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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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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 P_2O_5, 110 kg N and 90 kg P_2O_5, 165 kg N and 135 kg P_2O_5 kg ha^{-1}), one NPK combination (110 kg N, 90 kg P_2O_5 and 69 kg K_2O ha^{-1}), 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 P_2O_5 + 69 kg K_2O 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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3,277 in 2015/2016 and increased to 8,359 farmers in 2016/2017 (CSA, 2016/2017).

Potato is one of the important tuber crops that has 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 10º 01' 25'' to 10º 02' 50'' N latitude and from 34º 33' 50'' to 34º 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 km^2. The experimental site is located between 10° 02' 05'' N latitude and 34° 34' 09'' E longitudes at 4 km east of Asossa 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 Asossa is 1275 mm. The minimum and maximum temperatures are 14.33 and 28.43ºC, respectively. The dominant soil type of Asossa 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 Assosa 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 P_2O_5 ha^{-1}), full of recommended NP 100% (110 kg N + 90 kg P_2O_5 ha^{-1}) and 150% recommended NP (165 kg N + 135 kg P_2O_5 ha^{-1}) and full recommended NP and K (110 kg N + 90 kg P_2O_5 + 69 kg K_2O ha^{-1})

Table 1. Detailed nutrient contents of the chemical fertilizers used as treatments.

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

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

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 m^2 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 ground 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.

Days to 50% flowering

The number of days to 50% flowering was recorded (Shiri-e-Janagrad et al., 2009).

Leaf area index (LAI)

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

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

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

Leaf area =W*L*0.674,

Where, 0.674 is the correction factor according to [Sakllova, 1979 quoted by Djilani and Senoussi (2013)].

Above ground dry biomass (t ha^{-1})

This refers to the dry weight of leaves, stems and branches. It was determined from 5 randomly taken plants from the central rows just before senescence (at physiological maturity). Dry weight of the samples was taken after they were air-dried followed by oven-drying at 70°C (CIP, 1984).

Underground dry biomass (g)

This refers to the dry weight of roots, stolons, and tubers. It was determined from 5 randomly taken plants from the central rows at harvesting time. Sample dry weights were taken after air-drying the samples followed by oven-drying at 70ºC (CIP, 1984).

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

The weight of tubers, which were free from diseases, insect pests, and greater than or equal to 25 g in weight, was recorded as marketable tuber yield.

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 70ºC for 24 hours. The dry matter percent was calculated according to the following formula (Williams and Woodbury, 1968).

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

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 Lung'aho 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(+) 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 P_2O_5 + 69 kg K_2O 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 K_2O was supplied together with N and P_2O_5 as compared to control and other treatments without the involvements of K_2O. 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 P_2O_5 ha^{-1}, 110 kg N + 90 kg P_2O_5 ha^{-1} and165 kg N + 135 kg P_2O_5 ha^{-1} increased plant height by 9, 15, and 20%, respectively over the control. 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 P_2O_5 kg ha^{-1} prolonged the days required

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

Fertilizers applied kg ha^{-1}	NMS	PH (cm)	DF	LAI	AGDB ton ha^{-1}	UGDB (ton ha^{-1})
0 (Control)	2.33	53.17^{c}	50.00^{d}	1.93^{d}	0.74	0.782^{d}
$55N + 45P_2O_5$	3.27	57.77^{bc}	51.00^{cd}	2.29^{cd}	1.12	3.06^{c}
110 N + 90 P_2O_5	3.47	60.93^{bc}	52.33^{bc}	3.25^{ab}	1.64	4.31^{bc}
165 N + 135 P_2O_5	3.83	63.77^{b}	54.33^{a}	3.12^{abc}	1.92	5.06^{ab}
110 N + 90 P_2O_5 + 69 K_2O	3.17	73.93^{a}	52.33^{bc}	3.12^{abc}	2.05	6.31^{a}
100% NPSB + 91.9 N	3.6	63.2^{b}	52.00^{bc}	3.59^{ab}	1.79	4.41^{bc}
200% NPSB + 128.8 N	3.33	65.03^{ab}	53.67^{ab}	3.65^{a}	1.80	5.05^{ab}
100% NPSZnB + 93.1 N	3.67	58.5^{bc}	51.67^{dc}	2.71^{bcd}	1.79	3.35^{bc}
200% NPSZnB + 131.2 N	3.7	60.33^{bc}	52.67^{abc}	3.63^{a}	2.50	2.69^{c}
LSD 5%	Ns	5.18	1.68	0.91	Ns	1.78
CV %	19.39	8.39	1.86	17.39	36.13	21.07

Means followed by the same letter within a column are not significantly different at 5% level of significance; LSD = least significant difference; and CV = Coefficient of Variation; NMS = Number of Main Stem; PH = Plant Height; LAI = Leaf Area Index; AGDB = Above Ground Dry Biomass (ton ha^{-1}); UGDB = Under Ground Dry Biomass (ton ha^{-1}); DF = 50 % Day to Flowering.

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 finding 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 P2O5 + 69 kg K2O ha^{-1}) whereas the lowest underground dry biomass yields (0.782 tha^{-1}) was obtained from the control (Table 3). Plants treated with potassium together with recommended NP fertilizers showed significant response as compared to other treatments. This is due to the fact that potassium application activates number of enzymes involved in photosynthesis, carbohydrate metabolism and assists in the translocation of carbohydrates from leaves to tubers. Potassium increases the yield by increasing the number and yield of large sized tubers. According to Asmaa and Hafez (2010) higher application of potassium resulted in higher underground biomass production in potato as compared to lower K application.

Increasing application of chemical fertilizers NPSB and NPSZnB from 100 to 200% NPSB with N adjustment also increased underground dry biomass yield linearly as compared to 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_2O_5 + 69 kg K_2O 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_2O_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 3. Influence of the application of chemical fertilizer types and rates on yield and yield components of potato at Assosa, western Ethiopia.

Fertilizer applied kg ha^{-1}	MTW (g)	TTNPH	MTY (ton ha^{-1})	UMTY (ton ha^{-1})	TTY(ton ha^{-1})
0 (Control)	52.96^{b}	7.13	10.23^{c}	4.94	15.17^{c}
55 N + 45	58.92^{b}	8.73	17^{bc}	3.53	20.54^{bc}
110 N + 90 P_2O_5	56.04^{b}	10.33	19.35^{b}	4.97	24.32^{b}
165 N + 135 P_2O_5	66.54^{b}	10.07	21.88^{ab}	5.29	27.18^{ab}
110 N + 90 P_2O_5 + 69 K_2O	104.4^{a}	10.07	30.03^{a}	4.55	34.58^{a}
100% NPSB + 91.9 N	55.67^{b}	11.33	20.81^{b}	6.35	27.16^{ab}
200% NPSB + 128.8 N	61.52^{b}	12.67	22.25^{ab}	5.28	27.54^{ab}
100% NPSZnB + 93.1 N	66.12^{b}	8.8	17.12^{bc}	3.86	20.99^{bc}
200% NPSZnB + 131.2 N	68.68^{b}	9.73	18.74^{b}	4.67	23.41^{b}
LSD 5%	24.15	NS	8.27	NS	7.92
CV%	21.26	20.28	24.23	22.56	18.65

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

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 P_2O_5 + 69 kg K_2O 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 P_2O_5 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 Nitosols due to K fertilizer application.

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 P_2O_5 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 P_2O_5+ 69 kg K_2O 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.

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

Means followed by the same letter within a column are not significantly different at 5% level of significance; Ns = Not Significant; LSD = least significant difference; and CV = Coefficient of Variation; 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 P_2O_5 and 69 kg K_2O 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 P_2O_5, 69 kg K_2O 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 P_2O_5 ha^{-1}), two rates of blended fertilizers 100% NPSB + 91.9 kg N ha^{-1}, 200% NPSB +128.8 kg N ha^{-1} and full recommended NP (110 kg N, 90 kg P_2O_5, 69 kg K_2O 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 P_2O_5 and 69 kg K_2O 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 P_2O_5 and 69 kg K_2O 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 P_2O_5 kg ha^{-1}) with K (69 kg K_2O) 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.

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

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

Applied fertilizers kg ha^{-1}	TCV	MC	NB	MB	MRR%
0	0	-	55260	-	-
55 N, 45 P_2O_5	2502.91	2502.91	89303.09	34043.09	1360
100% NPSB, 91.9N	3063.19	560.28	109304.8	20001.71	3570
200% NPSB, 128.8 N	4903.59	1840.4	115264.4	5959.6	324
110N, 90 P_2O_5, 69 K_2O	5869.17	965.58	156262.8	40998.4	4246

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

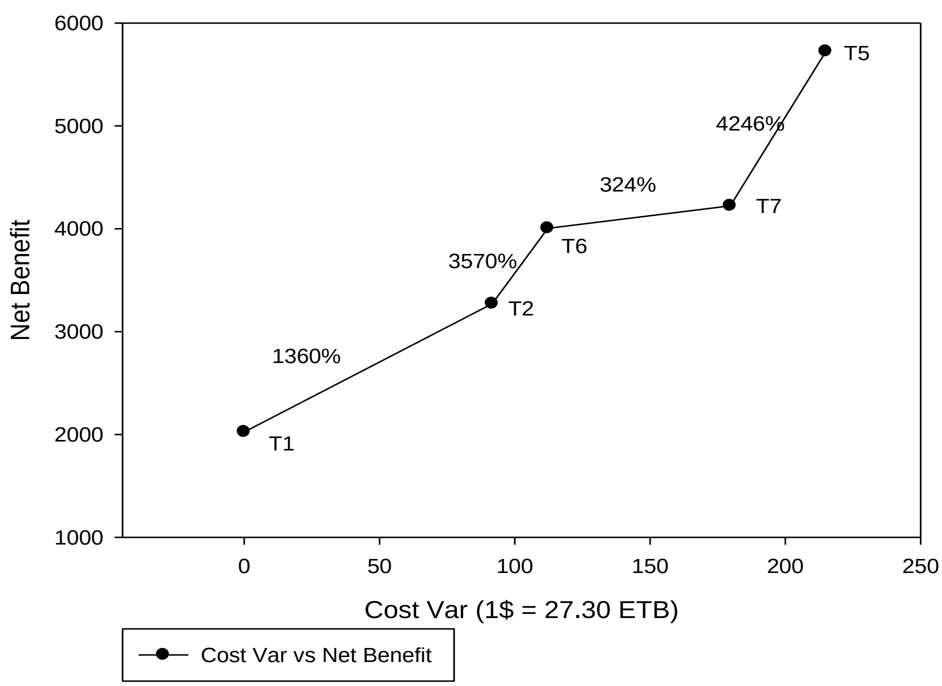

Figure 1. Net benefit curve and marginal rate of return of potato as influenced by chemical fertilizer types and rates at Assosa area Western, Ethiopia. T1 = Control; T2 = Half of recommended NP; T5 = Full recommended of NPK; T6 = 100% NPSB + 91.9 N kg ha^{-1}; T7 = 200% NPSB +128.8 kg N ha^{-1}, the 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 P_2O_5 and 69 kg K_2O 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 P_2O_5 and 69 kg K_2O 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.

REFERENCES

Allison MF, Flowler EJ, Allen JH (2001). Response of Potato (*Solanum tuberosum. L*) to Potassium Fertilizers. Journal of Agricultural Science 136:407-426.

Al-Moshileh AM, Errebi MA (2004). Effect of various potassium sulphate rates on growth, yield and quality of potato grown under sandy soil arid conditions. Proceedings of the IPI Regional Workshop on Potassium and Fertigation Development in West Asia and North Africa, Rabat, Nov. 2428-. Morocco, pp.

AsARC (Assosa Agriculture Research Center) (2017). Assosa Agricultural Research Center metrological data for 2017. Assosa, Ethiopia.

Asmaa RM, Hafez MM (2010). Increasing productivity of potato plants (S*olanum tuberosum* L) by using potassium fertilizer and humic acid application. Int. Academic Research Journal *2*(2):83-88.

Bekabil F, Befekadu B, Rupert S ,Tareke B (2011). Strengthening the teff Value Chain in Ethiopia (Unpublished Report). pp.12. Agricultural Transformation Agency.

Burtukan B (2016). Effect of nitrogen and phosphorus rates on growth, yield, yield components and quality of potato (S*olanum tuberosum* L.) at Dedo, South West Ethiopia. An MSc Thesis Presented to School of Graduate Study of Jimma University, Ethiopia.

CIMMYT(1988). From agronomic data to farmer recommendations: An economics training manual, (No 27): CIMMYT.

CIP (1984). International Potato Centre, Potato for the developing world. Lima, Peru.150p.

Dewis J, Fraitas P (1984). Physical and chemical methods of soil and water analysis. FAO Bulletin, No. 10, Rome 275p.

Diwaker B, Oswalt DL (1992). Research planning and data handling. ICRISAT, Andra Pradesh, India. 89p.

Djilani GA, Senoussi M (2013). Influence of organic manure on the vegetative growth and tuber production of potato (*Solanum tuberosum* L.) in Sahara Desert region. Algeria, International Journal of Agriculture and Crop Sciences 5(22):2724-2731.

EARO (2004). Research Strategy Document for Assosa Agricultural Research Center, Benishangul Gumuz National Regional State.Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia, pp. 1-6.

Esayas L (2015). Effect of blended fertilizers on yield and yield traits of durum wheat (*Triticum turgidum* l. var*. durum*) varieties in Ada district, Central Ethiopia. An MSc. Thesis presented to Haramaya University, Ethiopia.

EthioSIS (2013). Soil analysis report. Agricultural Transformation Agency (Unpublished).

EthioSIS (2014). Soil fertility status and fertilizer recommendation atlas for Tigray regional state, Ethiopia. July 2014, Addis Ababa, Ethiopia.

Fageria NK, Baligar VC, Jones CA (2011). Growth and Mineral Nutrition of Field Crops 3 Edition., Taylor & Francis Group. Available at: http://www.crcpress.com.

FAO (2008). International year of the potato. Available: http://www.potato 2008.org/en/world/africa.html.

FAO (2015). Potato World, Production and Consumption. Available online: http://www.potato2008.org/en/world/index.html (accessed on 11 January 2015).

FAOSTAT (2015). Data base of agricultural production. Food and Agriculture Organization, Rome, Italy.

Firew G, Nigussie D, Wassu M (2016). Response of potato (*solanum tuberosum* l.) to the application of mineral nitrogen and phosphorus under irrigation in Dire Dawa, Eastern Ethiopia. Journal of Natural Sciences Research. ISSN 2224-3186 (Paper) 6(7).

Gebremedhin W, Endale G, Berga L (2008a). Potato Variety Development. In: Root and Tubers. The untapped Resource, pp. 15-32. EIAR, Addis Ababa, Ethiopia

Gebremedhin G, W Giorgis, Endale G, Kiflu B (2008b). Overview of trends in root and tuber crops research in Ethiopia and potato agronomy. In Root and tuber crops, pp.1-5. Addis Abeba: Ethiopian Institute of Agricultural Research.

Habtam S (2012). Response of potato (*solanum tuberosum* l.) to the application of phosphorus and potassium fertilizers at Assosa, Benishangul gumuz regional state, Western Ethiopia on at Assosa area. An M.Sc. Thesis Presented to Haramaya University, Ethiopia.

Hazelton P, Murphy B (2007). Interpreting soil test results. What do all the numbers mean? 2nd Edition. CSIRO Publishing. 152p.

Hesse PR (1971). A Text Book of Soil Chemical Analysis.

Israel Z, Ali M, Solomon T (2012). Effect of different rates of nitrogen and phosphorus fertilization on yield and yield component of potato (*Solanum tuberosum* L.) at Mashan, Southwestern of Ethiopia. African Journal of Plant Science 3 (2): 016-024.

Jackson M (1967). Soil chemical analysis. Prentice-Hall of India, New Delhi.

Jones JB (2003). Agronomic Handbook: Management of Crops, Soils, and Their Fertility. CRC Press LLC, Boca Raton, FL, USA. 482p.

Kanzikwera CR, Tenywa JS, Osiru DSO, Adipala E, Bhagsari AS (2001). Interactive effect of Nitrogen and Potassium on dry matter and nutrient partitioning in true potato seed mother plants. African Crop Science Journal 9:127-146.

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

Marschner H (1995). Mineral nutrition of higher plants, second edition. Academic Press Inc., Sand Diego. 889p.

MoARD (2009). Ministry of Agriculture, Crop Variety Register. Issue No.12. Animal and Plant Health Regulatory Directorate, Addis Ababa, Ethiopia.

Motsara MR, Roy RN (2008). Guide to Laboratory Establishments for Plant nutrient Analysis: FAO Fertilizer and Plant Nutrition Bulletin 19.

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. An M.Sc Thesis Presented to School of Graduate Study of Haramaya University, Ethiopia.

Naz F, Ali A, Iqbal Z, Akhtar N, Asghar S, Ahmad B (2011). Effect of different levels of NPK fertilizers on the proximate composition of potato crop at Abbottabad. Sarhad Journal of Agriculture 27(3):353-356.

Nigussie D (2001). Phosphorus efficiency of selected vegetables. A Ph.D. Dissertation Presented to Hanover University, Fielderstadt, Germany.

Olsen SR, Cole CW, Watanabe FS, Dean LA (1954). Estimation of available phosphorous in soils by extraction with sodium bicarbonate circular 939, US. Department of Agriculture

Page AL (1982). Methods of soil analysis. Part II. Chemical and Microbiological Properties. Madison.

Ryan J, Rashid A (2001). Soil and plant analysis laboratory manual. second edition. jointly published by the international center for agricultural research in the dry areas (ICARDA) and the National Agricultural Research Center (NARC). Available from ICARDA, Aleppo, Syria, pp. 172.

Salam PK (2004). Annual Agricultural Research. New Series. 25(2): 329-332.

SAS (2004). SAS (Statistical Analysis System) statistical guide for personal computers, version 9.0. SAS Institute.

Shiri-e-Janagrad M, Tobeh A, Abbasi A, Jamaati-e-Somarin S, Hokmalipour S (2009). Vegetative growth of potato (Solanum tuberosum L.) cultivars, under the effects of different levels of nitrogen fertilizer. Research Journal of Biological Sciences 4(7):807-814.

Simret B, Nigussie D, Tekalign T (2010). Influence of inorganic nitrogen and potassium fertilizers on seed tuber yield and size distribution of potato. Proceedings of the National Workshop on Seed Potato Tuber Production and Dissemination, 12-14 March 2012.

Singh NP, Raghav M (2000). Response of potato to nitrogen and potassium fertilization under UP. tarai conditions. Journal of the Indian Potato Association 27:47-48.

Singh JP (1999). Potassium fertilization of potatoes in north India. pp. 123-127. In: Proc. of IPI Workshop on Essential Role of K in Diverse Cropping Systems, held at the 16th World Congress of Soil Science, Montpellier, France, 20-26 August 1998. International Potash Institute, Basel, Switzerland.

Tawfik AA (2001). Potassium and Calcium nutrition improves potato production in drip irrigated sandy soil. African Crop Science Journal 9:147-155.

Tekalign T (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Vander Zaag P (1981). Soil fertility requirements for potato production. International potato Center (CIP), Lima- Peru, Technical Information Bulletin*,* 14, 120-122.

Walkley A, Black AC (1934). An examination of the DEGTJAREFF method for western Potato Council. 2003. Botany of the potato plant. Adaptation from Guide to Commercial Potato Production on the Canadian Prairies.

Wassie H Shiferaw B (2011). Response of Irish Potato (*Solanum tuberosum*) to the Application of Potassium at Acidic Soils of Chencha, Southern Ethiopia. International Journal of Agricultural Biology 13:595-598.

Wassu M (2014). Genetic Variability in Potato (Solanum tuberosum L.) Genotypes for Late blight [*Phytophthora infestans* (Mont.) de Bary] Resistance and Yield at Haramaya, Eastern Ethiopia. East African Journal of Sciences (2014). Volume 8(1) 13-28.

William MA, Woodbury GW (1968). Specific gravity dry matter relationship and reducing sugar changes affected by potato variety, production area and storage. American Potato Journal 45(4):119-131.

Zelalem A, Tekalign T, Nigussie D (2009). Response of potato (*Solanum tuberosum* L.) to different rates of N and P fertilization on Vertisol at Debre Berhan, in the entral highlands of Ethiopia. African Plant Scientific Journal 3(2):16-24.