Research Article

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Growth and yield responses of potato (*Solanum tuberosum L.*) varieties to NPS blended fertilizer at Nedjo, Western Ethiopia

Volume 6 Issue 2 - 2022

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Received: March 17, 2022 | **Published:** April 08, 2022

Abstract

Potato (*Solanum tuberosum* L.) is one of the major crops grown in several agroecological zones in Ethiopia but understudied. A field study was carried out to assess compound fertilizer, nitrogen-phosphorus-sulfur (NPS), effect on plant growth, yield and economic returns of three local potato varieties; namely, Menagesha, Gudane and Belete. Potato grown with the 150kg NPS/ha recorded the highest number of main stems and var. Belete had the most followed by var. Gudane and then var. Menagesha. An increase in NPS rate of application from 0 to 150 kg N/ha prolonged the time expected to attain 50% flowering from *ca*. 57 to *ca*. 69days. Variety Menagesha seemed to be early maturing compared to the other varieties. Consistently, the highest leaf tissue N, P and S concentrations were recorded by var. Belete, compared to vars Gudane and Menagesha. All the yield components increased significantly ($P<0.05$) when the rate of NPS application was increased stepwise to 150kg NPS/ha. Varieties Belete and Gudane were superior in having the highest marketable number of tubers compared to var. Menagesha. The partial budget analysis also showed the highest net benefit of 292,812 and 292,630 Birr/ha with marginal rate of return of 11798% and 15263% at 150kg NPS/ha for vars Belete and Gudane, respectively. This study must be repeated prior to recommendation while future research must analyze tuber biochemical quality in response to NPS blended fertilizer application.

Keywords: compound fertilizer, soil fertility, plant nutrition, potato production, stem tuber yield

Introduction

Potato (*Solanum tuberosum* L.) belongs to the family, Solanaceae. It is the fourth major food crop in the world after maize, rice and wheat,[1] and the first among the root and tuber crops, which includes cassava (*Manihot esculenta*), sweet potato (*Ipomea batatas*) and yam (*Dioscorea* spp.).[2] Globally, more than one billion people eat potatoes as a staple food,[3] which makes it a vital crop for food security programs where population growth exceeds food supply.[4] The global production of fresh potato tubers is about 321million tons from a total area of 19.5million hectares.[5]

Potatoes were introduced to Ethiopia in 1858 by the German botanist Schimper.[6] Since then, it was acknowledged that Ethiopia has a great potential for potato production because 70% of its arable land is in highland areas, which is more than 1,500meters above sea level.[7] Based on volumes of production and consumption, potato in Ethiopia was ranked first among root and tuber crops.[8] It has good food security potential due to its high yield, nutritional quality, short growing period, and wider adaptability.[9] However, the average national potato yield is low about 13,768t/ha,[8] which is below the world average yield of 17,160t/ha.[10] Despite these low yields, there has not been a comprehensive research program to increase potato yield in the varied climatic zones throughout Ethiopia including Nedjo in the Oromia Region in the west.

Potato plants require high levels of irrigation and soil nutrient management due to its shallow root system and modified (food storage organ) stem at maturity.[11] Soil nutrients requirements by potato plants is considerably high and as such, farmers adopt high rate of fertilizer application to achieve potential tuber yield.[12] Besides, potato crop produces much more dry matter in a relatively short life cycle resulting in large amounts of nutrients removal per growing season, and most of the soils in the potato farming areas are incapable of meeting plant demand.[13] Currently, in the west Wollega zone of Nedjo district (Western Ethiopia), the yield as well as quality of potato are low because of lack of scientifically recommended agronomic practices.

Due to the nature of Ethiopian soils, researchers recommend the use of blended fertilizer, nitrogen-phosphorus-sulfur (NPS). NPS blended fertilizer has been tested on many crops under Ethiopian climatic conditions with positive outcomes, but not much work has been done on potato response to NPS, especially in Nedjo district (2017 Nedjo District Agriculture Office Annual Report). Physiologically, N nutrition is critical to plants due to its importance in chlorophyll synthesis and its absorption of light and plant metabolism, growth and development; P is required during early root development and vital for photosynthesis; S mirrors P requirement and aids in enzyme activation and function of chlorophyll. However, misapplication of NPS can pose agroecological problems and so, recommendation of the appropriate application rate is critical. Therefore, it was hypothesized that the appropriate rate of NPS blended fertilizer will improve growth and yield of local varieties of potato in the Nedjo district of Ethiopia. The objective of the present study was to determine the rate of application of NPS blended fertilizer that will improve plant growth, yield, and economic returns of three local potato varieties; namely, cvs Menagesha, Gudane and Belete. These are new varieties developed in Ethiopia and yet to be fully explored agronomically in the varied ecozones of Ethiopia and particularly, in the Nedjo district.

Materials and Methods

Location

The experiment was conducted between July and October 2019 at Nedjo ATVET College, West Wollega Zone of the Oromia National Regional State (western Ethiopia) (Figure 1). Nedjo is located at latitude: 9° 30' 00'' N; longitude: 300° 30' 00'' E; and 1735m above sea level.

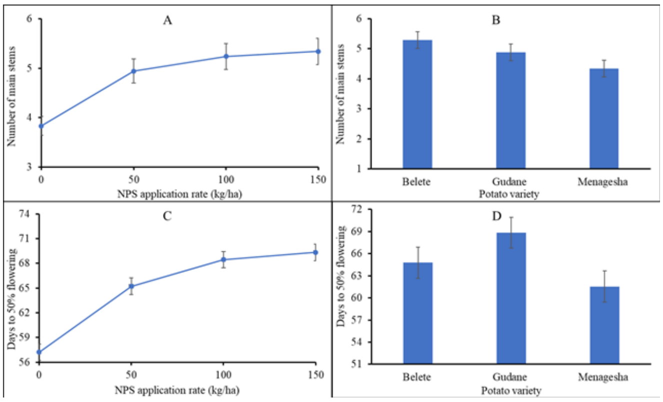

Figure 1 Main stem and 50% flowering of three potato varieties as influenced by nitrogen-phosphorus-sulfur (NPS) blended fertilizer.

The annual mean minimum and maximum temperatures of the location is between 12°C and 26°C, respectively. The annual rainfall varies between 1200mm to 1600mm according to the Nedjo Meteorological Station.

Experimental Materials

Three improved potato varieties used for the study were cvs Menagesha, Gudane and Belete. The varieties were newly released by Holeta Agricultural Research Centre, Holeta. Fifty (50)kg of NPS blended fertilizer containing approximately, 9% N, 18% P and 3.5% S with the remaining being fine river sand as filler was used in Table 1.

Treatments and Experimental Design

The treatments consisted of four rates of NPS (i.e., 0, 50, 100 and 150kg/ha) and three potato varieties (i.e., vars Gudang, Belete and Menagesha). The experiment was arranged in a randomized complete block factorial design with four replications (i.e., 4x3x4=48 treatment combinations). The gross plot size was 3m x 3m (9m^2) and the distance between adjacent plots and blocks was 0.5m and 1m, respectively. The subplot size was 1.5m x 2.4m (3.6m^2). There were four rows and 10 plants per row. The between and within row spacing was 75cm and 30cm, respectively.[14] Data were collected from the central rows by excluding one row from each side of the plot and one plant from both ends of the row.

Table 1 Description and source of potato varieties

No	Variety	Accession Code	Year of release	Breeding Center	Recommended altitude (m.a.s.l)[a]
1	Gudane	CIP-386423.13	2006	HARC	1600-2800
2	Belete	CIP-393371.58	2009	HARC	1600-2800
3	Menagesha	CIP-374080.5	1993	HARC	Above 2400

Source: MANR (2016) as cited by Tessema *et al.* (2020); ameters above sea level.

Experimental Procedure and crop management

The experimental field was ploughed using oxen (local farmers practice) to a depth of about 25-30cm and the plot was levelled off manually prior to planting. Two uniform and well sprouted seed tubers were planted at a depth of approximately, 5-7cm.[15] 50% of the different rates of NPS blended fertilizer treatments were applied at planting and the other half were applied two weeks after emergence. The plants were rain-fed throughout the growing period.

Data Collection and Analysis

The two outer rows were used as border plants and were not used for data collection.

Plant Growth and Yield Parameters: Plant height was measured from the ground level to the top of the plant 70days after planting (i.e., at flowering stage). Days to 50% flowering was determined by the number of days from the date of planting to the date at which 50% of the plants produce flowers. The sprouted stems of 10 randomly selected hills were counted and the mean number per hill was recorded at the flowering stage per treatment. Marketable tubers included tubers greater or equal to 25g weight, free from disease and insect attack, and free from defects. Potato tubers with size less than 25g, mechanically damaged with defects, and disease and insect pest attack were considered unmarketable. Tubers weighing between 16-50g were considered (small), and those weighing between 51-100g were classified as medium, and those tubers greater than 100g were classified as large.[16]

Total tuber N was determined using the Kjeldhal method.[17] Tuber samples were sent to Jimma University College of Agriculture and Veterinary Medicine laboratory for analysis. Agronomic nutrient use efficiency (ANUE) is defined as the economic production obtained per unit of nutrient applied. This index is usually used as a short-term indicator of the impact of applied nutrients on productivity and as input data for nutrient recommendations with reference to control plot yield, and was calculated according to the equation of Dobermann[18]:

$$\text{Agronomic Nutrient UE} = \frac{Yield_F - Yield_{WF}}{F_{applied}}$$

Where Yield$_F$ is potato tuber yield of the fertilized plot; Yield$_{WF}$ is potato tuber yield in the control plot; and F$_{applied}$ is quantity of fertilizer applied.

Potato Tuber Quality Variables: Potato Tuber dry matter content (%) was determined from randomly selected tubers and then washed, chopped, and mixed. A sample of 200g was dried at 70°C until constant dry weight was attained. The dry matter was then calculated as:

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

Specific gravity of potato tubers: This was determined from 5kg of potato tubers that were randomly selected from each treatment and washed, weighed in air and followed by re-weighing the same tubers suspended in water. The specific gravity of the tubers was then calculated as:

$$\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air - weight in water}}$$

Statistical Analysis

All data were subjected to analysis of variance using SAS statistical software version 9.3. The difference between treatment means was compared using the least significant difference method at the 5% level

Citation: Dereje A, Abebe T, Haile Y, et al. Growth and yield responses of potato (*Solanum tuberosum L.*) varieties to NPS blended fertilizer at Nedjo, Western Ethiopia. *Horticult Int J.* 2022;6(2):77–82. DOI: 10.15406/hij.2022.06.00245

of significance and correlation analysis among the variables was also performed. Graphs were plotted using Microsoft Excel.

Results and discussion

Plant growth and flower production components

The main effects of potato variety and NPS rate on the number of main stems (sprouts) per seed potato were highly significant (P<0.01) (Figure 1A&B) while the interaction effect was non-significant (P>0.05). Potato grown with the 150kg NPS/ha recorded the highest number of main stems, which is statistically at par with those of the 50 and 100kg NPS/ha treatments (Figure 1A).

Variety Belete was superior in affecting the number of main stems followed by var. Gudane and then var. Menagesha (Figure 1B). This might be due to the inherent genotypic variation in the number of buds per tuber in addition to the size of the tubers, physiological age of the seed, storage condition, and number of viable sprouts at planting. According to Masarirambi *et al.*,[19] seed tuber size, environmental variations and genetic factors of the varieties and agronomic practices *viz*., mother tuber size and plant spacing also have a significant influence on the number of potato stems.

The main effects of potato variety and NPS on days to 50% flowering were highly significant (P<0.01) while the interaction effect was not significant (P>0.05) (Figure 1C-D). An increase in NPS blended fertilizer rate of application from 0 to 150kg N/ha prolonged the time expected to attain 50% flowering from *ca*. 57 to *ca.* 69 days (Figure 1C). It is possible that an increase in the application rate of the NPS blended fertilizer may have promoted vegetative growth of the potato plants which in turn, delayed flower production. Simon and Selemawit (2019) made similar observation on delayed flowering of potato plants to *ca*. 65days at 150kg/ha NPS rate while the shortest time was *ca*. 52days under 100kg NPS/ha application rate. Among the different potato varieties, var. Menagesha was the earliest to reach the 50% flowering stage followed by var. Belete and then var. Gudane (Figure 1D). These differences in days of flowering among the different potato varieties are most probably associated with the genetic makeup of the varieties. Furthermore, the main effects of NPS and variety significantly (P<0.01) influenced days to 90% maturity of the potato plants whereas their interactions had no significant (P<0.05) effect (Table 2). The increase in application rate of NPS from 0 to 150kg/ha delayed the number of days to 90% plant maturity of all the potato varieties. Variety Menagesha seemed to be early maturing compared to the other varieties. The prolonged physiological maturity of the crop may be due to increased N levels as NPS was increased leading to extended vegetative growth and delayed reproductive development.

Plant height was significantly (P<0.01) influenced by the main effects of NPS and potato variety and their interactions (Table 2). As earlier observed by Simon and Selemawit[20] indicated that an increase in the rate of NPS from 0 to 15 kg/ha increased the mean plant height of the individual potato varieties. Overall, var. Gudane followed by var. Belete had the highest plant height while var. Menagesha was the shortest (Table 2).

Leaf tissue N, P and S concentration

Leaf tissue N concentration was significantly (P<0.01) influenced by the main effects of NPS and variety but not their interaction (Figure 2A&2B). Increasing NPS application rate from 0 to 150kg NPS/ha resulted in a gradual increase in leaf tissue N concentration from *ca*. 0.032% to *ca*. 0.244% (Figure 2A). Nitrogen is a very important nutrient to potato production and optimum leaf tissue N can be associated with optimum tuber yield and quality.[21] Leaf tissue concentration of P and S followed similar trend (Figure 2C&2F). Unlike N, the leaf tissue accumulation of P (Figure 2C) and S (Figure 2D) increased slowly from application rate from 0 to 50kg NPS/ha before rising sharply from application rate of 50 to 100kg NPS/ha and slowly peaked at 150kg NPS/ha. Consistently, the highest leaf tissue N, P and S concentrations were recorded by var. Belete, compared to vars Gudane and Menagesha (Figure 2B, 2D&2F). Thus, the different varieties demonstrated genetic variability for N, P and S uptake efficiency (*i.e*., the efficiency with which the crop captures available nutrient) and utilization efficiency (i.e., the efficiency with which nutrient is taken up). These indices are determinants of crop productivity and dry matter yield.[22] Increases in leaf tissue N, P and S is required to improve plant physiological activities like photosynthesis leading to improved plant growth, development, and productivity.

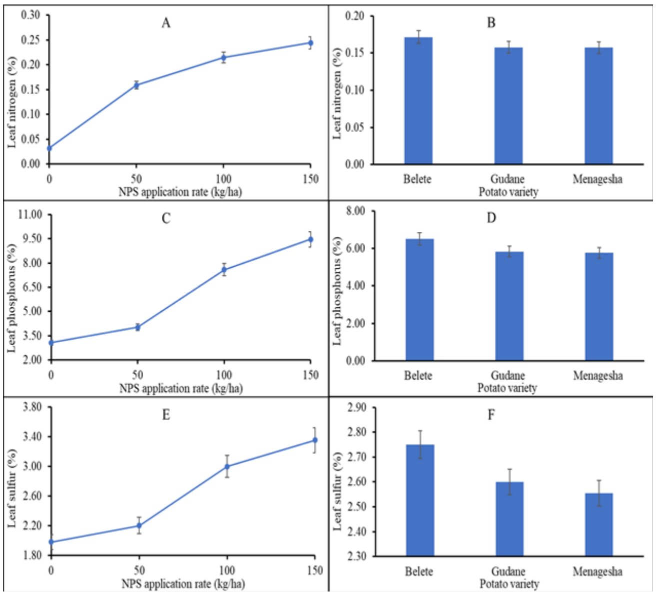

Figure 2 Leaf nutrients concentration of three potato varieties as influenced by nitrogen-phosphorus-sulfur (NPS) blended fertilizer.

Tuber yield and quality components

Potato tuber yield components i.e., total number of harvested tubers, and numbers of marketable and unmarketable tubers were significantly (P<0.01) affected by NPS application and variety except (Figure 3A-H). However, there was a non-significant (P>0.05) effect of variety on total number of tubers per hill (data not presented). All the yield components increased significantly (P<0.05) when the rate of NPS application was increased stepwise to 150kg NPS/ha. The total number of tubers was increased by the highest NPS application rate of 150kg/ha (Figure 3A). Varieties Belete and Gudane were superior in having the highest marketable number of tubers compared to var. Menagesha (Figure 3B). The trend in the potato yield components affected the fin.

The percentage number of unmarketable potato tubers were not statistically (P>0.05) different among the fertilizer treatments (Figure 3C). However, the proportion of the number of tubers that cannot be marketed was least in var. Belete followed by var. Gudane, but highest in var. Menagesha (Figure 3D).

The average tuber weight of potato was significantly (P<0.005) affected by variety x NPS interaction but not the individual main effects (Table 2). Increasing NPS application rate increased tuber fresh weight, irrespective of variety. The highest response of the potato varieties was when 150kg NPS/ha was applied. For instance, tuber weights of vars Belete, Gudane and Menagesha were increased by 39.5%, 60.9% and 35.5%, respectively, as NPS application rate was increased from 0 to 150kg NPS/ha. There was a strong association (r=0.89, P<0.002) between average weight of tuber and tuber yield. The treatment trend was 150>100>50kg NPS/ha for the average tuber weight and total and marketable tuber yield (Table 2 and Figure 3E&F). The increase in mean tuber weight and total and marketable yields in response to increased application rate of NPS fertilizer can be ascribed to faster plant growth, more foliage and increase in leaf area. Additionally, the resultant increase in the supply of P-containing fertilizer may have induced root development and the formation of larger tubers and tuber weight. The percentage of unmarketable tuber yield were highest in the control plot and was reduced as NPS rate increased from 0 to 150kg/ha (Figure 3G). For the varieties, the percentage unmarketable yield was highest in var. Menagesha but low and similar in vars Belete and Menagesha (Figure 3H). The significant (P<0.05) difference among varieties for unmarketable yield of potato tubers can be attributed to differences in genotypic characteristics such as adaptability, time to crop maturity and probably, tolerance to environment stressors.

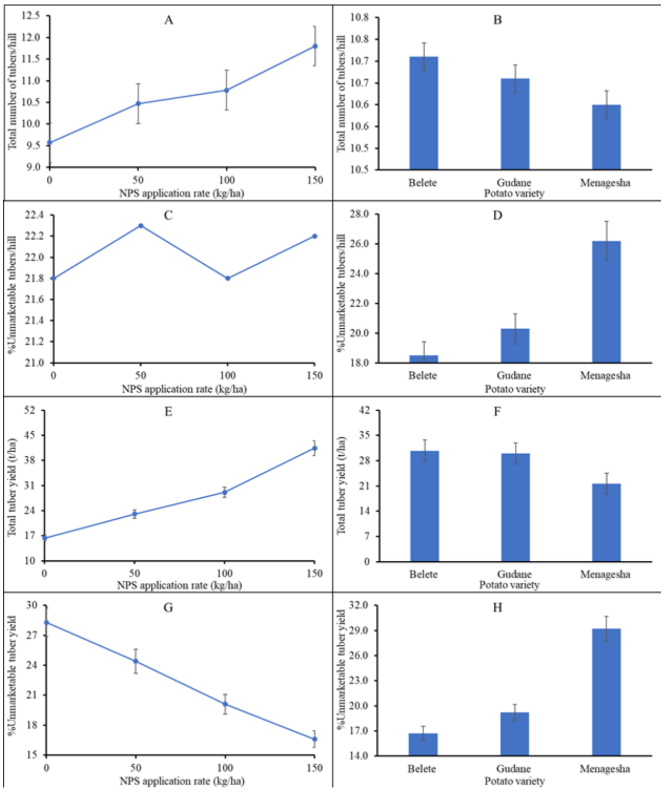

Figure 3 Tuber yield components of three potato varieties as influenced by nitrogen-phosphorus-sulfur (NPS) blended fertilizer.

Variations in potato variety had a significant (P<0.05) influence on specific gravity and dry matter content of potato tubers whereas NPS rate alone and NPS x variety interaction were not significant (P>0.05) (data not presented). The trend for the specific gravity was var. Belete (1.11kg/m^3) > var. Gudane (1.09kg/m^3) = var. Menagesha (1.08kg/m^3). The trend for the dry matter content was Belete (24.5%) = Gudane (24.1%) > Menagesha (22.6%). This result aligns with the study by Wassu (2016) who also reported high dry matter content of var. Belete compared to 17 other potato varieties grown in Ethiopia. Imbalance in plant nutrients can cause imbalance in shoot-to-root ratio and re-absorption of materials like water, nutrients, and macromolecules from tubers, which often leads to reduced tuber size and weight and increased unmarketable tubers.[23] Lemma *et al*.[24] Reported a maximum total tuber yield of 40.5t/ha for var. Belete, which is not different from the tuber yield four other varieties i.e., vars Gudane, Gabissa, Gorebella and Bedassa. The yield differences might be due to genetic factors playing an important role in stolon development and the tuberization process.

Partial budget analysis

Partial budget analysis of net benefit, total cost and marginal rate of returns are presented in Table 3. Cost and benefit information is a prerequisite for a farmer to make decision on any new technology. The results in the present study indicated that the application of NPS blended fertilizer and the introduction of new potato variety resulted in a higher net benefit (Table 3). All the economic indices increased as NPS application rate increased, irrespective of the variety. The results demonstrated a maximum net benefit (NB) of 292,812 Ethiopian Birr (equivalent to $5,741USD) and 292,630 Ethiopian Birr per hectare (equivalent to $5,738USD) with an acceptable marginal rate of returns (MRR) of 11798% and 15263% for treatment 150kg NPS/ha applied to vars Belete and Gudane, respectively (Table 3).

Although var. Belete seemed to have done best overall for agronomic performance and yield (Table 2 & Figure 3), var. Gudane seemed to be potentially more profitable for farmers as demonstrated in Table 3. The lowest NB of Birr 86616/ha was recorded by var. Menagesha in the control plot.[25]

Table 2 Days to 90% flowering, plant height and tuber yield of three potato varieties as influenced by nitrogen-phosphorus-sulfur (NPS) blended fertilizer

NPS rate (kg/ha)	Days to 90% maturity	Plant height (cm)	Mean tuber fresh weight (g)	Marketable tuber yield (t/ha)
			var. Belete	
0	110.7e	53.5f	52.5de	13.8d
50	112.0d	59.1cde	55.9de	19.5cd
100	113.4c	60.8bc	74.6a	28.0b
150	114.0c	62.6b	73.2ab	41.2a
			var. Gudane	
0	113.7c	52.5f	48.5ef	14.1d
50	115.4b	57.7de	51.5de	19.6bcd
100	116.0b	59.5cd	65.8bc	24.1bc
150	117.0a	65.7a	78.0a	41.2a
			var. Menagesha	
0	107.2g	49.8g	40.1f	12.0d
50	110.0f	57.0e	49.6e	14.5d
100	111.0c	58.8cde	59.0cd	18.6cd
150	112.0d	60.6bc	54.3de	18.3cd
CV (%)	0.30	2.30	8.6	22.6

Differences in alphabetical letters denote significant difference at P≤0.05; CV is coefficient of variation.

Table 3 Partial budget analysis of marketable tuber yield of potato as influenced by NPS fertilizer rates and Variety at Nedjo

NPS rate (kg/ha)	AMY (t/ha)	GFB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	MRR (%)
			var. Belete		
0	12.393	99144	0	99144	0
50	17.505	140040	2300	137740	1678

Table Continued...

NPS rate (kg/ha)	AMY (t/ha)	GFB (ETB/ ha)	TVC (ETB/ha)	NB (ETB/ ha)	MRR (%)
			var. Belete		
100	25.191	201528	3100	198428	7586
150	37.089	296712	3900	292812	11798
			var. Gudane		
0	12.654	101232	0	101232	0
50	17.613	140904	2050	138854	1835
100	21.672	173376	2850	170526	3959
150	37.035	296280	3650	292630	15263
			var. Menagesh		
0	10.827	86616	0	86616	0
50	13.05	104400	2050	102350	768
100	16.704	133632	2850	130782	3554
150	16.488	131904	3650	128254	D

AMY, Adjusted marketable yield; GFB, Gross field benefit; TVC, Total variable cost; NB, Net benefit; MRR, Marginal rate of return; D, Dominated treatments; NPS cost, 16 Birr kg^{-1}. The selling price of potato at the local market at the harvest time was estimated at Birr 800/quintal, and average purchasing costs for different variety of potato seed = Birr 13/kg.

Conclusion

The three different potato varieties i.e., vars Belete, Gudane and Menagesha differentially responded to the different application rates of NPS blended fertilizer. In terms of agronomic performance including total yield and proportion of marketable yield, there was a consistent trend where var. Belete followed by var. Gudane performed better than var. Menagesha, especially as NPS rate increases from 0 to 150kg/ha. The *ca*. 41.2t/ha achieved by applying 150kg NPS/ha to vars Belete and Gudane is comparable to yields in major growing countries like USA (47.2t/ha), Netherlands (45.7t/ha) and Japan (47.7t/ha).[10] Potato quality indices like specific gravity and dry matter content were all high in var. Belete compared to vars Gudane and Menagesha. This implies var. Belete will be good for processing, but for a return on investment, var. Gudane will be a good candidate for farmers and for use as a cooking potato. However, this study needs to be repeated under different agro-ecological zones in Nedjo district of Ethiopia prior to recommendation to farmers.[26]

Acknowledgements

The authors acknowledge the Agricultural Transformation through Stronger Vocational Education (ATTSVE) for providing training for this study.

Funding

The authors acknowledge Global Affairs Canada for providing funding for this study through the ATTSVE Project.

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Citation: Dereje A, Abebe T, Haile Y, et al. Growth and yield responses of potato (*Solanum tuberosum L.*) varieties to NPS blended fertilizer at Nedjo, Western Ethiopia. *Horticult Int J.* 2022;6(2):77–82. DOI: 10.15406/hij.2022.06.00245