹) was low as per Olsen et al. (1954). Exchangeable potassium (9.98 mg kg⁻¹), available sulfur (3.01 mg kg⁻¹), and zinc (0.34 ppm) were very low at the experimental site in accordance with EthioSIS (2014). According to Jones (2003), soil boron content was low (0.61 ppm). The organic carbon (1.75%) was medium at the experimental site (Tekalign, 1991). These results signify that the soils require additional supply of plant nutrients to enrich the soil and make them available to the plants.

Potato phenology and growth parameters
The results revealed that the applied chemical fertilizer types and rates significantly (p< 0.01) influenced days to 50% flowering, plant height, leaf area index and underground dry biomass of potato; but not number of main stems and above ground biomass (Table 3). Application of 110 kg N + 90 kg P₂O₅ + 69 kg K₂O ha⁻¹ significantly increased plant height by 16-21 cm, compared to other treatments. It was observed that plants treated with control had the shortest shoot length compared to the rest of the treatments. However, shoot elongation was slightly higher with plants treated with unblended fertilizer (average mean difference of 2.3 cm) than blended fertilizers. Additionally, significant increase in plant height was observed when K₂O was supplied together with N and P₂O₅ as compared to control and other treatments without the involvements of K₂O. This shows that potash contributes to increased cell division, and elongation results in higher canopy development. This is in line with Marschner (1995) who reported that potassium enhanced cellular growth and development. Increasing application of combined N and P at rates ranging from 0 to 55kg N + 45 kg P₂O₅ ha⁻¹, 110 kg N + 90 kg P₂O₅ ha⁻¹ and165 kg N + 135 kg P₂O₅ ha⁻¹ increased plant height by 9, 15, and 20%, respectively over the control. This finding is in line with the results of Singh and Ragav (2000) who reported that a significant interaction between N and K, leading to the better utilization of N in presence of K, contributed to an increased plant height. The results are also in agreement with Firew et al. (2016) who reported that increasing nitrogen and phosphorus rates increased the height of potato plants.

Increasing N and P application ranging from 0 to 165 kg N + 135 kg P₂O₅ kg ha⁻¹ prolonged the days required...
to attain 50% flowering of potato by about 4 days as compared to the control. This is perhaps because of the fact that the applied N enhanced the photosynthetic activity and prolonged the vegetative growth of potato, while optimum P facilitates cell division and promotes root development of potato. This result is in line with the findings of Zelalem et al. (2009) and Israel et al. (2012) that noted excessive vegetative growth and delayed flowering due to high nitrogen levels.

Plants treated with 200% NPSB +128.8 kg ha\(^{-1}\) N produced 89% higher leaf area index as compared to controls. However, leaf area index was slightly higher with plants treated with chemical fertilizers. This might be due to the combination of macro with micro nutrients like Zn and B fertilizer blends to NPS. These results are in line with the findings of Salam (2004) who reported that B increased plant growth, leaf area index, and root length of crops. Above ground dry biomass was not significantly (p>0.05) affected by chemical fertilizer types and rates applied (Table 3). The present result is in contrary to the findings of Israel et al. (2012) who stated that increasing phosphorus and nitrogen fertilizer rates increased above ground dry biomass yield significantly.

The highest above ground dry biomass (2.5 ton ha\(^{-1}\)) was recorded with the application of 200% NPSZnB + 131.2 N, while the least was recorded with the control (0.74 ton ha\(^{-1}\)). The underground dry biomass yields (6.31 t ha\(^{-1}\)) was obtained with application of NPK (110 kg N + 90 kg P\(_2\)O\(_5\) + 69 kg K\(_2\)O ha\(^{-1}\)) whereas minimum marketable tuber yield (10.23 t ha\(^{-1}\)) was recorded from the control. This present finding is in agreement with that of Zelalem et al. (2009), Israel et al. (2012) and Mulubrhan, (2004) who reported that interaction of nitrogen and phosphorous significantly influenced tuber dry weight of potatoes.

**Potato tuber yield response to chemical fertilizers**

Analysis of variance showed that marketable and total tuber yields were significantly (P < 0.05) influenced by chemical fertilizers types and rates, while unmarketable tuber yield was not affected significantly (P > 0.05) (Table 4). Maximum marketable tuber yield (30.03 t ha\(^{-1}\)) was obtained from application of NPK (110kg N + 90 kg P\(_2\)O\(_5\) + 69 kg K\(_2\)O ha\(^{-1}\)) whereas minimum marketable tuber yield (10.23 t ha\(^{-1}\)) was recorded from the control. Increasing N and P fertilizers rates from 0 to 150% NP (165 kg N+ 135 kg P\(_2\)O\(_5\) ha\(^{-1}\)) increased marketable tuber yield by 114% as compared to control. Thus, the application of K with NP resulted in higher marketable tuber yields when compared to NP and chemical fertilizers rates. This is due to potassium increases tuber yield, size of tuber, resistance against drought and diseases.

Increasing chemical fertilizers rates of NPSB and

### Table 2. Growth parameters of potato as influenced by chemical fertilizer types and rates at Assosa, western Ethiopia.

<table>
<thead>
<tr>
<th>Fertilizers applied kg ha(^{-1})</th>
<th>NMS</th>
<th>PH (cm)</th>
<th>DF</th>
<th>LAI</th>
<th>AGDB ton ha(^{-1})</th>
<th>UGDB (ton ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Control)</td>
<td>2.33</td>
<td>53.17(c)</td>
<td>50.00(d)</td>
<td>1.93(d)</td>
<td>0.74</td>
<td>0.782(d)</td>
</tr>
<tr>
<td>55N + 45P(_2)O(_5)</td>
<td>3.27</td>
<td>57.77(bc)</td>
<td>51.00(cd)</td>
<td>2.29(cd)</td>
<td>1.12</td>
<td>3.06(c)</td>
</tr>
<tr>
<td>110 N + 90 P(_2)O(_5)</td>
<td>3.47</td>
<td>60.93(bc)</td>
<td>52.33(bc)</td>
<td>3.25(ab)</td>
<td>1.64</td>
<td>4.31(bc)</td>
</tr>
<tr>
<td>165 N + 135 P(_2)O(_5)</td>
<td>3.83</td>
<td>63.77(b)</td>
<td>54.33(a)</td>
<td>3.12(ab)</td>
<td>1.92</td>
<td>5.06(ab)</td>
</tr>
<tr>
<td>110 N + 90 P(_2)O(_5) + 69 K(_2)O</td>
<td>3.17</td>
<td>73.93(b)</td>
<td>52.33(bc)</td>
<td>3.12(bc)</td>
<td>2.05</td>
<td>6.31(a)</td>
</tr>
<tr>
<td>100% NPSB + 9.1 N</td>
<td>3.6</td>
<td>63.2(b)</td>
<td>52.00(bc)</td>
<td>3.59(ab)</td>
<td>1.79</td>
<td>4.41(bc)</td>
</tr>
<tr>
<td>200% NPSB + 128.8 N</td>
<td>3.33</td>
<td>65.03(ab)</td>
<td>53.67(ab)</td>
<td>3.65(a)</td>
<td>1.80</td>
<td>5.05(ab)</td>
</tr>
<tr>
<td>100% NPSZnB + 93.1 N</td>
<td>3.67</td>
<td>58.5(bc)</td>
<td>51.67(bc)</td>
<td>2.71(bc)</td>
<td>1.79</td>
<td>3.35(bc)</td>
</tr>
<tr>
<td>200% NPSZnB + 131.2 N</td>
<td>3.7</td>
<td>60.33(bc)</td>
<td>52.67(abc)</td>
<td>3.63(a)</td>
<td>2.50</td>
<td>2.69(c)</td>
</tr>
<tr>
<td>LSD 5%</td>
<td></td>
<td>5.18</td>
<td>1.68</td>
<td>0.91</td>
<td>1.78</td>
<td>1.78</td>
</tr>
<tr>
<td>CV %</td>
<td>19.39</td>
<td>8.39</td>
<td>1.86</td>
<td>17.39</td>
<td>36.13</td>
<td>21.07</td>
</tr>
</tbody>
</table>

Means followed by the same letter within a column are not significantly different at 5% level of significance; LSD = least significant difference; and CV = Coefficient of Variation; NMS = Number of Main Stem; PH = Plant Height; LAI = Leaf Area Index; AGDB = Above Ground Dry Biomass (ton ha\(^{-1}\)); UGDB = Under Ground Dry Biomass (ton ha\(^{-1}\)); DF = 50 % Day to Flowering.
NPSZnB from 100 to 200% NPSB with adjusted N increased marketable tuber yield as compared to control. Generally, increasing the rates of chemical fertilizers with adjusted N increased marketable tuber yield. The current result agrees with work of many researchers who stated that increasing N and P rates increased marketable tuber yield (Israel et al., 2012; Burtukan, 2016).

The combined application of NPK (110 kg N + 90 kg P₂O₅ + 69 kg K₂O ha⁻¹) fertilizers improved total tuber yield by 128% as compared to the control. Increasing nitrogen and phosphorus fertilizer rates from 0 to 150% NP (165 kg N + 135 kg P₂O₅ ha⁻¹) increased total tuber yield of potato by 79% as compared to the control. This finding is similar to that of Mulubrhan (2004) who stated that increasing nitrogen and phosphorus application increased total tuber yield.

Many previous studies reported growth, production and tuber quality increase (Al-Moshileh and Errebi, 2004) and yield and quality of potato tubers improvement (Asmaa and Hafez, 2010; Naz et al., 2011; Wassie and Shiferaw, 2011). In addition to the above stated benefits, potassium enhances nitrogen use efficiency by favoring protein formation. Wassie and Shiferaw (2011) also reported potato yield increased by 114-341% on Nitosol due to K fertilizer application.

Table 3. Influence of the application of chemical fertilizer types and rates on yield and yield components of potato at Assosa, western Ethiopia.

<table>
<thead>
<tr>
<th>Fertilizer applied kg ha⁻¹</th>
<th>MTW (g)</th>
<th>TTNPH</th>
<th>MTY (ton ha⁻¹)</th>
<th>UMTY (ton ha⁻¹)</th>
<th>TTY (ton ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Control)</td>
<td>52.96ᵇ</td>
<td>7.13</td>
<td>10.23ᵇ</td>
<td>4.94</td>
<td>15.17ᵇ</td>
</tr>
<tr>
<td>55 N + 45</td>
<td>58.92ᵇ</td>
<td>7.83</td>
<td>17.8ᵇ</td>
<td>5.33</td>
<td>20.54ᵇ</td>
</tr>
<tr>
<td>110 N + 90 P₂O₅</td>
<td>56.04ᵇ</td>
<td>10.33</td>
<td>19.35ᵇ</td>
<td>4.97</td>
<td>24.32ᵇ</td>
</tr>
<tr>
<td>165 N + 135 P₂O₅</td>
<td>66.54ᵇ</td>
<td>10.07</td>
<td>21.88ᵇ</td>
<td>5.29</td>
<td>27.16ᵇ</td>
</tr>
<tr>
<td>110 N + 90 P₂O₅ + 69 K₂O</td>
<td>104.4ᵃ</td>
<td>10.07</td>
<td>30.03ᵃ</td>
<td>4.55</td>
<td>34.58ᵃ</td>
</tr>
<tr>
<td>100% NPSB + 91.9 N</td>
<td>55.67ᵇ</td>
<td>11.33</td>
<td>20.81ᵇ</td>
<td>6.35</td>
<td>27.16ᵇ</td>
</tr>
<tr>
<td>200% NPSB + 128.8 N</td>
<td>61.52ᵇ</td>
<td>12.67</td>
<td>22.25ᵇ</td>
<td>5.28</td>
<td>27.54ᵇ</td>
</tr>
<tr>
<td>100% NPSZnB + 93.1 N</td>
<td>66.12ᵇ</td>
<td>8.8</td>
<td>17.12ᵇ</td>
<td>3.86</td>
<td>20.99ᵇ</td>
</tr>
<tr>
<td>200% NPSZnB + 131.2 N</td>
<td>68.68ᵇ</td>
<td>9.73</td>
<td>18.74ᵇ</td>
<td>4.67</td>
<td>23.41ᵇ</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>24.15</td>
<td>NS</td>
<td>8.27</td>
<td>NS</td>
<td>7.92</td>
</tr>
<tr>
<td>CV%</td>
<td>21.26</td>
<td>20.28</td>
<td>24.23</td>
<td>22.56</td>
<td>18.65</td>
</tr>
</tbody>
</table>

Means followed by the same letter within a column are not significantly different at 5% level of significance; NS = Not Significant; LSD = least significant difference; and CV = Coefficient of Variation; MTW = Mean Tuber Weight (g); TTNPH = Total Tuber Number per Hill; MTY = Marketable Tuber Yield (ton ha⁻¹); UMTY = Unmarketable Tuber Yield (ton ha⁻¹); TTY = Total Tuber Yield (ton ha⁻¹).

Potato tuber quality in response to chemical fertilizer

Specific gravity, small and medium size tubers were non-significantly (P>0.05) affected by chemical fertilizer rates and types (Table 5). These results are in agreement with several findings which reported non-significant response in specific gravity of tubers due to N and P fertilizer application (Zelalem et al., 2009; Simret et al., 2010). The present finding of small and medium tuber size is contrary to the findings of Firew et al. (2016) who reported that small and medium sized tubers were affected by nitrogen and phosphorus fertilizer rates.

On the other hand, large sized tubers were significantly (P<0.05) affected by chemical fertilizer types and rates (Table 5). This result is in agreement with the findings of Habtam (2012) who reported that potassium increased the yield of large sized tubers. Increasing application of fertilizers from 0 to 150% NP (165 kg N + 135 kg P₂O₅ ha⁻¹) increased yield of large-sized tubers by 163% as compared to the control. This result is in line with the findings of Firew et al. (2016) who stated that increasing N and P increased large tuber-sized yield of potatoes. Increase in the yield of large-sized tubers due to potassium fertilization may be ascribed to the stimulating effect of potassium on photosynthesis, phloem loading and translocation, as well as synthesis of large molecular weight substances within storage organs that may be contributing to the rapid bulking of the tubers (Singh, 1999). Additionally, it could also be due to the role K plays in carbohydrate formation, transformation and movement of starch from leaves to tubers (Vander, 1981). The increase of chemical fertilizer (NPSB and NPSZnB) application from 100 to 200% with adjusted N, increased yield of large-sized tubers as compared to the control.

Tuber dry matter content was significantly (P < 0.05) affected by application of fertilizer rates and types (Table 4). The highest tuber dry matter content (26.8%) was obtained with the application of NPK (110 kg N+90 kg P₂O₅+ 69 kg K₂O ha⁻¹). The highest dry matter was obtained due to potassium application with NP fertilizers, since K is known to play a significant role on tuber dry matter content. Similarly, Tawfik (2001) reported that
Table 4. Quality parameters of potato as influenced by chemical fertilizers types and rates at Assosa, western Ethiopia season.

<table>
<thead>
<tr>
<th>Fertilizers (kg ha⁻¹)</th>
<th>Potato tuber size distribution in t ha⁻¹</th>
<th>SG</th>
<th>TDMC %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SSTY (&lt;39 g)</td>
<td>MSTY (39-75 g)</td>
<td>LSTY (&gt;75 g)</td>
</tr>
<tr>
<td>Control</td>
<td>1.77</td>
<td>6.74</td>
<td>6.66</td>
</tr>
<tr>
<td>55 N + 45 P₂O₅</td>
<td>2.66</td>
<td>6.32</td>
<td>11.55</td>
</tr>
<tr>
<td>110 N + 90 P₂O₅</td>
<td>3.56</td>
<td>6.38</td>
<td>14.38</td>
</tr>
<tr>
<td>165 N + 135 P₂O₅</td>
<td>3.68</td>
<td>5.99</td>
<td>17.53</td>
</tr>
<tr>
<td>110 N + 90 P₂O₅ + 69 K₂O</td>
<td>2.41</td>
<td>5.37</td>
<td>26.84</td>
</tr>
<tr>
<td>100% NPS + 91.9 N</td>
<td>4.64</td>
<td>6.66</td>
<td>15.86</td>
</tr>
<tr>
<td>200% NPSB + 128.8 N</td>
<td>4.56</td>
<td>6.46</td>
<td>16.52</td>
</tr>
<tr>
<td>100% NPSZnB + 93.1 N</td>
<td>2.05</td>
<td>6.2</td>
<td>12.74</td>
</tr>
<tr>
<td>200% NPSZnB + 131.2 N</td>
<td>4.03</td>
<td>7.07</td>
<td>12.31</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>Ns</td>
<td>Ns</td>
<td>9.45</td>
</tr>
<tr>
<td>CV %</td>
<td>47.27</td>
<td>30.71</td>
<td>36.59</td>
</tr>
</tbody>
</table>

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

potato plants fertilized with high K had significantly higher dry matter content than those fertilized with low K. On the other hand, a significant reduction in percent dry matter content can be due to an increase in the application rate of N fertilizer (Kanzikwera et al., 2001). This may be attributed to the fact that high rates of N stimulate top growth more than tuber growth, thereby delaying tuber formation and maturity. This result is coherent with the findings of Allison et al. (2001) that the balanced nutrient management with nitrogen, potassium and phosphorous fertilizers led to highest tuber specific gravity and tuber dry matter in potato.

Partial budget analysis

The results of the partial budget analysis revealed that the highest net benefit of Birr 156,262.8 ha⁻¹ was recorded with NPK (110 kg N, 90 kg P₂O₅ and 69 kg K₂O ha⁻¹) fertilizer application; whereas, the lowest net benefit of Birr 55,260 was obtained from the control treatment (Table 6). Based on partial budget analysis, it is advisable to apply full recommended NPK to get optimum yield of potato for Assosa area. Maximum yield and minimum cost evidently lead to high income. For every 1.00 Birr invested for the application of potassium combined with NP, farmers can obtain 1.00 Birr recovery, and an additional 42.5 Birr ha⁻¹ by applying recommended NPK (110 kg N, 90 kg P₂O₅, 69 kg K₂O ha⁻¹) (Table 6).

When the new technology surpassed the conventional practice, it is said to be undominated. In contrary, when the new technology yields lower benefit, then the technology is said to be dominated (CIMMYT, 1988). The dominant analysis revealed that the net benefit of some treatments was un-dominated. Thus, unfertilized plot, half of recommended NP (55 kg N + 45 kg P₂O₅ ha⁻¹), two rates of blended fertilizers 100% NPSB + 91.9 kg N ha⁻¹, 200% NPSB + 128.8 kg N ha⁻¹ and full recommended NP (110 kg N, 90 kg P₂O₅, 69 kg K₂O ha⁻¹) treatments were undominated (Table 6). These results indicated that the net benefit increased with increasing the total cost that varies (Figure 1). So, farmers select un-dominated treatments compared to dominated treatments.

The analysis indicated that all un-dominated treatments were above minimum acceptable marginal rate of return for farmers to accept the fertilizer recommendation. It is important to note that the acceptable minimum marginal rate of return for farmers to accept the fertilizer recommendation is 50-100% (CIMMYT, 1988). Thus, the application of NPK (110 kg N, 90 kg P₂O₅ and 69 kg K₂O ha⁻¹) resulted in the highest net benefit and higher marginal rate of return (4246 %) and higher tuber yield. So, application of 110 kg N, 90 kg P₂O₅ and 69 kg K₂O ha⁻¹ is advisable for farmers to use for profitable potato production at Assosa area.

Conclusion

The results showed that increasing N and P application rates delayed flowering of potato as compared to the control treatment. Application of chemical fertilizers, NP (110 N + 90 P₂O₅ kg ha⁻¹) with K (69 kg K₂O) increased potato height by about 39% as compared to the control. Increasing application of chemical fertilizer types and rates revealed significant (p < 0.05) influence on leaf area index, underground dry biomass, total tuber yield, marketable tuber yield and mean tuber weight. Applications of 50%NP, 100% NPK, 100% NPSB with
Table 5. Dominance analysis with chemical fertilizers types and rates application on potato tuber yield production at Assosa, western Ethiopia.

<table>
<thead>
<tr>
<th>Fertilizers (kg ha(^{-1}))</th>
<th>AVMTY kg ha(^{-1})</th>
<th>10% Ad. MTY kg ha(^{-1})</th>
<th>GB</th>
<th>TCV</th>
<th>NB</th>
<th>B:C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>10230</td>
<td>9210</td>
<td>55260</td>
<td>0</td>
<td>55260</td>
<td>-</td>
</tr>
<tr>
<td>55 N, 45 P(_2)O(_5)</td>
<td>17000</td>
<td>15301</td>
<td>91806</td>
<td>2502.9</td>
<td>89303.09</td>
<td>35.68</td>
</tr>
<tr>
<td>100% NPSB, 91.9 N</td>
<td>20810</td>
<td>18728</td>
<td>112368</td>
<td>3063.19</td>
<td>109304.8</td>
<td>35.68</td>
</tr>
<tr>
<td>100% NPSZnB, 93.1 N</td>
<td>17120</td>
<td>15411</td>
<td>92466</td>
<td>3152.69</td>
<td>89313.31D</td>
<td>28.33</td>
</tr>
<tr>
<td>110 N, 90 P(_2)O(_5)</td>
<td>19350</td>
<td>17412</td>
<td>104472</td>
<td>4824.97</td>
<td>99647.03D</td>
<td>20.65</td>
</tr>
<tr>
<td>200% NPSB, 128.8 N</td>
<td>22250</td>
<td>20028</td>
<td>120168</td>
<td>4903.59</td>
<td>115264.4</td>
<td>23.51</td>
</tr>
<tr>
<td>100% NPSZnB, 93.1 N</td>
<td>18740</td>
<td>16863</td>
<td>101178</td>
<td>5095.21</td>
<td>96082.79D</td>
<td>18.86</td>
</tr>
<tr>
<td>110 N, 90 P(_2)O(_5), 69 K(_2)O</td>
<td>30030</td>
<td>27022</td>
<td>162132</td>
<td>5869.17</td>
<td>156262.8</td>
<td>26.62</td>
</tr>
<tr>
<td>165 N, 135 P(_2)O(_5)</td>
<td>21880</td>
<td>19695</td>
<td>118170</td>
<td>5998.4</td>
<td>111022.52D</td>
<td>15.53</td>
</tr>
</tbody>
</table>

AVMTY kg ha\(^{-1}\) = Average Marketable Tuber Yield kg ha\(^{-1}\), 10% Ad. MTY = Adjusted Marketable Total Yield; GB = Gross Benefit, TCV = Total Cost that Vary; NB = Net Benefit; D = Dominated.

Table 6. Marginal rate of return of un-dominated treatments as influenced by chemical fertilizers types and rates with potato tuber yield at Assosa, western Ethiopia.

<table>
<thead>
<tr>
<th>Applied fertilizers kg ha(^{-1})</th>
<th>TCV</th>
<th>MC</th>
<th>NB</th>
<th>MB</th>
<th>MRR%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>-</td>
<td>55260</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>55 N, 45 P(_2)O(_5)</td>
<td>2502.91</td>
<td>2502.91</td>
<td>89303.09</td>
<td>34043.09</td>
<td>1360</td>
</tr>
<tr>
<td>100% NPSB, 91.9 N</td>
<td>3063.19</td>
<td>560.28</td>
<td>109304.8</td>
<td>20001.71</td>
<td>3570</td>
</tr>
<tr>
<td>200% NPSB, 128.8 N</td>
<td>4903.59</td>
<td>1840.4</td>
<td>115264.4</td>
<td>40998.4</td>
<td>4246</td>
</tr>
<tr>
<td>110 N, 90 P(_2)O(_5), 69 K(_2)O</td>
<td>5869.17</td>
<td>965.58</td>
<td>156262.8</td>
<td>40998.4</td>
<td>4246</td>
</tr>
</tbody>
</table>

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

Figure 1. Net benefit curve and marginal rate of return of potato as influenced by chemical fertilizer types and rates at Assosa area Western, Ethiopia. T1 = Control; T2 = Half of recommended NP; T5 = Full recommended of NPK; T6 = 100% NPSB + 91.9 N kg ha\(^{-1}\); T7 = 200% NPSB + 128.8 kg N ha\(^{-1}\), the exchange rate of 1 $ is 27.30 Ethiopian Birr.
adjusted N and 200%NPSB with adjusted N fertilizers resulted in higher net benefits with the acceptable marginal rate of return (above 100%). The partial budget analysis revealed that application of 110 kg N, 90 kg P₂O₅ and 69 kg K₂O ha⁻¹ resulted in the highest net benefit and marginal rate of returns. In nutshell, on the basis of marketable tuber yield, net benefit and MRR, we recommend 110 kg N, 90 kg P₂O₅ and 69 kg K₂O ha⁻¹ fertilizers for profitable and sustainable potato production at Assosa area, western Ethiopia.

CONFLICT OF INTERESTS
The authors have not declared any conflict of interests.

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