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Response of Potato (*Solanum tuberosum* L.) Varieties to Blended Nitrogen, Phosphorus and Sulfur Fertilizer Rate at Kokate, Southern Region

Asfaw Berhanu Sadebo [a], Gobeze Loha Yada [a*], Asfaw Kifle Wadole [b] and Abrham Bosha [c]

[a] *Department of Plant Sciences, Wolaita Sodo University, Wolaita Sodo, Ethiopia.*
[b] *Areka Agricultural Research Center, Areka, Ethiopia.*
[c] *Department of Horticulture, Wolaita Sodo University, Wolaita Sodo, Ethiopia*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Low production and productivity of potato in Ethiopia is associated with poor soil fertility and limitation of high yielding crop variety. Matching high yielding cultivar with optimum fertilization of balanced nutrients is of paramount important to boost tuber yield of potato. Hence, a field experiment was conducted during 2019/20 cropping season at Kokate testing site of Areka Agricultural Research Center in southern Ethiopia in order to evaluate the response of potato varieties to NPS fertilizer rates. Treatments used in the study were two improved varieties of potato (Gudane and Belete) one local cultivar with six rates of blended NPS (0, 50, 100, 150, 200 and 250 kg/ha NPS) combined in factorial and laid out in a randomized complete block design with three replications. As this investigation indicated that at all rates of NPS fertilizer, improved varieties out yielded the local cultivar Asmara with relative superiority of variety Belete for marketable tuber yield. Economic analysis revealed that the highest net benefit of 276326 Birr/ha with marginal rate of return (MRR) 3762% was obtained from variety Belete at NPS fertilizer rate of 200 kg/ha followed by variety Gudane at the same fertilizer rate with net benefit of 270350 Birr/ha and MRR of 3372%. Based on this finding, varieties Belete and Gudane could be used for production at NPS fertilizer rate of 200 kg/ha near study area and similar agro-ecologies.

**Corresponding author: Email: gobezeyada@gmail.com;*

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1. INTRODUCTION

Potato (*Solanum tuberosum* L) is one of humankind's most valuable food crops covering a major part of the diets of more than a billion consumers globally [1]. It contains about 79% water, 18% starch as a good source of energy, 2% protein and 1% vitamins including vitamin C, minerals including calcium and magnesium and many trace elements [2]. Potato is a high potential food security crop in Ethiopia due to its high yield potential, nutritional quality, short growing period and wider adaptability [3]. Thus, it is grown in many parts of the country. In *meher* season (June to October) the production area for potato has reached about 69,610.81 ha with total yields of 968,969.6 ton that cultivated by over 1.12 million households. On the other hand, the average national tuber yield 13.9 t/ha is low as compared to world's average which is 19.6 t/ha and to other potato producing countries of the world such as New Zealand (48.98 t/ha), Netherlands (41.99 t/ha), South Africa (36.09 t/ha), Egypt (27.24 t/ha), and Morocco (29.33 t/ha) [4].

Low production and productivity of potato in Ethiopia is associated with different factors, such as poor soil fertility, variety, environmental conditions and cultural practices where fertilizer application has prominent effects on the quality and tuber yield of potato [5,6]. Deficiency of any or combinations of nitrogen (N), phosphorus (P) and potassium (K) can result in retarded growth or complete crop failure under severe cases [7]. This might be caused by land degradation due to up slop cultivation, flooding, soil acidity, low rate of technology adoption by farmers, low inherited soil fertility, limited use of chemical fertilizers are some major negative intervention that slow agricultural productivity in Ethiopia. Soil fertility depletion owing to high rates of erosion is considered to be the fundamental biophysical root cause for declining per capita food production in Africa, including Ethiopia in the fields of smallholders [8]. Balanced fertilization guarantees optimal crop production, better quality product and benefits for growers with supposed best solution for minimizing the risk of nutrient imbalances. Nutrients such as N, P and S can often be included in new fertilizer formula and the use of balanced fertilizers in deficient soils can improve fertilizer-use efficiency and crop profitability [9]. Although potato is a major crop produced near experimental area, its productivity is less than its actual and potential yield due to poor fertility of the soil owing to leaching of major nutrients, fixation of P, constraints of soil acidity, high cost of planting materials, disease and pest and unavailability of high yielding variety. Generally, there is little information on blended NPS fertilizer rates on potato production. Hence, this trial was initiated to evaluate the response of potato varieties to NPS fertilizer rates.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

Field experiment was conducted during 2019/20 cropping season at Kokate testing site of Areka Agricultural Research Center in southern Ethiopia. An approximate geographical coordinates of the site is 6°52'42'' N latitude and 37°48'25' E longitude having an altitude of 2150 *m.a.s.l.* The mean annual rainfall of the area ranges in between 1200-1300 mm and the daily mean temperature are 18-28^{0}C. The soil type of the experimental site is classified as clay loam textural class with soil pH of 5.1 [10].

2.2 Treatments and Experimental Design

Treatments consisted in two improved varieties of potato (Gudane and Belete) and one local cultivar with its name Asmara and six rates of blended NPS rates (0, 50, 100, 150, 200 and 250 kg/ha NPS). The treatments were combined in factorial and laid out in a randomized complete block design (RCBD) with three replications. The potato varieties Gudane (CIP-386423.13) and Belete (CIP393371.58) were released by Holeta Agricultural Research Center with good adaptability to altitude ranges of 1600-2800 masl with days to maturity of 110-120. Plot size was 3.75 m wide and 3 m long with total gross area of 11.25 $m^{2.}$ Blended fertilizer NPS which constituted in 19% N, 38% P_2O_5 and 7% S was used and applied as proposed per plot at planting. The experimental field was ploughed, pulverized and leveled in order to get smooth seed bed. Planting was carried out using well sprouted potato tubers. All crop management practices such as cultivation, weeding etc., carried out as desired. Diseases and insect damages were visually monitored during the crop growing season.

2.3 Data Collection and Measurements

Days to flowering was recorded when 50% of plants per plot extrude flowering. Days to physiological maturity was recorded when 90% of the plants per plot ready for harvest as indicated by the senescence of the haulms. Plant height was measured from ground level to apex for five randomly selected plants per plot at flowering. Number of stems and tubers per hill per hill were determined by counting for five randomly selected plants per plot at flowering and harvesting, respectively. Size categories of tubers was made by taking ten tubers randomly per plot and categorized into small (< 39 g), medium (39-75 g) and large (>75 g) [11] and each category was expressed in percentage. Marketable tuber yield was determined by weighing tubers harvested from central rows avoiding border effects. Tubers separated into marketable and unmarketable by farmers near trial site based on local market criteria. Unmarketable tuber yield was determined by weighing tubers that rejected by farmers with respect to local market criteria. Total tubers yield was determined as summation of marketable and unmarketable tuber yield. Dry matter content of tuber was determined by taking ten tubers from each plot and chopping into small pieces of 1-2 cm, mixed thoroughly and two sub-samples each weighing 200 g was weighed. The exact weight of each sub-sample was determined and recorded as a fresh weight. Each sub-sample was placed in a paper bag and subjected to an oven drying at 72^{o}C for 72 hours until constant dry weight was attained by checking the weight at intervals. Each sub-sample was immediately weighed and recorded as dry weight. Then, percent dry matter content for each sub-sample was calculated as:

$$\text{Dry matter (\%)} = \frac{\text{Weigt of sample after drying (g)}}{\text{Intial weigt of sample (g)}} \text{ x } 100$$

Specific gravity was determined as the ratio of the tuber weight in air to the tubers weight in water. Tubers of all shapes and size categories which weighed about 3-5 kg were randomly taken from each plot. The selected tubers were washed with water and then the samples were first weighed in air and re-weighed suspended in water. Specific gravity was then calculated using the following formula [12] as:

$$\text{Specific gravity} = \frac{\text{Weight in air (kg)}}{\text{Weight in air (kg)} - \text{Weight in water}} \text{ x100}$$

Total starch content as calculated from the specific gravity using the following equation [13] as:

Starch (% or g/100 g) =17.546 +199.07 × (specific gravity-1.0988)

For economic analysis, the mean grain yields of the treatments were used in partial budget analysis and for each pair of ranked treatments of MRR was calculated [14] as:

MRR (%)=

$$\text{MRR (\%)} = \frac{\text{Change in NB (NBb} - \text{NBa)}}{\text{Change i TCV (TCVb} - \text{TCVa)}} \text{ x } 100$$

Where, NBa = NB with the immediate lower TCV, NBb, = NB with the next higher TCV, TCVa

= the immediate lower TCV and TCVb = the next highest TCV. The field price of 1 kg of potato tuber yield at the time of harvesting in December 2019 was taken as 8 Birr/kg based on the market price of potato at Kokate near experimental site. Price of NPS that used as fertilizer source was 17.00 Birr/kg and the daily laborer expense was 60 Birr. All data collected were subjected to analysis of variance using SAS version 9.3 [15] and whenever the effects of the treatments were found to be significant the means were compared using the least significant differences (LSD) test at 5% probability level.

3. RESULTS AND DISCUSSION

3.1 Days to Flowering and Physiological Maturity

The main effect of varieties had significant effect on days to flowering and physiological maturity (Table 1). Days to flowering ranged from 54.43 to 61.38 whereas the days to physiological maturity from 99.36 to 110.16. The longest days to flowering (61.38) and physiological maturity (110.16) were observed for variety Gudane followed by variety Belete with mean days to flowering of 58.05 and physiological maturity of 109.34. The shortest days to flowering (53.43) and physiological maturity (99.36) were recorded for Asmara. The differences among varieties for phenological traits were probably attributed to their inherent variability. Similarly, the main effect of NPS fertilizer rates resulted in significant differences on days to flowering and physiological maturity (Table 1). Both parameters were prolonged as NPS fertilizer rates increased from 0 to 250 kg/ha indicating that increment in dosage of NPS fertilization delayed phenological traits. The difference of 12.63 and 10.79 days was observed between the highest dose and unfertilized plots with respect to days to flowering and physiological maturity, respectively.

Significant differences were detected due to effect of varieties by NPS fertilizer interactions on days to flowering and physiological maturity (Table 1). Days to flowering and physiological maturity were relatively prolonged with increasing NPS fertilizer rates. All varieties attained longer days to flowering and physiological maturity at the highest NPS fertilizer rate. The longest days to flowering (68.33) and physiological maturity (113.67) were observed for variety Gudane at NPS fertilizer rate of 250 kg/ha followed by the same variety at NPS fertilizer rate of 200 kg/ha with mean days to flowering of 66.50 and physiological maturity for variety Belete of amounted mean of 113.50. The shortest days to flowering (48.70) and physiological maturity (92.67) were recorded for Asmara from unfertilized plots (Table 1). The differences of 19.63 and 21.00 days to flowering and physiological maturity were observed between the longest and shortest days to flowering and physiological maturity, respectively. The prolonged days to flowering and physiological maturity with increasing NPS fertilizer rates might be attributed to extended vegetative growth period due to availability nutrients in soil system for plant uptakes. As this result clearly showed that potato varieties responded differently to variable rates of NPS fertilization due to their inherent variability. Local cultivar Asmara exhibited relative earliness while the improved varieties showed similarity with respect to days to flowering and physiological maturity. Similar findings [16,17] were reported that increasing rates of NPS fertilization prolonged days to flowering in potato. In contrast, it was indicated [18] that there was no significant difference on days to flowering in potato due to the application variable rates of blended fertilizer treatments.

3.2 Plant Height

The main effect of varieties showed significant differences on plant height. Plant height for potato varieties ranged from 18.35 to 63.33 cm. The tallest plant (63.33 cm) was recorded for variety Belete followed by variety Gudane with mean plant height of 62.10 cm. The shortest plant height (18.35 cm) was seen for Asmara (Table 2). The variation in plant height among the varieties probably attributed to genotypic variability among varieties. It was reported [19] that height of the crop plants is mainly controlled by the genetic makeup of a genotype and it can also be affected by the environmental factors. Similarly, the main effect of NPS fertilizer rates resulted in significant differences on plant height. Generally, plant height tended to increase as NPS fertilizer rates increase from 0 to 250 kg/ha. The tallest plant height (56.67 cm) was observed at NPS fertilizer rate of 250 kg/ha followed by NPS fertilizer rate of 200 kg/ha with mean plant height of 53.77 cm. The shortest plant height (38.92 cm) was achieved from unfertilized plots (Table 2). Likewise, significant differences were detected due to effect of varieties by NPS fertilizer rates interactions on plant height. Plant height was relatively improved with increasing NPS fertilizer rates all varieties where all varieties had higher plant heights at the highest NPS fertilizer rate. The tallest plant height (75.30 cm) was observed for variety Belete at NPS fertilizer rate of 250 kg/ha followed by variety Gudane at the same fertilizer rate with mean plant height of 73.10 cm. The shortest plant height (15.06 cm) was recorded for Asmara from unfertilized plots (Table 2).

3.3 Number Stems and Tubers Per Hill

The main effect of varieties showed significant differences on number of stems per hill and tubers per plant. Variety Belete yielded the highest number of stems per hill (4.63) and tubers per plant (10.10) followed by variety Gudane with mean number of stems per hill of 4.37 and tubers per plant of 8.77. The lowest number of stems per hill (4.07) and tubers per plant (7.82) were recorded for cultivar Asmara (Table 2). Potato varieties produced variable number of stems per hill attributed to their inherent differences [20]. Similarly, the main effect of NPS fertilizer rates had significant differences on number of stems per hill and tubers per plant. Number of stems per hill as affected by main effect of NPS fertilizer rates ranged from 2.98 to 5.88 whereas tubers per plant from 5.95 to 12.27. The greatest number of stems per hill (5.88) and tubers per plant (12.27) were recorded at NPS fertilizer rate of 250 kg/ha followed by NPS fertilizer rate of 200 kg/ha with mean number of stems per hill 5.18 and tubers per plant of 11.12. The lowest number of stems per hill (2.98) and tubers per plant (5.95) were obtained from unfertilized plots (Table 2). Increasing NPS fertilization rates led to increased production of number of stems per hill [21,17]. On the other hand, investigations [22,23,16] have shown that mineral fertilizers like N and P fertilization did not have significant effect on the number of stems per hill of potato. Conversely, varieties by NPS fertilizer rates interactions did not have significant effect on number of stems per hill and tubers per plant (Table 2).

Table 1. Days to flowering and physiological maturity as affected by varieties and NPS rates

Varieties	NPS rates (kg/ha)	Days to Flowering	Days to physiological maturity
	0	54.00^{gh}	104.63^{g}
	50	56.46^{ef}	108.17^{ef}
Gudanie	100	59.70^{d}	110.27^{d}
	150	63.30^{c}	111.80^{bcd}
	200	66.50^{ab}	112.40^{abc}
	250	68.33^{a}	113.67^{a}
	0	51.30^{ij}	104.00^{g}
	50	53.23^{hi}	106.50^{f}
Belete	100	55.80^{fg}	108.33^{e}
	150	59.50^{d}	111.30^{cd}
	200	63.20^{c}	112.40^{abc}
	250	65.30^{bc}	113.50^{ab}
	0	48.70^{k}	92.67^{k}
	50	50.36^{jk}	95.67^{j}
Asmara l	100	52.46^{hij}	97.67^{i}
	150	54.30^{fgh}	100.33^{h}
	200	56.50^{ef}	103.33^{g}
	250	58.26^{de}	106.50^{f}
	LSD	2.22	1.73
	Gudanie	61.38^{a}	110.16^{a}
Variety means	Belete	58.05^{b}	109.34^{b}
	Asmara	53.43^{c}	99.36^{c}
	LSD	0.90	0.70
	0	51.33^{f}	100.43^{f}
	50	53.35^{e}	103.44^{e}
NPS rate means	100	55.98^{d}	105.42^{d}
	150	59.03^{c}	107.81^{c}
	200	62.06^{b}	109.38^{b}
	250	63.96^{a}	111.22^{a}
	LSD	1.28	1.00
	CV (%)	2.33	0.99

Means followed by different letters within a column are significantly different at 5% probability level

Table 2. Plant height, stems per hill and tuber per hill as affected by varieties and NPS rates

Varieties	NPS rates (kg/ha)	Plant height (cm)	Stems per hill	Tuber per hill
	0	50.16^{g}	2.96	6.00
	50	54.63^{f}	3.56	6.76
Gudane	100	59.80^{e}	4.03	7.63
	150	64.93^{d}	4.56	9.36
	200	70.00^{c}	5.23	10.63
	250	73.10^{ab}	5.90	12.26
	0	51.33^{g}	3.13	6.50
	50	55.63^{f}	3.80	7.40
Belete	100	60.30^{e}	4.30	8.73
	150	66.23^{d}	4.76	10.80
	200	71.00^{bc}	5.56	13.26

Varieties	NPS rates (kg/ha)	Plant height (cm)	Stems per hill	Tuber per hill
	250	75.30^{a}	6.23	3.93^{a}
	0	15.06^{l}	2.86	5.36
	50	16.10^{kl}	3.23	6.23
Asmara	100	17.76^{jk}	3.73	7.13
	150	19.20^{ij}	4.33	8.13
	200	20.33^{hi}	4.76	9.46
	250	21.63^{h}	5.53	10.63
	LSD	2.30	NS	NS
	Gudanie	62.10^{b}	4.37^{b}	8.77^{b}
Variety means	Belete	63.33^{a}	4.63^{a}	10.10^{a}
	Asmara	18.35^{c}	4.07^{c}	7.82^{c}
	LSD	0.94	0.19	0.59
	0	38.92^{f}	2.98^{f}	5.95^{f}
	50	42.12^{e}	3.53^{e}	6.80^{e}
NPS rate means	100	45.95^{d}	4.02^{d}	7.83^{d}
	150	50.12^{c}	4.55^{c}	9.43^{c}
	200	53.77^{b}	5.18^{b}	11.12^{b}
	250	56.67^{a}	5.88^{a}	12.27^{a}
	LSD	1.33	0.28	0.83
	CV (%)	2.90	6.74	9.80

Means followed by different letters within a column are significantly different at 5% probability level, NS= not significant

Table 3. Tuber size distribution as affected by varieties and NPS rates

Varieties	NPS rates (kg/ha)	Tuber size distribution (%)		
		Small	Medium	Large
	0	62.41	17.23	23.23^{g}
	50	41.30	22.81	32.42^{f}
Gudane	100	30.28	26.68	36.55^{ef}
	150	27.01	30.63	43.20^{cde}
	200	23.64	34.26	44.61^{cd}
	250	13.49	42.53	52.86^{bc}
	0	83.16	20.64	25.38^{g}
	50	77.20	24.91	34.38^{f}
Belete	100	57.30	28.34	42.03^{de}
	150	27.78	32.16	44.35^{cd}
	200	20.08	34.64	49.86^{bc}
	250	17.39	47.01	64.11^{a}
	0	97.58	2.32	0.00^{h}
	50	94.18	4.30	0.00^{h}
Asmara	100	88.45	5.94	0.00^{h}
	150	49.28	7.82	0.00^{h}
	200	41.19	11.86	0.36^{h}
	250	38.00	17.02	1.76^{h}
	LSD	NS	NS	6.81
	Gudane	33.02^{c}	29.02^{a}	38.81^{b}
Variety means	Belete	41.15^{b}	31.28^{a}	43.35^{a}
	Asmara	68.11^{a}	8.21^{b}	0.35^{c}
	LSD	12.84	2.30	2.78
	0	81.05^{a}	13.39^{e}	16.20^{e}
	50	70.89^{ab}	17.34^{d}	22.26^{d}
NPS rate means	100	58.67^{b}	20.32^{cd}	26.19^{cd}
	150	34.69^{c}	23.54^{c}	29.18^{bc}
	200	28.30^{c}	26.92^{b}	31.61^{b}

Varieties	NPS rates (kg/ha)	Tuber size distribution (%)		
		Small	Medium	Large
	250	22.96[c]	35.52[a]	39.57[a]
	LSD	18.16	3.25	3.93
	CV (%)	38.35	14.88	14.94

Means followed by different letters within a column are significantly different at 5% probability level, NS= not significant

3.4 Tuber Size Distribution

The main effect of varieties showed significant differences on proportion of small, medium and large sized tubers. Cultivar Asmara yielded the highest proportion of small sized tubers (68.11%) while variety Belete yielded the highest proportion of medium (31.28%) and large sized tubers (43.35). The lowest proportion of small sized tubers (33.02%) was recorded for variety Gudane. Cultivar Asmara produced 8.21% medium and 0.35% large sized tubers (Table 3). In line with this, the main effect of NPS fertilizer rates had significant differences on proportion of small, medium and large sized tubers. The greatest proportion of small sized tubers (81.05%) was recorded from unfertilized plots. The lowest proportion of small sized tuber (22.96%) was obtained from 250 kg/ha (Table 3). However, varieties by NPS fertilizer rates interactions did not have significant effect on proportion of small and medium sized tubers (Table 3). In contrast, significant differences were detected due to effect of varieties by NPS fertilizer interaction on proportion of large sized tuber (Table 3). Proportion of large sized tubers was relatively increased with increasing NPS fertilizer rates for all varieties where all varieties had higher large sized tubers at the highest NPS fertilizer rate. The highest proportion of large sized tuber (64.11%) was observed for variety Belete at NPS fertilizer rate of 250 kg/ha followed by variety Gudane at the same fertilizer rate with mean proportion of large sized tubers of 52.86%. Cultivar Asmara yielded nearly no large sized tubers (Table 3). This was probably an indication that tuberliation is essentially influenced by availability nutrients. Concomitant result [24] was reported that the proportion of small-sized tubers reduced with increasing the nutrient dosage.

3.5 Marketable Tuber Yield

The main effect of varieties showed significant differences on marketable tuber yield. The highest marketable tuber yield (35.35 t/ha) was recorded for variety Belete followed by variety Gudane with mean marketable tuber yield of 33.61 t/ha. The lowest marketable tuber yield (22.63 t/ha) was seen for Asmara (Table 4). The variation in marketable tuber yield among the varieties probably attributed to genotypic variation among varieties. Similarly, the main NPS fertilizer rates resulted in significant differences on marketable tuber yield. Generally, marketable tuber yield tended to increase with increasing NPS fertilizer rates from 0 to 250 kg/ha. The highest marketable tuber yield (36.95 t/ha) was observed at NPS fertilizer rate of 250 kg/ha followed by NPS fertilizer rate of 200 kg/ha with mean marketable tuber yield of 35.62 t/ha. The lowest marketable tuber yield (22.04 t/ha) was achieved from unfertilized plots (Table 4). Likewise, significant differences were detected due to effect of varieties by NPS fertilizer rates interactions on marketable tuber yield. Marketable tuber yield was relatively improved with increasing NPS fertilizer rates for all varieties where all varieties had higher marketable tuber yield at the highest NPS fertilizer rate. At all levels of NPS fertilizer, improved varieties out yielded the local cultivar Asmara with relative superiority of variety Belete. The highest marketable tuber yield (43.55 t/ha) was observed for variety Belete at NPS fertilizer rate of 250 kg/ha followed by variety Gudane at the same fertilizer rate with mean marketable tuber yield of 40.58 t/ha. The lowest marketable tuber yield (12.84 t/ha) was recorded for Asmara from unfertilized plots (Table 4). The unfertilized plots produced the lowest marketable tuber yield of potato probably due to the absence of adequate nutrient level needed for proper growth, development and yield. Moreover, the linear regression $Y = 25.56 + 0.064X_1$ with R^2=0.97 (Gudane), $Y = 27.69+ 0.061X_2$ with R^2=0.98 (Belete) and $Y= 16.23+ 0.051X_3$ R^2=0.80 (Asmara) were significant ($P \le 0.05$) indicated that potato varieties exhibited responsiveness to different rates NPS fertilizer rates (Fig. 1). As this analysis showed that marketable tuber yield was increased at rate of 0.064 for variety Gudane, 0.061 for Belete and 0.051 for Asmara within NPS fertilizer rates of 0 to 250 kg/ha. Hence, NPS fertilizer rate optimization is essential for marketable tuber yield of potato which is an indication that varieties reacted differently to variable rates of

NPS fertilizer rates due to their inherent variability. Comparable result [17, 23] was recorded that the application of NPS fertilizer at the rate of 272 kg/ha gave the marketable tuber yield of 47.02 t/ha of potato.

3.6 Unmarketable Tuber Yield

The main effect of varieties resulted in significant differences on unmarketable tuber yield. The highest unmarketable tuber yield (2.10 t/ha) was recorded for Asmara followed by variety Belete with mean unmarketable tuber yield of 1.54 t/ha. The lowest unmarketable tuber yield (1.21 t/ha) was seen for variety Gudane (Table 3). Similarly, the main NPS fertilizer rates resulted in significant differences on unmarketable tuber yield. The highest unmarketable tuber yield (2.04 t/ha) was observed at NPS fertilizer rate of 200 kg/ha followed by NPS fertilizer rate of 250 kg/ha with mean unmarketable tuber yield of 1.80 t/ha. The lowest unmarketable tuber yield (1.17 t/ha) was achieved from unfertilized plots (Table 4). Likewise, significant differences were detected due to effect of varieties by NPS fertilizer rates interactions on unmarketable tuber yield. Unmarketable tuber yield exhibited inconsistency for all varieties as NPS fertilizer rates increased from 0 to 250 kg/ha. The highest unmarketable tuber yield (3.17 t/ha) was observed for cultivar Asmara at NPS fertilizer rate of 200 kg/ha followed by the same cultivar at NPS fertilizer rate of 50 kg/ha with mean unmarketable tuber yield of 2.73 t/ha. The lowest unmarketable tuber yield (0.57 t/ha) was observed for variety Gudane from unfertilized plots (Table 4). It was reported [25] that unmarketable tuber yield of potato was variable in response to different rates of NPS fertilizer.

3.7 Total Tuber Yield

The main effect of varieties had significant differences on total tuber yield. The highest total tuber yield (36.89 t/ha) was recorded for variety Belete followed by variety Gudane with mean total tuber yield 34.82 t/ha. The lowest total tuber yield (24.74 t/ha) was seen for cultivar Asmara (Table 4). The yield differences among varieties might be related to their genetic makeup in the efficient utilization of inputs like nutrients [26]. Similarly, the main NPS fertilizer rates resulted in significant differences on total tuber yield. Generally, total tuber yield tended to increase with increasing NPS fertilizer rates from 0 to 250 kg/ha. The highest total tuber yield (38.75 t/ha) was observed at NPS fertilizer rate of 250 kg/ha followed by NPS fertilizer rate of 200 kg/ha with mean total tuber yield of 37.67 t/ha. The lowest total tuber yield (23.22 t/ha) was achieved from unfertilized plots (Table 4). In line with this, significant differences were detected due to effect of varieties by NPS fertilizer interactions on total tuber yield. Total tuber yield was relatively tended to increase with increasing NPS fertilizer rates from 0 to 250 kg/ha for all varieties with relative superior performance of variety Belete over others. Varieties Gudane and Belete had higher total tuber yield at NPS fertilizer rate of 250 kg/ha whereas cultivar Asmara yielded higher total tuber yield at NPS fertilizer rate of 200 kg/ha. At peak a yield advantage 36.30% for variety Gudane and 47.98% for Belete over local cultivar Asmara. Regarding the overall effect, the highest total tuber yield (45.46 t/ha) was observed for variety Belete at NPS fertilizer rate of 250 kg/ha followed by variety Gudane at the same fertilizer rate with mean total tuber yield of 41.87 t/ha. The lowest total tuber yield (14.34 t/ha) was recorded for Asmara from unfertilized plots (Table 4). This investigation indicated that both improved varieties were better than local cultivar Asmara with superior performance of variety Belete.

3.8 Dry Matter Content, Specific Gravity and Total Starch Content

The main effect of varieties showed significant differences on dry matter content, specific gravity and total starch content of tubers. The highest dry matter content of tuber (19.39%) was recorded for variety Gudane whereas the highest specific gravity (1.095 g/cm^3) and total starch content (16.93 g/100g) were observed for variety Belete. The lowest dry matter content of tuber (17.16%), specific gravity (1.040 g/cm^3) and total starch content (5.96 g/100g) were obtained from Local cultivar (Table 5). It was reported [27] that dry matter content and specific gravity were influenced by the environment and genotypes. Similarly, the main effect of NPS fertilizer rates resulted in significant differences on dry matter content, specific gravity and total starch content (Table 5). Generally, all quality parameters exhibited the tendency of increasing with increasing NPS fertilizer rates from 0 to 250 kg/ha. The highest dry matter content of tuber (20.44%), specific gravity (1.100 g/cm^3) and total starch content (17.94 g/100g) were observed at NPS fertilizer rate of 250 kg/ha. The lowest dry matter content of tuber (16.89%), specific gravity (1.04 g/cm^3) and total starch content (6.70

g/100g) were achieved from unfertilized plots (Table 5). The increase in tuber dry matter content in response to increasing rates of NPS fertilization signifies the importance of balanced nutrient application for production of potato tubers with high dry matter content. Likewise, significant differences were detected due to effect of varieties by NPS fertilizer interactions on dry matter content, specific gravity and total starch content of tubers (Table 5). Generally dry mater content, specific gravity and total starch content tended to increase for all varieties with increasing NPS fertilizer rates from 0 to 250 kg/ha. All varieties attained higher dry matter content, specific gravity and total starch content at the highest NPS fertilizer rate where the improved varieties out-yielded the local cultivar Asmara at all levels of NPS fertilizer for quality traits. The highest dry matter content of tuber (22.35%) was observed for variety Gudane at NPS fertilizer rate of 250 kg/ha whereas specific gravity (1.153 g/cm^3) and total starch content (28.40 g/100g) were observed for variety Belete at NPS fertilizer rate of 250 kg/ha. The lowest dry matter content of tuber (16.05%), specific gravity (1.030 g/cm^3) %) and total starch content (3.98 g/100g) were recorded for Asmara from unfertilized plots (Table 4).

Potato cultivars with a dry matter content of ≥ 20% are the most preferred for processing [28]. Based on this criteria, varieties Gudane and Belete mate the demand at NPS fertilizer rate of 200 and 250 kg/ha whereas local cultivar Asmara failed to meet the demand at all levels of NPS fertilizer rates. Likewise, specific gravity is the measure of choice for estimating dry matter, total solids and starch content and ultimately for determining the processing quality of potato varieties [29,30]. It was reported [31] that potato tuber with specific gravity greater than 1.08 g/cm^3 are the most preferred for processing of tuber into different potato products. Based on this criteria, variety Gudane at NPS fertilizer rate ≥ 150 kg/ha and variety Belete at NPS fertilizer rate of ≥ 100 kg/ha mate the demand of processing while local cultivar Asmara at all levels of NPS fertilizer rates failed to fulfill the criteria. In line with this, starch in tubers is responsible for potato sensory, cooking and processing properties [32]. The mash quality, the mealiness and texture of cooked potatoes are affected by the tuber starch content. Moreover, the starch content in tubers affects tuber bruise susceptibility, which in turn depends on the size of the starch cells [30]. For the processing industry, the optimal tuber starch content better to be ≥ 15 g/100g. Based on this grouping, variety Gudane fulfilled the criteria at NPS rate of ≥ 200 kg/ha whereas variety Belete at ≥ 150 kg/ha NPS fertilizer. However, local cultivar Asmara failed to meet the criteria at all levels of NPS fertilizer rates (Table 5).

Table 4. Marketable, unmarketable and total tuber yield as affected by varieties and NPS rates

Varieties	NPS rates (kg/ha)	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	Total tuber yield (t/ha)
	0	25.31^{i}	0.57^{j}	25.88^{j}
	50	27.59^{g}	1.28^{g}	28.87^{i}
Gudane	100	33.77^{e}	0.93^{i}	34.70^{f}
	150	35.15^{d}	1.69^{e}	36.85^{d}
	200	39.25^{c}	1.49^{f}	40.74^{c}
	250	40.58^{b}	1.29^{g}	41.87^{b}
	0	27.98^{g}	1.46^{f}	29.44^{i}
	50	30.73^{f}	1.26^{g}	31.99^{g}
Belete	100	34.25^{e}	1.67^{e}	35.92^{e}
	150	35.52^{d}	1.47^{f}	36.99^{d}
	200	40.08^{b}	1.47^{f}	41.55^{b}
	250	43.55^{a}	1.91^{d}	45.46^{a}
	0	12.84^{l}	1.50^{f}	14.34^{m}
	50	20.95^{k}	2.73^{b}	23.68^{l}
Asmara	100	23.67^{j}	1.14^{h}	24.81^{k}
	150	24.06^{j}	1.86^{d}	25.93^{j}
	200	27.55^{g}	3.17^{a}	30.72^{h}
	250	26.72^{h}	2.22^{c}	28.94^{i}
	LSD	0.66	0.06	0.66

Varieties	NPS rates (kg/ha)	Marketable tuber yield (t/ha)	Unmarketable tuber yield (t/ha)	Total tuber yield (t/ha)
	Gudanie	33.61^{b}	1.21^{c}	34.82^{b}
Variety means	Belete	35.35^{a}	1.54^{b}	36.89^{a}
	Asmara	22.63^{c}	2.10^{a}	24.74^{c}
	LSD	0.27	0.02	0.27
	0	22.04^{f}	1.17^{f}	23.22^{f}
	50	26.42^{e}	1.75^{c}	28.18^{e}
NPS rate means	100	30.56^{d}	1.25^{e}	31.81^{d}
	150	31.58^{c}	1.67^{d}	33.26^{c}
	200	35.62^{b}	2.04^{a}	37.67^{b}
	250	36.95^{a}	1.80^{b}	38.75^{a}
	LSD	0.38	0.03	0.38
	CV (%)	1.31	2.26	1.25

Means followed by different letters within a column are significantly different at 5% probability level

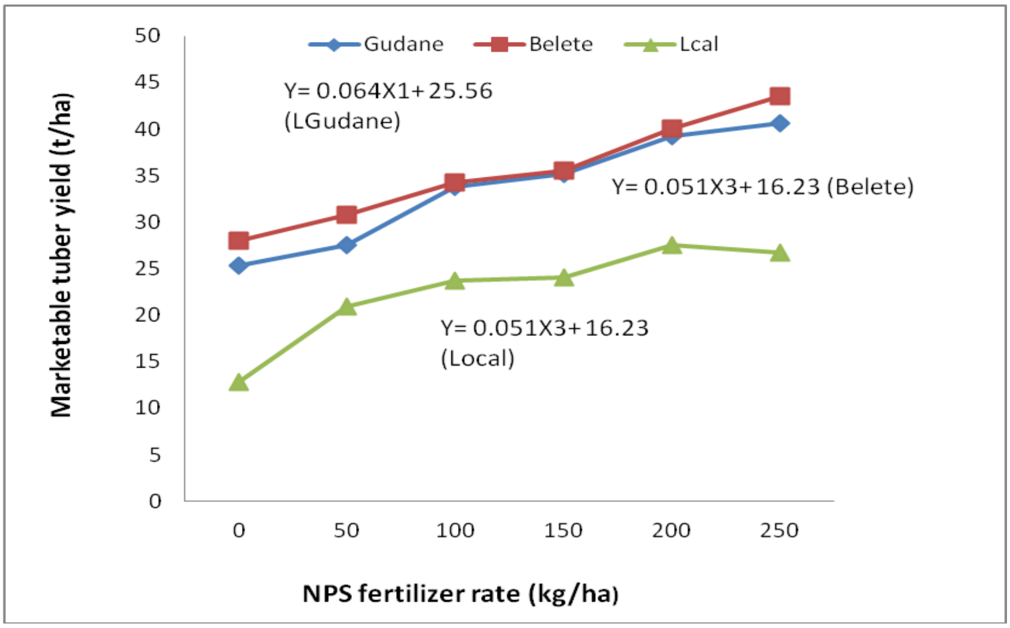

Fig. 1. Correlation of marketable tuber yield of potato varieties with NPS fertilizer rates

Table 5. Dry matter content, specific gravity and total starch content as affected by varieties and NPS rates

Varieties	NPS rates (kg/ha)	Dry matter content (%)	Specific gravity (g/cm^3)	Total starch content (g/100g)
	0	17.22^{ij}	1.046^{ijk}	7.10^{ijk}
	50	18.06^{fgh}	1.054^{hi}	8.69^{hi}
Gudane	100	18.98^{de}	1.064^{gh}	10.61^{gh}
	150	19.53^{cd}	1.080^{ef}	13.87^{ef}
	200	20.20^{bc}	1.088^{cde}	15.46^{cde}
	250	22.35^{a}	1.097^{c}	17.90^{c}
	0	17.41^{hij}	1.056h^{i}	9.02^{hi}
	50	18.62^{ef}	1.075^{fg}	12.87^{fg}
Belete	100	18.91^{de}	1.083^{def}	14.46^{def}
	150	19.53^{cd}	1.093^{cd}	16.46^{cd}
	200	20.25^{b}	1.113^{b}	20.37^{b}
	250	20.66^{b}	1.153^{a}	28.40^{a}
Asmara	0	16.05^{l}	1.030^{l}	3.98^{l}

Varieties	NPS rates (kg/ha)	Dry matter content (%)	Specific gravity (g/cm^3)	Total starch content (g/100g)
	50	16.44^{kl}	1.033^{l}	4.45^{l}
	100	16.96^{jk}	1.038^{kl}	5.44^{kl}
	150	17.46^{hij}	1.042^{jkl}	6.24^{jkl}
	200	17.76^{ghi}	1.048^{ijk}	7.43^{ijk}
	250	18.33^{efg}	1.052^{ij}	8.23^{ij}
	LSD	0.68	0.01	2.27
	Gudane	19.39^{a}	1.071^{b}	12.15^{b}
Variety means	Belete	19.23^{a}	1.095^{a}	16.93^{a}
	Asmara	17.16^{c}	1.040^{c}	5.96^{c}
	LSD	0.27	4.66	0.92
	0	16.89^{f}	1.044^{f}	6.70^{f}
NPS rate means	50	17.70^{e}	1.054^{e}	8.67^{e}
	100	18.28^{d}	1.061^{d}	10.17^{d}
	150	18.84^{c}	1.071^{c}	12.19^{c}
	200	19.40^{b}	1.083^{b}	14.42^{b}
	250	20.44^{a}	1.100^{a}	17.94^{a}
	LSD	0.39	6.60	1.31
	CV (%)	2.21	0.64	11.74

Means followed by different letters within a column are significantly different at 5% probability level

Table 6. Profitability as affected by varieties and NPS rates

Varieties	Blended NPS rates (kg/ha)	Total revenue (ETB)	Net profit (ETB)	MRR (%)
	0	182232	173432	-
	50	198648	188948	1724
Gudane	100	243144	232594	1134
	150	253080	241680	1068
	200	282600	270350	3372
	250	292176	279076	1026
	0	201456	192656	-
	50	221256	211556	2100
Belete	100	246600	236050	2881
	150	255744	244344	975
	200	288576	276326	3762
	250	313560	300460	2839
	0	92448	83648	-
	50	150840	141140	388
Asmara	100	170424	159874	2204
	150	173232	161832	230
	200	198360	186110	2856
	250	192384	179284	-823

3.9 Economic Benefit

Economic analysis with respect to NPS fertilizer application for potato varieties is depicted in Table 6. Economic analysis is important to identify experimental treatments with an optimum return to develop recommendation optimum rate fertilizer for potato varieties. Economic analysis revealed that the highest net benefit of 276326 Birr/ha with marginal rate of return (MRR) 37621% was obtained from variety Belete at NPS fertilizer rate of 100 kg/ha followed by variety Gudane at the same NPS fertilizer rate with net benefit of 270350 Birr/ha with MRR of 3372%.

4. CONCLUSION

As this investigation indicated that at all rates of NPS fertilizer, improved varieties out yielded the local cultivar Asmara with relative superiority of variety Belete for marketable tuber yield. Hence, NPS fertilizer rate optimization is essential for marketable tuber yield and quality parameters.

Economic analysis revealed that the highest net benefit of 276326 Birr/ha with marginal rate of return (MRR) 3762% was obtained from variety Belete at NPS fertilizer rate of 200 kg/ha followed by variety Gudane at the same fertilizer rate with net benefit of 270350 Birr/ha and MRR of 3372%. Based on this finding, varieties Belete and Gudane could be used for production at NPS fertilizer rate of 200 kg/ha near study area and similar agro-ecologies. Yet, repeating the experiment over seasons and locations is also suggested for strong recommendation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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