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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Optimum rates of NPS fertilizer application for economically profitable production of potato varieties at Koga Irrigation Scheme, Northwestern Ethiopia

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Abstract: Field experiments have been conducted with the objective of identifying optimum rate of the newly introduced NPS fertilizer for profitable production of potato at Koga Irrigation Scheme, Northwestern Ethiopia. Six NPS fertilizer rates and three potato varieties which were factorial combined and laid down in Randomized Complete Block Design in three replicates were tested on two different farmlands. Most growth, yield, and yield components of potato were increased with increasing rates of NPS fertilizer which differed with varieties and locations. Highest marketable tuber yields of *Belete* (55.37 t ha^{-1}) and *Gudene* (46.83 t ha^{-1}) varieties were recorded with the of 283.75 kg ha^{-1} NPS fertilizer in location I (soil with low phosphorous content). The yields of *Gudene* variety recorded at the range of 181.6 to 283.75 kg ha^{-1} NPS fertilizer were however statistically similar. Farmer's local potato variety on the other hand recorded the highest marketable tuber yield (28.98 t ha^{-1}) in location II (soil with high phosphorous content) supplied with 227.0 kg ha^{-1} NPS which was similar with yields at the range of 102.12 to 283.75 kg ha^{-1} NPS fertilizer. On soils with low phosphorous content, production of *Belete*, and *Gudene* varieties with application of 283.75 and 181.60 kg ha^{-1} NPS fertilizer rates, respectively, are recommended while on soils with high phosphorous content production of local, and *Gudene* varieties supplied with 136.20 and 181.60 kg ha^{-1} NPS, respectively, are recommended for higher profitability of potato production at Koga Irrigation Scheme.

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PUBLIC INTEREST STATEMENT

Potato is the most important cash and food security crop grown in the highlands of Ethiopia. It is produced both under rain fed and irrigated production systems. Despite its multifaceted importance, the productivity of potato generally in the country is very low which is mostly associated among others with inappropriate agronomic practices including use of improper fertilizer rates. Thus development of location specific fertilizer rates which depend mostly on the fertility status of the soils, are paramount necessary to boost the productivity of potato and thus the incomes and food security of the smallholder farmers in the country at large and in Amhara Region in particular.

Subjects: Agriculture & Environmental Sciences; Plant & Animal Ecology; Soil Sciences

Keywords: *Belete* variety; *Gudene* variety; marginal rate of return; tuber weight; tuber yield

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important cold season vegetables which are consumed worldwide. It is considered as inexpensive and nutritive food security crop, as it produces more dry matter, protein and calories per unit area and time than the major cereal crops (Rai & Yadav, 2005). With the global annual production of about 381.7 million tons (FAOSTAT, 2017), the Africa's potato production is reached over 30 million tons in the year 2013 (FAOSTAT, 2015).

The production of potato in Ethiopia is in increasing trend where it is concentrated mostly in mid-altitudes and highlands of the country. According to Tekalign (2006) about 70% of the agricultural land in Ethiopia is suitable for the production of potato. Potato ranks first among root and tuber crops in Ethiopia both in volume of production and consumption followed by cassava, sweet potato and yam where smallholder farmers are the major producers as food, and cash crop (Cetral Statistic Agency [CSA], 2016).

According to CSA (2016) northwestern Ethiopia where Koga Irrigation Scheme is located contributes about 40% of the national potato production. However, its productivity of the crop generally in the country (7.97 t ha^{-1}) as well as in northwestern part of the country (8.53 t ha^{-1}) is very low compared to the world average (Cetral Statistic Agency, 2016). Inappropriate agronomic practices and shortage of seed tubers of improved potato varieties are among others the major constraints of potato production in the country (Alemayehu, Tessafa, Bizuayehu, & Ayele, 2015). Moreover soil nutrient depletion, moisture stresses, diseases and insect pests are the challenges of potato producing smallholder farmers in the country (Chanie, Teshome, Temesgen, & Berihun, 2009).

Soil fertility status is among others the most important parameter that limits the yielding potentials of various crops including potato (Benepal, 1967). On the other hand, fertilizer responses of crops vary with the crop varieties used and climatic conditions of the production areas (Maity & Arora, 1980; Singh & Singh, 1995; Singh, Singh, Saimbani, & Kooner, 1993; Tisdale, Nolson, Beaton, & John, 1995). In this regard, various researches have been conducted throughout Ethiopia with the objectives of determining the fertilizer requirements of potato. The research results conducted by Tsehai (1988) indicated that application of 150 kg N and 66 kg P_2O_5 per hectare for the production of potato under rain-fed condition recorded tuber yield advantages of 32% over the unfertilized controls. An experiment conducted on clay soil in the eastern part of Ethiopia indicated that application of 87 kg N and 46 kg P_2O_5 per hectare was needed for optimum yield of potato (Beyene, 1998).

According to Ethiopian Institute of Agricultural Research [EIAR], (2000) application of 110 kg N and 90 kg P_2O_5 per hectare was required for the production of potato on black soil in central highlands. On the other hand Ayichew, Tsegaw, and Dessacha (2009) recommended application of 138 kg N and 20 kg P_2O_5 per hectare for optimum productivity of potato on vertisols at central highlands of the country.

On the other hand, the sources of plant nutrients for Ethiopian agriculture over the past five decades have been limited to urea, and Diammonium Phosphate (DAP) fertilizers which contain only nitrogen and phosphorus that may not satisfy the nutrient requirements of crops including potato. In this regard however, Shiferaw (2014) reported that Ethiopian soils lack most of the macro and micronutrients that are required to sustain optimal growth and development of crops. This is exacerbated especially by Ethiopian fertilizer rates that are below international and regional standards (Agriculture Growth Program [AGP], 2013). Consequently, the yield and productivity of crops including potato in Ethiopia are much lower than other countries.

To avert the situation the Ministry of Agriculture of Ethiopia has been recently introduced a new compound fertilizer (NPS) containing nitrogen, phosphorous and sulfur with the ratio of 19% N, 38% P_2O_5 and 7% S. This fertilizer has been currently substituted DAP in Ethiopian crop production system as main source of phosphorous (Ministry of Agriculture and Natural Resource [MoANR], 2013). The situation is even more challenging for the researchers and smallholder farmers to understand the effects and identify the optimum rates of the newly introduced NPS fertilizer that contains sulfur for economical production of crops including potato. Therefore the main objectives of the current study were to evaluate the response of potato varieties to the newly introduced NPS fertilizer in two different locations with different status of soil phosphorus content at Koga Irrigation Scheme and to track economic and agronomic optimum rates of its application.

2. Materials and methods

2.1. Description of the study area

The study was conducted on two different farmer`s crop land during the 2015/2016 irrigation season at Koga Irrigation Scheme. It is one of the irrigation schemes developed by the government of Ethiopia to enhance the production and productivity of horticultural crops in northwestern Ethiopia. The irrigation scheme is about 7,000 ha large and mostly used for the production of vegetables including onion, potato, tomato, pepper, cabbage, carrots and etc. by smallholder farmers using furrow irrigation system. Moreover, cereal crops like wheat, maize and etc. are also produced during the main rainy season in the scheme (Alemayehu et al., 2015). The topography of the irrigation scheme is gentle slope and it is located at 11° 10′ N to 11° 25′ N latitude and 37° 02′ E to 37° 17′ E longitude with the average altitude of about 1960 meter above sea level. According to Bahir Dar Meteorology Station report (unpublished), the area received an annual mean rainfall of about 1,395.23 mm for the last 10 years (2005–2015). The mean maximum and minimum temperatures of the area are 27 and 12.8°C, respectively.

To have insight on some of the physico-chemical properties, soil samples were taken randomly from eight spots of each experimental field at the depth of 20 cm and one composite sample for each field was prepared. The two experimental locations were about 1.5 km apart and have soil depth which is enough for the production of tuber crops. The samples were analyzed in the laboratory of Amhara Design & Supervision Works Enterprise, Soil Chemistry and Water Quality Section.

The collected soil samples were air dried in wooden tray, ground and sieved to pass through a 2 mm sieve to exclude components other than soil. The pH of the soils was determined by diluting the soil with water in 1:2.5 ratios. After equilibrating the solution for 2–3 h, the suspension was filtered and the pH was measured by a glass electrode. Organic carbon content of the soil was determined based on oxidation of organic carbon with acid dichromate medium following the Walkley and Black method as described by Horneck, Sullivan, Owen, and Hart (2011). Total nitrogen contents of the samples were determined by Micro-Kjeldahl method (Horneck et al., 2011) and soil cation exchange capacity (CEC) was determined by ammonium acetate method (Cottenie, 1980). Salinity of the sample soils was measured as electrical conductivity (EC) and expressed as decisiemens (ds/m) as described by Rhoades, Chanduvi, and Lesch (2002). Available phosphorus was also determined using Olsen method as described by Olsen and Dean (1965). Particle size (soil texture) was determined by using hydrometer method of Bouyoucos (Day, 1965).

2.2. Type of experiment and data collection

2.2.1. Experimental design and treatments

The experiment consisted of three potato varieties (two improved varieties: *Belete*, *Gudene* and one farmer`s local variety) and six levels of NPS fertilizer rates (0, 102.15, 136.20, 181.60, 227.00, and 283.75 kg ha^{-1}) which were factorial combined in two experimental locations. Since NPS fertilizer is new for Ethiopian agriculture, it lacks baseline information about the levels of NPS fertilizer to be used in this study. Thus NPS levels were therefore determined in the way that about 1/4th of phosphorous (P_2O_5) present in blanket recommendation (150 kg ha^{-1}) was added and subtracted. The treatments were arranged in Randomized Complete Block Design (RCBD) with three replications.

Each plot of the experiment was three meters wide and three meters long (3 × 3 m) and accommodated 40 plants with the spacing of 0.75 and 0.30 m between rows and plants, respectively, as recommended by EIAR (2007). Healthy, medium-sized and sprouted potato seed tubers were used for the experiment. Gibbrelic acid was sprayed for uniform sprouting of potato seed tubers. Each plot contains four rows where each rows contained ten plants.

Based on the treatments, the total quantity of NPS fertilizer was applied at the time of planting. The quantity of nitrogen in NPS fertilizer was subtracted and remaining nitrogen calculated from the blanket recommendation (290 kg ha^{-1} urea) was applied in the form of urea in two splits 25 and 50 days after planting for each treatment. Other cultural practices like weeding, irrigation intervals, cultivation and plant protection methods were done uniformly for all experimental plots as recommended by EIAR (2007).

2.2.2. Data collection and analysis

Growth and yield related parameters were collected from the net plot area of each plot to avoid border effects using the standard procedures described below. Growth parameters considered were plant height, number of stem shoots per hill, flowering, and maturity date while yield parameters were fresh weight, and dry matter content of tubers, marketable, unmarketable, and total tuber yields.

2.2.2.1. Plant height (cm): It was collected by measuring the plant heights from the soil surface to the tip of the main stem of ten randomly selected plants using ruler at physiological maturity of the crop and the mean values in cm were computed for further analysis.

2.2.2.2. Number of stem shoots per hill: It was recorded by counting the main stems of five randomly selected hills at 45 days after planting and the mean value was computed and used for further analysis.

2.2.2.3. Days to flowering and maturity (days): Days to flowering in each plot was recorded by counting the number of days elapsed from the time of planting up to the time when 50% of the plants in the plot flowered. Similarly maturity date was recorded by counting the number of days elapsed from the time of planting up to the time when the haulm of 90% of the plants in the plot dried.

2.2.2.4. Fresh and dry tuber weights (g): Fresh weight of a tuber was recorded by measuring the weights of ten randomly selected tubers in each plot using sensitive balance and the average fresh weight was computed and used for further analysis. Similarly, the average tuber dry matter content was recorded by measuring the dry matter weights of ten randomly selected tubers after drying them in oven at 110°C for 72 h and expressing it in percentage using the formula below as described by Abebe, Shermari, Thunya, and Oranch (2012).

$$\textit{Tuber dry matter}\ (\%) = \left(\frac{\text{Weight of oven dried tuber}}{\text{Fresh tuber weight}}\right) \times 100$$

2.2.2.5. Tuber yield (t ha^{-1}): Tubers which were free of mechanical, disease and insect pest damages and medium to large in size were considered as marketable. On the other hand, tubers which were damaged, small in size were considered as unmarketable as described by Tesfaye, Shermari and Thunya (2013). The weights of such tubers obtained from the net plot area of each plot was measured in kilogram using scaled balance and expressed in t ha^{-1} and considered as marketable yield as well as unmarketable tuber yield. Finally the total tuber yield was obtained from the sum of marketable and unmarketable yields.

Table 1. Physico-chemical properties of experimental soils at Koga Irrigation Scheme

Site	Soil class	pH (H_2O) 1:2.5	EC (dS/m)	CEC (cmol(+)/kg	OM (%)	TN (%)	Av. P (ppm)
Location I	Silty clay	6.08	0.14	46.00	1.21	0.06	9.75
Location II	Silty clay loam	6.58	0.20	36.00	0.67	0.03	37.50

The collected data of all parameters of potato were subjected to the analysis of variance (ANOVA) by using JMP 5 Statistical Discovery Software and mean separations were carried out using Least Significant Means Tukey HSD based on the results of ANOVA results. Moreover, local market prices of potato (seed and table potato), NPS, and urea fertilizers as well as labor costs were collected to calculate variable costs incurred in each treatment for the production of potato and used for economic analysis, where the procedures described by CIMMYT (1988) were used to evaluate the economic benefits of NPS fertilizer application for the production of potato varieties in the two different locations of the study area.

3. Results and discussion

3.1. Physico-chemical properties of the experimental soils

The results of the soil analysis are presented in Table 1. The soil of location I was silty clay while that of location II was silty clay loam (Day, 1965). As all soil have less 1.0 ds/m, they had low salt concentrations. On the other hand CEC of the soil of location II was medium while that of location I was high as indicated by Richards (1954).

According to Olsen and Dean (1965), the soil of location I had low available phosphorus while the soil of location II contained relatively high available phosphorus. The relative high available phosphorous in location II is probably associated with the pH value (6.58) which is more suitable (near neutral) for availability of phosphorous. According to Horneck et al. (2011), the soils of both locations contained generally low total nitrogen and organic matter.

3.2. Growth parameters of potato as affected by NPS application rate, variety and location at Koga Irrigation Scheme

3.2.1. Plant height and stem shoot number

Plant heights of potato were highly significantly affected by main, two, and three way interactions of NPS application rate, variety and location. Number of stem shoots per plant or hill on the other hand was highly significantly affected by the main effects of the three factors as well as the interaction effect of NPS rate and potato variety (NPS rate × Variety) as well as the three way interaction effect of the three factors (NPS rate × variety × location).

The longest plant heights were observed on *Belete* (65.63 cm) and *Gudene* (65.00 cm) varieties that were grown in location II and supplied with 281.75 kg ha^{-1} NPS fertilizer while the highest number of stem shoots (10.27) was recorded on *Belete* variety grown location II and supplied with the same rate of NPS fertilizer (Table 2). Application of 281.75 kg ha^{-1} NPS fertilizer in location II increased the height by 35.9% and the shoot number by 24.8% of *Belete* variety compared to the corresponding control plants without NPS fertilizer.

Sulfur plays an essential role in chlorophyll formation and many reactions of living cells Tisdale et al. (1995). The results of the present study are in line with the findings of various researchers where potato plant heights and stem shoot numbers were increased with the application of sulfur containing fertilizers (Chettri, Mondal, & Roy, 2002; Choudhary, 2013; Sharma, 2015). In this regard, Jemberie (2017) found that application of 272.0 kg ha^{-1} NPS fertilizer on *Belete* variety recorded the longest

Table 2. Growth parameters of potato as affected by three way interaction of NPS application rates, varieties and locations at Koga Irrigation Scheme

Variety	NPS fertilizer rates (kg ha^{-1})	Plant height (cm)		Number shoots/plant	
		Location I	Location II	Location I	Location II
Belete	0.00	50.33 fghi	48.20fghi	8.03fgh	8.23efg
	102.15	49.50fghi	51.13fghi	7.93fghi	8.27defg
	136.20	50.17fghi	54.20 cdef	8.07fgh	8.60cdef
	181.60	59.33abcd	62.53ab	8.13fg	8.93bcd
	227.00	60.67ab	63.67ab	8.87bcde	9.13bc
	283.75	60.00abc	65.53a	9.47b	10.27a
Gudene	0.00	40.00kl	45.67ijk	6.53mno	7.13jklm
	102.15	47.17ghij	50.53fghi	6.67lmno	7.20jklm
	136.20	51.67fghi	53.13defg	7.00jklm	7.40hijk
	181.60	59.67abc	58.00bcde	7.27ijkl	7.67ghij
	227.00	59.50cd	63.13ab	7.27ijkl	7.93fghi
	283.75	59.67abc	65.00a	7.60ghijk	8.07fgh
Local	0.00	33.67 m	39.40klm	4.13s	5.60pqr
	102.15	36.83 lm	41.87jkl	5.13r	5.53qr
	136.20	39.77klm	46.67hij	5.27r	6.00opq
	181.60	38.77klm	51.43fghi	5.73pqr	6.13opq
	227.00	40.07kl	54.00 cdef	6.07opq	6.53mno
	283.75	39.67klm	52.67efgh	6.27nop	6.93klmn
P-values		0.0003		0.0008	
CV (%)		3.748		2.861	
SE±		1.919		0.207	

Notes: *p*-values = probability; CV = coefficient of variance; SE = standard error; means followed by the same letter(s) are not significantly different.

plant height (64.8 cm) and the highest stem shoot numbers per plant or hill (9.3) which are in agreement with the results of the present study. Increased plant heights and leaf numbers have been also observed on other vegetable crops including cabbage, onion and garlic by application of NPS fertilizer (Gebremeskel, 2016; Yayeh, Alemayehu, Hailesilassie, & Yigzaw, 2017; Yosef, 2016).

The longest plant heights and increased stem shoot numbers in location II compared to those in location I observed in the present study can be associated with the complementary effects of nutrients in NPS fertilizer and the relatively high amount of phosphorous and organic matter content presented in the soil of location II as indicated in Table 1. Moreover, physico-chemical properties of the soil of location II could also contributed to the development of the potato plants.

Results of the other researchers on the other hand demonstrated that stem shoot numbers per plant are mostly determined by the genetic makeup (Lynch & Tai, 1989), the physiological age, and size of potato seed tubers (Allen, 1978; De la Morena, Guillén, & del Moral, 1994; Harris, 1978) rather than mineral nutrients in the fertilizers. The relative low number of stem shoots per plants and short plant heights observed on local variety compared to the other improved potato varieties in this study can be also associated with the genetic makeup of the varieties as indicated by Mekashaw (2016) where *Belete* variety was longer and had more stem shoots per plant than the farmer`s local variety.

Table 3. Days of flowering and maturity of potato as affected by NPS application rates, varieties and locations at Koga Irrigation Scheme

Variety	NPS rate (kg ha^{-1})	Days of flowering (days)		Date of maturity (days)	
		Location I	Location II	Location I	Location II
Belete	0.00	71.67jklm	71.00klm	100.67kl	105.00ijk
	102.15	79.00def	75.33ghi	108.33defghi	108.67 cdefghi
	136.20	80.00cd	78.67defg	109.33bcdefghi	108.67 cdefghi
	181.60	79.67cde	78.33defg	110.67abcdefg	108.67cdefghi
	227.00	80.67cd	80.67cd	114.00a	109.00cdefghi
	283.75	83.00bc	80.33 cd	113.67ab	112.67abcd
Gudene	0.00	70.00 lm	69.00 m	99.00 lm	108.33defghi
	102.15	73.67ijk	75.67fghi	106.00hij	106.33ghij
	136.20	76.33efghi	78.67defg	107.00fghij	108.33defghi
	181.60	75.67fghi	80.33 cd	108.00efghi	109.33bcdefghi
	227.00	78.67defg	86.67a	110.00abcdefgh	111.33abcdef
	283.75	79.67cde	84.67ab	111.00bcdef	113.00abc
Local	0.00	65.33n	62.67n	95.67 m	99.67 lm
	102.15	71.33jklm	73.33ijkl	107.33efghi	107.00fghij
	136.20	74.67hij	74.67hij	108.00efghi	109.00cdefghi
	181.60	76.00fghi	83.00bc	108.67cdefghi	102.67jkl
	227.00	77.33defgh	86.33ab	109.00cdefghi	106.33 ghij
	283.75	78.33defg	88.00a	111.00bcdef	111.67abcde
p-values		<0.0001		0.0097	
LSD		3.411		2.887	
CV (%)		2.044		1.238	
SE±		1.578		1.335	

Notes: *p*-values = probability; CV = coefficient of variance; SE = standard error; means followed by the same letter(s) are not significantly different.

3.2.2. Flowering and maturity date

The main effects of NPS rate, variety and location as well as their two, and three way interactions affected highly significantly flowering, and maturity dates of potato. Local (88.0 days), and *Gudene* varieties (86.67 days) supplied with 283.75 kg ha^{-1} and 227.00 NPS kg ha^{-1} NPS fertilizer, respectively, recorded the highest 50% flowering days in location II. By *Belete* variety however, the highest days of flowering (83.00 days) was recorded by application of 283.75 kg ha^{-1} NPS fertilizer on plants grown in location I (Table 3). Application of 283.75 kg ha^{-1} NPS fertilizer on local, and *Gudene* varieties prolonged maturity by 12 and 4.67 days, respectively, in location II while by 13 days on *Belete* variety grown in location I, compared to the respective control plants without NPS fertilizer application.

Generally, increasing NPS fertilizer rates in location II prolonged days of potato flowering compared to the corresponding NPS rates applied in location I. Local variety without NPS fertilizer application flowered and matured earlier than the other two improved potato varieties without NPS fertilizer.

The results of the present study clearly indicated that increasing NPS fertilizer rates increased days to 50% flowering and maturity of potato varieties in both locations where the differences among the varieties are most probably associated with genetic makeup of the varieties. Increasing NPS fertilizer rates may promote the vegetative phase of potato plants that may in turn prolong flowering and maturity of potato plants. The results of the present study are generally in agreement with the findings of various researchers where increasing fertilizer rates, including NPS prolonged days to flowering and maturity of different vegetables including potato in different agro-ecologies (Ayichew et al., 2009; Gebremeskel, 2016; Mekashaw, 2016; Yosef, 2016). *Belete* variety flowered and matured after 84, and 112 days of planting, respectively, when potato plants were applied with 272 kg ha^{-1} of NPS fertilizer (Jemberie, 2017) which is in conformity with the results of the present study.

3.3. Tuber yield of potato as affected by NPS application rate, variety and location at Koga Irrigation Scheme

3.3.1. Fresh weight and dry matter content of potato tuber

Tuber fresh weight was highly significantly affected by the main effects of NPS rate, variety and location as well as the interaction effects of NPS rate × variety and NPS rate × location. The three way interaction of NPS rate, variety and location (NPS rate × variety × location) however affected tuber fresh weight of potato significantly ($p = 0.017$). The highest mean tuber fresh weights of 97.33 and 92.33 g were on *Belete*, and Gudene, varieties, respectively, grown in location I and supplied with 272.0 kg ha^{-1} NPS where no significant difference was observed when compared each other. Application of 283.75 kg ha^{-1} NPS fertilizer on local variety grown in location I recorded the highest mean tuber fresh weight (71.67 g) which is similar with the tuber weight obtained from plants supplied with 272.0 kg ha^{-1} NPS rate (Figure 1).

Fresh weights of potato tubers generally increased with increasing NPS application rates in all the tested varieties where the mean tuber fresh weights obtained from location I were relatively higher than those obtained from location II of the corresponding treatments (Figure 1). Moreover, *Belete* variety produced much bigger tubers than the other two varieties where tubers of *Gudene* variety have intermediate size.

The dry matter contents of the tubers were highly significantly affected by the main effects of NPS rate and potato variety as well as the interaction effect of variety and location (variety × location). Moreover tuber dry matter was also significantly influenced by interaction effect of NPS rate and potato variety (NPS rate × variety). However the three way interaction of NPS rate, variety and location (NPS rate × variety × location) had not significantly affected the dry matter content of potato tubers.

Figure 1. Three way interaction effect of NPS application rate, variety and site on tuber fresh weight of potato at Koga Irrigation Scheme.

Note: (I) = Location I; (II) = Location II.

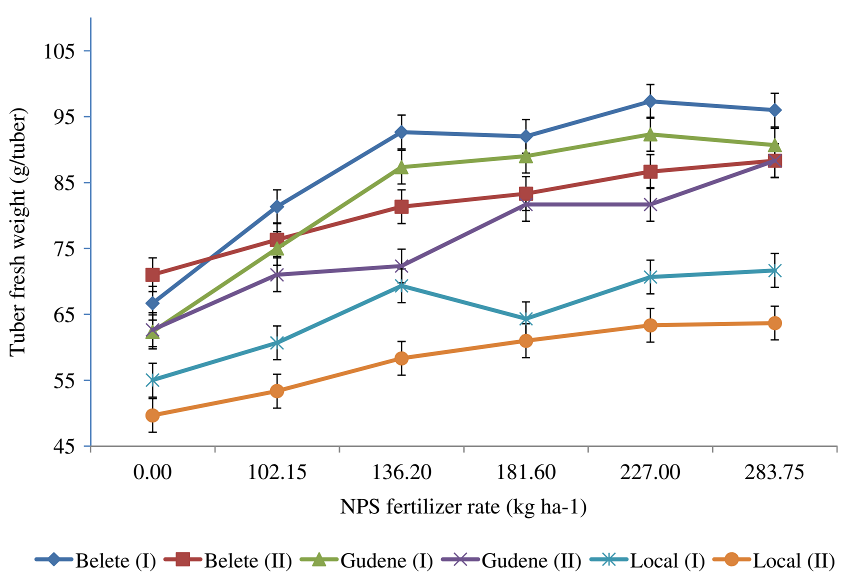


Table 4. Tuber dry matter content of potato as affected by NPS application rates and varieties at Koga Irrigation Scheme

NPS rate (kg ha^{-1})	Potato varieties		
	Belete	*Gudene*	Local
	TDM (%)	TDM (%)	TDM (%)
0	35.10de	34.33ef	29.75i
102.15	35.12de	34.73e	30.30hi
136.20	36.83bcd	35.30de	31.20ghi
181.60	37.38ab	34.77e	31.98gh
227.75	38.45ab	35.55cde	32.33g
283.73	39.13a	37.13bc	32.85 fg
p-value	0.0154		
CV (%)	2.508		
SE±	0.867		

Notes: *p*-values = probability; CV = coefficient of variance; SE = standard error; TDM = tuber dry matter content; means followed by the same letter(s) are not significantly different.

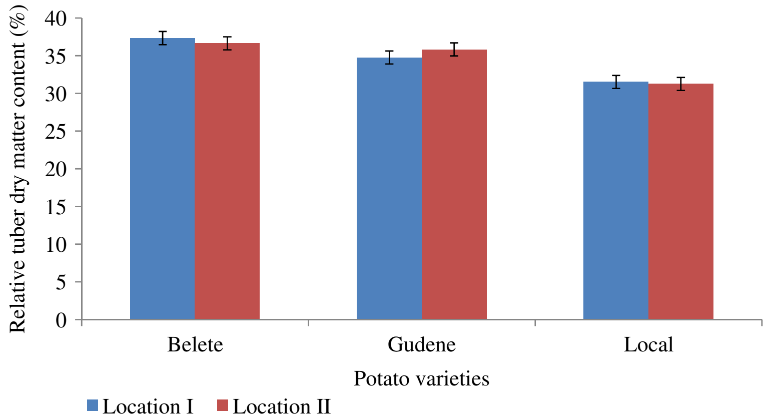
The highest significant mean tuber dry matter contents of 39.13, 37.13 and 32.85% were recorded on *Belete*, *Gudene*, and local varieties, respectively, when plants were applied with 283.75 kg ha^{-1} NPS fertilizer rate (Table 4). On the other hand, *Belete*, and *Gudene* varieties grown in both experimental locations recorded the highest tuber dry matter contents compared to the respective tubers of local variety grown in both locations (Figure 2). Tubers of *Belete* variety had the highest dry matter contents followed by *Gudene*, and local varieties across the NPS application rates and locations in this study.

The results of the present study clearly indicated that the application of NPS fertilizer increased mean tuber weights of potato varieties in all experimental locations that are also in line with the findings of various researchers (Jemberie, 2017; Mekashaw, 2016; Sharma & Arora, 1987). The relative bigger tuber sizes in location I observed in the present study is probably associated with the relative small number of shoots per plant in location I (Table 2) where competition of the plants for growth factors is relatively lower that may contribute to bigger tubers in this location. In this regard, Abebe et al. (2012) and Sharma (2015) observed relatively medium and small-sized potato tubers with increasing stem shoots per plant. Furthermore, the relative smaller tuber weight recorded from plants grown in location II may be associated with insignificant damages of plants by bacterial wilt at the end of the growing season that may reduced bulking of potato tubers.

Research results also indicated that increasing potato tuber size is possible up to certain level of available phosphorous in the soil. Further increase of phosphorous containing fertilizers however may not increase the tuber weights rather it hasten the maturity of potato plants that may result medium, and small-sized tubers (Hanley, Jarvis, & Ridgman, 1965; Sharma & Arora, 1987; Sommerfeldt & Knutson, 1965) which is generally in agreement the results of the preset study. The relative bigger tuber sizes of *Belete*, and *Gudene* varieties observed in the present study is most probably associated by the genetic makeup of the varieties which is in agreement with the findings of Mekashaw (2016) where *Belete* variety produced much bigger tubers than the farmer`s local variety in her study.

The increase of tuber dry matter with increasing NPS application rates observed in the present study is probably the results of accumulation and partitioning of more assimilates in tubes as indicated by the findings of various researchers (Abebe et al., 2012; Ayichew et al., 2009; Sharma, 2015). According to Jemberie (2017) application of 272 kg^{-1} of NPS fertilizer recorded the highest tuber dry matter content on *Belete* variety of potato. Moreover tuber dry matter content depends on the

Figure 2. Tuber dry matter content of potato as affected by variety and location at Koga Irrigation Scheme.



potato varieties which is in line with the findings of other researchers (Mekashaw, 2016; Tsehai, 1988) where improved potato varieties generally recorded the highest tuber dry matter content compared to farmer's local varieties.

3.3.2. *Tuber yields of potato*

Marketable tuber yield of potato was highly significantly affected by the main effects of NPS rate and potato variety as well as interaction effects of NPS rates with experimental locations (NPS rate × location) and potato varieties (NPS rate × variety). Moreover, the three way interaction effect of NPS rates, varieties and experimental locations (NPS × variety × location) significantly influenced marketable yield of potato.

Increasing NPS application rates in both experimental locations generally increased marketable yields of the tested potato varieties. The highest marketable yield of *Belete* (55.37 t ha^{-1}) variety was recorded in location I by the application of 283.75 kg ha^{-1} NPS fertilizer which was statistically similar with yield recorded in location II. Similarly, the highest marketable yield of *Gudene* (46.83 t ha^{-1}) variety was recorded in location I by application of 283.75 kg ha^{-1} NPS fertilizer which was statistically similar with those yields recorded with 181.60 and 272.0 kg ha^{-1} NPS fertilizer application rates (Table 5). Application of 283.75 kg ha^{-1} NPS fertilizer increased marketable yields by 174.2% and 155.5% in *Belete* and *Gudene* varieties, respectively, compared to the respective unfertilized control plants. On the other hand, the highest marketable yield of local variety with the value of 28.98 t ha^{-1} was recorded in location II when potato plants were supplied with 272.0 kg ha^{-1} NPS fertilizer which was statistically similar with yields recorded with the application of NPS fertilizer rates between 136.2 and 283.75 kg ha^{-1}. No significant difference was observed between marketable yields of potato varieties grown in the two locations.

Similar trends have been also generally observed in unmarketable and total tuber yields of potato where 58.70 and 49.26 t ha^{-1} were the highest total tuber yields recorded by *Belete*, and *Gudene* varieties, respectively, grown in location I with application of 283.75 kg ha^{-1} NPS fertilizer (Table 5). The same rate of NPS fertilizer also recorded the highest total tuber yield of local variety (30.74 t ha^{-1}) grown in location II which was statistically similar with tuber yield obtained from plants grown in location I.

Results of the present study revealed that application of NPS fertilizer increased tuber yields of potato varieties where the optimum application rates depend on varieties and locations. The results are generally in agreement with the findings of different researchers who reported positive response of potato varieties for tuber yields with increasing levels of NPS fertilizer rates at different areas (Abewa & Agumas, 2012; Alva, 2004; Ayichew et al., 2009; Boke, 2014; Jemberie, 2017; Mekashaw, 2016). Positive influence of NPS fertilizer and other sulfur-containing fertilizers have been also recorded on various vegetable crops (Gebremeskel, 2016; Hariyappa, 2003; Nasiruddin, Farooque, &

Table 5. Tuber yields of potato as affected by interaction effects of NPS application rate, variety and locations at Koga Irrigation Scheme

Variety	NPS (kg ha^{-1})	Marketable yield (t ha^{-1})		Unmarketable yield (t ha^{-1})		Total yield (t ha^{-1})	
		Location I	Location II	Location I	Location II	Location I	Location II
Belete	0.00	20.19jklm	28.07fghij	3.70ab	1.48defg	23.89hij	30.19efgh
	102.15	31.30efghi	35.00cdefg	3.89a	1.67cdefg	35.19defg	36.67cdef
	136.20	34.82cdefg	35.56cdef	3.33abcd	1.48defg	38.15cde	37.04cdef
	181.60	39.63bcde	40.19bcde	1.85bcdefg	1.48defg	41.48bcd	41.67bcd
	227.00	41.11bcd	43.11bcd	2.04abcdefg	1.89bcdefg	43.15bcd	45.00bc
	283.75	55.37a	47.41ab	3.33abcd	2.41abcdefg	58.70a	49.82ab
Gudene	0.00	18.33klm	25.93ghijk	2.41abcdefg	0.56 g	20.74ijk	26.48ghij
	102.15	31.30efghi	34.06defgh	3.52abc	0.94 fg	34.82defg	35.00defg
	136.20	28.82fghij	35.19cdef	2.44abcdefg	1.67cdefg	31.26efgh	36.85cdef
	181.60	40.56bcd	39.26bcde	2.96abcde	1.48defg	43.52bcd	40.74bcd
	227.00	43.59bc	40.00bcde	2.15abcdefg	1.30efg	45.74bc	41.30bcd
	283.75	46.83ab	42.57bcd	2.43abcdefg	2.43abcdefg	49.26b	45.00bc
Local	0.00	12.59 m	16.11 lm	1.48defg	1.30efg	14.07 k	17.41jk
	102.15	21.02jklm	19.07klm	2.78abcdef	1.57defg	23.80hij	20.65ijk
	136.20	23.52ijkl	24.63ijkl	1.11efg	1.67cdefg	24.63hij	26.30ghij
	181.60	23.70ijkl	25.00hijkl	1.85bcdefg	1.48defg	25.56hij	26.48ghij
	227.00	27.15fghijk	28.98fghij	3.22abcd	1.11efg	30.37efgh	30.09efgh
	283.75	26.67fghijk	28.89fghij	2.22abcdefg	1.85bcdefg	28.89fghi	30.74efgh
p-values		0.0128		0.0010		0.0202	
CV (%)		8.686		28.110		8.256	
SE±		2.789		0.582		2.822	

Notes: *p*-values = probability; CV = coefficient of variance; SE = standard error; means followed by the same letter(s) are not significantly different.

Baten, 1993; Yayeh et al., 2017; Yosef, 2016; Zaman, Hashem, Jahiruddin, & Rahim, 2001). Application of sulfur containing fertilizers like NPS improves availability of micronutrients by amending the soil pH (Marschner, 1995) that may in turn increase yields of vegetable crops including potato.

3.4. Economically optimum rate of NPS application on different locations of Koga Irrigation Scheme for higher marginal rate of return of potato

The fertilizer and potato variety related costs, gross incomes and associated net return for location I and location II are presented in Tables 6 and 7, respectively. Overall benefits of application of NPS fertilizer on potato varieties exceed non-application both in yields and net benefits in both locations.

In location I the highest net benefit of potato was recorded from *Belete* variety supplied with 283.75 kg ha^{-1} of NPS fertilizer followed by *Gudene* variety supplied with the same rate of NPS fertilizer (Table 6). Application of 283.75 and 227.00 kg ha^{-1} NPS fertilizer for *Belete* variety grown in location II recorded the 1st and 2nd highest net benefits while application of 283.75 kg ha^{-1} NPS fertilizer for *Gudene* variety recorded the 3rd highest net benefit of potato (Table 7).

Based on the procedures described by CIMMYT (1988), the highest marginal rate of return was obtained from *Belete* variety followed by *Gudene*, and local varieties grown in location I which were supplied with NPS application rates of 283.75, 181.60, and 102.15 kg ha^{-1}, respectively (Table 8).

Table 6. Variable cost and gross incomes of potato production as influenced by NPS application rates and varieties in location I of Koga Irrigation Scheme

Variety	NPS rate (kg ha^{-1})	Cost of fertilizer (Eth-Birr)		Labor cost (Eth-Birr)	Potato seed cost (Eth-Birr)	Total variable cost (Eth-Birr)	Marketable yield (t ha^{-1})	Gross income (Eth-Birr)	Net benefit (Eth-Birr)	Rank
		Urea	NPS							
Belete	0.00	3,259.60	0.00	1,087.50	14,850.00	19,197.10	20.19	100,950.00	81,752.90	16
	102.15	2,785.36	1,430.10	1,312.34	14,850.00	20,377.80	31.3	156,500.00	136,122.20	9
	136.20	2,627.28	1,906.80	1,387.29	14,850.00	20,771.36	32.04	160,200.00	139,428.64	7
	181.60	2,416.50	2,542.40	1,487.22	14,850.00	21,296.12	39.63	198,150.00	176,853.88	6
	227.00	2,205.73	3,178.00	1,587.15	14,850.00	21,820.87	41.11	205,550.00	183,729.13	4
	283.75	1,942.26	3,972.50	1,712.06	14,850.00	22,476.82	55.37	27,6850.00	254,373.18	1
Gudene	0.00	3,259.60	0.00	1,087.50	14,625.00	18,972.10	18.33	91,650.00	72,677.90	17
	102.15	2,785.36	1,430.10	1,312.34	14,625.00	20,152.80	31.3	156,500.00	136,347.20	8
	136.20	2,627.28	1,906.80	1,387.29	14,625.00	20,546.36	28.82	144,100.00	123,553.64	10
	181.60	2,416.50	2,542.40	1,487.22	14,625.00	21,071.12	40.56	202,800.00	181,728.88	5
	227.00	2,205.73	3,178.00	1.587.15	14,625.00	21,595.87	43.59	217,950.00	196,354.13	3
	283.75	1,942.26	3,972.50	1,712.06	14,625.00	22,251.82	46.83	234,150.00	211,898.18	2
Local	0.00	3,259.60	0.00	1,087.50	7,500.00	11,847.10	12.59	62,950.00	51,102.90	18
	102.15	2,785.36	1,430.10	1,312.34	7,500.00	13,027.80	21.02	105,100.00	92,072.20	15
	136.20	2,627.28	1,906.80	1,387.29	7,500.00	13,421.36	23.52	117,600.00	104,178.64	14
	181.60	2,416.50	2,542.40	1,487.22	7,500.00	13,946.12	23.7	118,500.00	104,553.88	13
	227.00	2,205.73	3,178.00	1,587.15	7,500.00	14,470.87	27.15	135,750.00	121,279.13	11
	283.75	1,942.26	3,972.50	1,712.06	7,500.00	15,126.82	26.67	133,350.00	118,223.18	12

Notes: seeding rate of potato = 1.5 t ha^{-1}; tuber seed price: Belete variety = 9.90 Eth-Birr kg^{-1}, Gudene variety = 9.75 Eth-Birr kg^{-1}, local variety = 5.0 Eth-Birr kg^{-1}; price of table potato at farm gate = 5.0 Birr kg^{-1}; labor cost = 75.0 Eth-Birr Man-day^{-1}; Price of NPS, and urea fertilizer = 14.0, and 11.24 Eth-Birr kg^{-1}, respectively.

1 USD = 23.50 Eth-Birr.

Table 7. Variable cost and gross incomes of potato production as influenced by NPS application rates and varieties in location II of Koga Irrigation Scheme

Variety	NPS rate (kg ha^{-1})	Cost of fertilizer (Eth-Birr)		Labor cost (Eth-Birr)	Potato seed cost (Eth-Birr)	Total variable cost (Eth-Birr	Marketable yield (t ha^{-1})	Gross income (Eth-Birr)	Net benefit (Eth-Birr)	Rank
		Urea	NPS							
Belete	0.00	3,259.60	0.00	1,087.50	14,850.00	19,197.10	28.07	140,350.00	121,152.90	13
	102.15	2,785.36	1,430.10	1,312.34	14,850.00	20,377.80	35.00	175,000.00	154,622.20	9
	136.20	2,627.28	1,906.80	1,387.29	14,850.00	20,771.36	35.56	177,800.00	157,028.64	7
	181.60	2,416.50	2,542.40	1,487.22	14,850.00	21,296.12	40.19	200,950.00	179,653.88	4
	227.00	2,205.73	3,178.00	1,587.15	14,850.00	21,820.87	43.11	215,550.00	193,729.13	2
	283.75	1,942.26	3,972.50	1,712.06	14,850.00	22,476.82	47.41	237,050.00	214,573.18	1
GudeneLocal	0.00	3,259.60	0.00	1,087.50	14,625.00	18,972.10	25.93	129,650.00	110,677.90	15
	102.15	2,785.36	1,430.10	1,312.34	14,625.00	20,152.80	34.06	170,300.00	150,147.20	10
	136.20	2,627.28	1,906.80	1,387.29	14,625.00	20,546.36	35.29	176,450.00	155,903.64	8
	181.60	2,416.50	2,542.40	1,487.22	14,625.00	21,071.12	39.26	196,300.00	175,228.88	6
	227.00	2,205.73	3,178.00	1.587.15	14,625.00	21,595.87	40.00	200,000.00	178,404.13	5
	283.75	1,942.26	3,972.50	1,712.06	14,625.00	22,251.82	42.57	212,850.00	190,598.18	3
Local	0.00	3,259.60	0.00	1,087.50	7,500.00	11,847.10	16.11	80,550.00	68,702.90	18
	102.15	2,785.36	1,430.10	1,312.34	7,500.00	13,027.80	19.07	95,350.00	82,322.20	17
	136.20	2,627.28	1,906.80	1,387.29	7,500.00	13,421.36	24.63	123,150.00	109,728.64	16
	181.60	2,416.50	2,542.40	1,487.22	7,500.00	13,946.12	25.00	125,000.00	111,053.88	14
	227.00	2,205.73	3,178.00	1,587.15	7,500.00	14,470.87	28.98	144,900.00	130,429.13	11
	283.75	1,942.26	3,972.50	1,712.06	7,500.00	15,126.82	28.89	144,450.00	129,323.18	12

Notes: seeding rate of potato = 1.5 t ha^{-1}; tuber seed price: Belete variety = 9.90 Eth-Birr kg^{-1}, Gudene variety = 9.75 Eth-Birr kg^{-1}, local variety = 5.0 Eth-Birr kg^{-1}; price of table potato at farm gate = 5.0 Birr kg^{-1}; labor cost = 75.0 Eth-Birr Man-day^{-1}; Price of NPS, and urea fertilizer = 14.0, and 11.24 Eth-Birr kg^{-1}, respectively.

1 USD = 23.50 Eth-Birr.

Table 8. Economical benefits of potato as influenced by different rates of NPS fertilizer and varieties for location I (soils with low available phosphorus) at Koga Irrigation Scheme

Variety × NPS fertilizer rate ($kg\ ha^{-1}$)		Total variable cost (Eth-Birr)	Net benefit (Eth-Birr)	MRR (%)	Rank
Local	0.00	11,847.1	51,102.9	–	
Local	102.15	13,027.8	92,072.2	3,469.921	3
Local	136.20	13,421.36	104,178.6	3,076.086	5
Local	181.60	13,946.12	104,553.9	71.50864	10
Local	227.00	14,470.87	121,279.1	3,187.249	4
Gudene	102.15	20,152.8	136,347.2	265.1932	9
Belete	136.20	20,771.36	139,428.6	498.1575	8
Gudene	181.60	21,071.12	181,728.9	14,111.61	2
Gudene	227.00	21,595.87	196,354.1	2,787.062	6
Gudene	283.75	22,251.82	211,898.2	2,369.724	7
Belete	283.75	22,476.82	254,373.2	18,877.78	1

Notes: MRR = marginal rate of return; 1 USD = 23.50 Eth-Birr.

Applying 102.15 and 181.60 $kg\ ha^{-1}$ NPS fertilizer for *Gudene,* and local varieties, respectively, recorded relatively the least marginal rate of returns.

In location II, the highest marginal rate of return was obtained from local variety supplied with 136.20 $kg\ ha^{-1}$ NPS fertilizer followed by *Gudene* variety supplied with 181.60 $kg\ ha^{-1}$ NPS fertilizer. Local variety of potato supplied with 227.00 $kg\ ha^{-1}$ NPS fertilizer recorded the 3rd highest marginal rate of return (Table 9).

Although the improved potato varieties (*Belete* and *Gudene*) gave much higher tuber yields in location II, they recorded relatively low marginal rate of returns compared to the local variety which is obviously associated with relatively high purchase prices of the seed tubers of these varieties as indicated in Tables 6 and 7. It is therefore advisable to improve the availability of seed tubers of such improved potato varieties through encouraging the private sector to participate in the potato seed

Table 9. Economical benefits of potato as influenced by different rates of NPS fertilizer and varieties for location II (soils with high available phosphorous) at Koga Irrigation Scheme

Variety × NPS fertilizer rate ($kg\ ha^{-1}$)		Total variable cost (Eth-Birr)	Net benefit (Eth-Birr)	MRR (%)	Rank
Local	0.00	1,1847.10	68,702.90	–	
Local	102.15	13,027.80	82,322.20	1153.495	8
Local	136.20	13,421.36	109,728.60	6,963.615	1
Local	181.60	13,946.12	111,053.90	252.5455	12
Local	227.00	14,470.87	130,429.10	3,692.247	3
Gudene	102.15	20,152.80	150,147.20	347.0317	11
Belete	102.15	20,377.80	154,622.20	1,988.889	6
Gudene	136.20	20,546.36	155,903.60	760.1962	9
Belete	136.20	20,771.36	157,028.60	500.00	10
Gudene	181.60	21,071.12	175,228.90	6,071.709	2
Belete	181.60	21,296.12	179,653.90	1,966.667	7
Belete	227.00	21,820.87	193,729.10	2,682.251	5
Belete	283.75	22,476.82	214,573.20	3,177.721	4

Notes: MRR = marginal rate of return; 1 USD = 23.50 Eth-Birr.

tuber production as well as supporting farmer`s cooperatives to engage in the sector by responsible stakeholders so as to improve the production and productivity of potato in the study area.

4. Conclusion

In the present study, most growth, and yield components of potato varieties were increased with increased application rates of NPS fertilizer in both locations that have different soil phosphorous content. The findings also showed that the responses of potato varieties to applied NPS fertilizer were different with the rates of application, the varieties used and the phosphorous contents of the experimental soils.

The highest marketable tuber yields of *Belete* and *Gudene* varieties were recorded by application of 283.75 kg ha^{-1} NPS fertilizer in location I with relatively low phosphorous content. The highest marketable yield of *Gudene* variety recorded in this location was however statistically similar with those yields of the variety that were obtained by application of NPS fertilizer at the rates ranging from 181.2 and 283.75 kg ha^{-1}. In farmers local variety however, the highest marketable tuber yield was recorded by application of 227.0 kg ha^{-1} NPS fertilizer in location II with high soil phosphorus content which was statistically similar with the yields of the variety obtained at NPS fertilizer rates ranging from 136.2–283.75 kg ha^{-1}.

Based on the results of economic analysis, application of 283.75, 181.60 and 102.15 NPS fertilizer rates are recommended for the production of *Belete*, *Gudene*, and local varieties, respectively, on soils with low phosphorous content at Koga Irrigation Scheme. On soils with relatively high phosphorus content however, application of 136.20 and 181.60 kg ha^{-1} NPS fertilizer rates are recommended for the production of local, and *Gudene* varieties, respectively, for economical and profitable production of potato at Koga Irrigation Scheme.

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Competing interest
The authors declare no competing interest.

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Authors' contributions
Melkamu Alemayehu coordinated the project. Moreover he conceived and designed the experiments and analyzed the data and wrote the manuscript. Minwyelet Jemberie performed the experiments. All authors approved the manuscript.

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