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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Integrated application of compound NPS fertilizer and farmyard manure for economical production of irrigated potato (*Solanum tuberosum* L.) in highlands of Ethiopia

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Abstract: Application of organic and inorganic fertilizers is essential for sustainable production of crops including potato. This study was therefore initiated to identify the optimum rate of farmyard manure (FYM) and blended compound NPS fertilizer for profitable production of potato in Koga Irrigation Scheme, Northwestern highlands of Ethiopia. Four rates of FYM (0, 4.5, 9, and 13.5 t ha⁻¹) and NPS fertilizer (0, 81.7, 163.4, and 245.1 kg ha⁻¹) were laid down in Randomized Complete Block Design with three replications. The results revealed that FYM and blended NPS fertilizer as well as their combination influenced most of the tested growth and yield parameters of potato including plant height, main stem number, and tuber weight. Application of 245.1 kg ha⁻¹ NPS combined with 13.5 t ha⁻¹ FYM recorded the highest marketable and total tuber yields of 43.52 and 47.04 t ha⁻¹, respectively. Although, the highest marginal rate of return was obtained from plants supplied with the combination of 4.5 t ha⁻¹ FYM and 163.4 kg ha⁻¹ NPS fertilizer, combined application of 245.1 kg ha⁻¹ NPS and 13.5 t ha⁻¹ FYM is recommended for economical production of potato in the study area as it recorded the highest net benefit with acceptable marginal rate of return.

ABOUT THE AUTHOR

Melkamu Alemayehu is an associate professor in Horticulture and Head of the Horticulture Research Group in College of Agriculture and Environmental Sciences, Bahir Dar University, Ethiopia. His key research interest is improving agronomic practices for enhanced productivity of horticultural crops. Mr. Minwyelet Jemberie is researcher at Adet Agricultural Research Center. His key research interest is implementing improved soil fertility management strategies for improved productivity of vegetable crops and thus ensuring food security in Amhara Region. Mr. Tadele Yeshiwas and Ms. Masho Aklile are instructors in College of Agriculture and Environmental Sciences, Bahir Dar University, Ethiopia. Their key research interest is introducing best practices for improved production and productivity of root and tuber crops so as to alleviate food and nutrition insecurity.

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 poor utilization of organic and inorganic fertilizers, which is not advisable for sustainable crop production including potato. Thus, development of location specific rates of organic and inorganic fertilizers 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: crop productivity; inorganic fertilizers; organic fertilizers; potato tuber yield

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the most important food security crops in Ethiopia. In recent years, potato production is in increasing trend (Cochrane & Bekele, 2018) where mid and high altitudes in the country are suitable for its production. The annual production of potato in Ethiopia is estimated to be 968,969.6 tons. Of which, about 40% is produced in highlands of Amhara Region, Northwestern Ethiopia. Productivity of potato in Ethiopia is 13.9 t ha⁻¹ (Central Statistic Agency [CSA], 2018), which is relatively low compared to other African countries like Algeria, Egypt, and Malawi with the productivity of 30.9, 26.4, and 18.4 t ha⁻¹, respectively (FAOSTAT, 2017). Low level of potato productivity is mainly due to poor agronomic practices including improper fertilization, poor pest management practices, use of low-quality seed tubers (Fuglie, 2007), and soil nutrient depletion (Chanie, Teshome, Temesgen, & Berihun, 2017). Nutrient demand of potato on the other hand is very high (Trehan, Upadhyay, Kumar, Jatav, & Lal, 2008) due to its poor, coarser, and shallow root system as well as removal of nutrients within the dry matter of potato produced in relatively shorter life cycle (Dechassa, Schenk, Claassen, & Steingrobe, 2003).

Ethiopian farmers are using mostly inorganic fertilizers like urea and NPS while organic fertilizers are not such commonly used for the production of potato and other crops. Application rates of inorganic fertilizers are mostly below the needs of the crops (Alemayehu, Tessafa, Bizuayehu, & Ayele, 2015; Kahsay, 2019; Ministry of Agriculture and Natural Resource [MoANR], 2013; Shiferaw, 2014; Yayeh, Alemayehu, Hailesilassie, & Desalegn, 2017), which is associated with unavailability and/or untimely delivery and higher prices of inorganic fertilizer (Place, Barrett, Freeman, Ramisch, & Vanlauwe, 2003; Yamano & Arai, 2011). Reports also indicated that application of inorganic fertilizers alone may increase erosion, and compaction of soils, environmental pollution and public health risk as well as depletion of essential micronutrients and thus reduction of overall soil, and crop productivity (Adeinyan & Ojeniyi, 2003; Balemi, 2012; Khan, Shil, & Noor, 2008; Ojeniyi, Awodun, & Odedina, 2007).

Organic fertilizers like farmyard manure (FYM) improve plant nutrient availability, physical, chemical, and biological properties of soils and thus enhances crop yields sustainably (Baia et al., 2018; Girma, Beyene, & Biazin, 2017; Gosling & Shepherd, 2005; Islam, Akhter, Majid, Ferdous, & Alam, 2013; Khan et al., 2008; Masrie, Dechassa, Tana, Alemayehu, & Abebie, 2015). Their sole application however may not being feasible due to their use as energy sources in most developing countries, high labor demand for their preparation and low content and slow release of nutrients (Palm, Myers, & Nandwa, 1997; Zeleke, Agegnehu, Abera, & Rashid, 2010). Therefore, integrated use of organic and inorganic fertilizers is crucial to enhance production and productivity of crops so as to supply ever increasing world's population with sufficient food (Gomiero, 2016; Tilman, Balzer, Hill, & Bafort, 2011; White, Crawford, lvarez, & Moreno, 2012).

The positive effects of combined application of organic and inorganic fertilizers on vegetative growth and yield of different crops including potato have been demonstrated by various researches whereby their rates differ with the soil fertility, type and composition of fertilizers, and environmental conditions (Ahamad, Dagar, & Mani, 2014; Ahmed, Zaki, Shafeek, Helmy, & Abd El-Baky, 2015; Boke, 2014; Najm, Hadi, Fazeli, Darzi, & Rahi, 2012). According to Suh et al. (2015), application of 20 t ha⁻¹ cow dung and 5 l ha⁻¹ foliar inorganic fertilizer was the most appropriate combination for potato production where organic fertilizer improved physical properties of the soils. Similarly, Islam et al. (2013) reported highest tuber yield of potato, increased NPK uptake, and availability of nutrients as well as maximum marginal benefit-cost ratio from plants supplied with 3 t ha⁻¹ poultry manure along with reduced rate of recommended dose of chemical fertilizers. Kafle, Shrivastav, and Marasini (2019) observed higher tuber number and yield when potato plots were treated with combinations of organic (poultry manure, FYM, and vermicompost) and

inorganic fertilizers compared to 100% recommended dose of NPK inorganic fertilizers. Application of 100% NPK+ 30 t ha⁻¹ FYM (Singh & Kushwah, 2006) and 100% NPK+ 50 t ha⁻¹ FYM (Phom, David, Narendra Swaroop, & Thomas, 2018) also recorded significantly higher tuber yield of potato.

Even though organic and inorganic fertilizers are necessary for sustainable crop production, studies on the effects of organic and inorganic fertilizers on the production of potato in the study area are limited. The present study was therefore initiated to identify the optimum rate of FYM and compound NPS fertilizer for economical production of potato at Koga Irrigation Scheme, Northwestern Ethiopia.

2. Materials and methods

2.1. Description of the study area

The study was conducted during the 2016 irrigation season at Koga Irrigation Scheme, which is found in Mecha District, Northwestern Ethiopia. According to the rating of Horneck, Sullivan, Owen, and Hart (2011) and Olsen and Dean (1965), the experimental soil has contained low available phosphorous, total nitrogen, and organic matter with textural classification of silty clay and a pH of 6.08 as indicated in Table 1.

Koga Irrigation Scheme with the total area of about 7000 ha was developed by the Government of Ethiopia to enhance commercial horticultural crops production in the region. The irrigation scheme is located between 11°10'N to 11°25'N latitude and 37°02'E to 37°17'E longitude, and has the mean annual rainfall of about 1,395.23 mm. The mean maximum and minimum temperatures of the scheme are 27°C and 12.8°C, respectively.

2.2. Type of experiment and data collection

2.2.1. Experimental treatment, design and procedure

The treatments consisted of four rates of well-decomposed FYM and blended NPS fertilizer which were factorial combined in Randomized Complete Block Design with three replications.

Each plot of the experiment was three meters wide and long and accommodated 40 plants in four rows with the spacing of 0.75 m and 0.30 m between rows and plants, respectively, as recommended by Ethiopian Institute of Agriculture Research [EIAR] (2007). Healthy, medium-sized and uniformly sprouted seed tubers of *Belete* variety of potato were used for the experiment. The whole quantity of NPS fertilizer was applied at the time of planting while FYM was applied about three weeks before planting. Other cultural and management practices were performed uniformly for all plots as recommended by EIAR (2007) for the production of potato.

2.2.2. Data collection and analysis

Plant height was collected by measuring stem heights of 10 randomly selected plants grown in net plot area using ruler at physiological maturity while number of stem shoots per hill was counted from five randomly selected hills at the beginning of flowering.

Days to flowering was recorded by counting the number of days elapsed from date of planting up to the date when 50% of the plants in the plot contained at least one flower. Days to

Table 1. Physical and chemical properties of the experimental soil at Koga Irrigation Scheme

pH (H ₂ O) 1:2.5	EC (dS/m)	CEC (cmol (+)/kg)	OM (%)	TN (%)	Av. P (ppm)	Texture
6.08	0.14	46.00	1.21	0.06	9.75	Silty clay

Source: Alemayehu, Jemberie, and Yildiz (2018)

physiological maturity was recorded by counting the number of days elapsed from date of planting up to the date when the haulm of 90% of the plants in the plot dried.

Tuber weight in gram was recorded by measuring the fresh weights of 10 randomly selected tubers harvested from the net plot area using sensitive balance. Tubers that are free of mechanical, disease and insect pest damages and medium to large in diameter (≥ 30 mm) are considered as marketable as described by Abebe, Shermari, and Thunya (2013). The weight of such tubers obtained from the net plot area and converted in hectare base was considered as marketable yield. Tubers that were harvested from the net plot area were weighed and converted in hectare bases.

The collected data were subjected to two-way ANOVA by using JMP 5 Statistical Discovery Software and mean separation was carried out using Tukey HSD at 1% or 5% significance level based on the ANOVA results. Moreover, local market prices of NPS fertilizer and FYM as well as labor costs were collected to calculate variable costs, which vary with treatments to calculate the economics of each treatment using the procedure described by CIMMYT (1988).

3. Results and discussion

3.1. Growth and phenology of potato as affected by NPS fertilizer and farmyard manure

3.1.1. Plant height of potato

Plant heights of potato were influenced by the main as well as interaction effects of FYM and NPS fertilizer. The longest potato plants were observed with combination of 245.1 kg ha⁻¹ NPS and 13.5 t ha⁻¹ FYM that were statistically similar with plant height recorded by the combination of 245.1 kg ha⁻¹ NPS and 9.0 t ha⁻¹ FYM. Combination of 245.1 kg ha⁻¹ NPS with 13.5 t ha⁻¹ FYM increased plant height by 70% while that of 245.1 kg ha⁻¹ NPS with 9.0 t ha⁻¹ FYM increased by 65.4% compared to the control plants without NPS fertilizer and FYM (Table 2).

Table 2. Height of potato plants as affected by the combination of NPS fertilizer and FYM

Farmyard manure (t ha ⁻¹)	NPS fertilizer (kg ha ⁻¹)	Plant height (cm)
0.00	0.00	36.20k
	81.70	45.33ghi
	163.40	45.87ghi
	245.10	47.93fg
4.50	0.00	40.67j
	81.70	47.03fgh
	163.40	52.67cd
	245.10	56.13b
9.00	0.00	43.20ij
	81.70	49.47ef
	163.40	53.87bc
	245.10	59.87a
13.50	0.00	44.33hi
	81.70	50.93de
	163.40	55.47bc
	245.10	61.80a
P-values		0.0001
CV (%)		1.913
SE+		0.946

Note: P-values = probability level; CV = coefficient of variance; SE = standard error; means within column followed by the same letter(s) are not significantly different.

The increased plants heights with the application of relatively high doses NPS fertilizer observed in the present study may be due to the fact that nitrogen increases in cell size, elongation and enhancement of cell division which ultimately increased vigorous growth of the plant. Similarly, phosphorous stimulates root development which eventually improved the growth and development of plant. Sulfur as essential nutrient also plays significant role in chlorophyll formation and involved in the metabolic and enzymatic processes of living organisms which may improve the growth and development of plants including potato. Similar findings were also reported by Ahmed et al. (2015), Alemayehu & Jemberie, (2018) and Yayeh et al. (2017) where application of nitrogen and blended NPS fertilizers increased heights of potato plants and other vegetable crops.

The increase in plant height of potato observed by combined application of NPS fertilizer and FYM could be due to the improved physical, chemical, and biological properties of the soil that ultimately increased water absorption and nutrient utilization and thus plant heights. Moreover, application of NPS and FYM may provide balanced micro and macronutrients as well as enhanced availability of plant nutrients, which would help to enhance the metabolic activity of microorganisms and improvement of plant growth. The results are in agreement with the findings of other researchers who observed longer plants when potato plants were applied with combined organic and inorganic fertilizers (Ahamad et al., 2014; Ahmed et al., 2015; Islam et al., 2013; Suh et al., 2015).

3.1.2. Number of main shoots of potato

The analysis of variance revealed that FYM and NPS fertilizers had significant effects on the shoot numbers of potato while their interaction had not influenced this parameter. Increasing the rate of FYM to 9.0 t ha⁻¹ and that of NPS to 163.4 kg ha⁻¹ significantly increased the shoot numbers of potato. However further increase in the rate of both fertilizers had no significant effect on shoot numbers of potato (Figures 1 and 2).

The increased shoot numbers per hill of potato observed in the present study is obviously due to the nutritional effects of nutrients found in NPS fertilizers, which is in line with the findings of different researchers where NPS and other inorganic fertilizers increased main shoot numbers of potato (Ahmed et al., 2015; Alemayehu & Jemberie, 2018; Shaaban & Kisetu, 2014). Increase in shoot numbers as a result of FYM application may be attributed to nitrogen and other plant nutrients found in FYM, which are necessary for plant growth and their tissues (Ahmed et al., 2015). FYM also improves the availability of plant nutrients, which is perhaps through improvement of soil pH (Girma et al., 2017; Islam et al., 2013; Masrie et al., 2015). Studies have also shown that organic fertilizers such as FYM influences plant growth and production through improving

Figure 1. Main stem shoot numbers of potato as affected by of FYM.

Means followed by the same letter(s) are not significantly different.

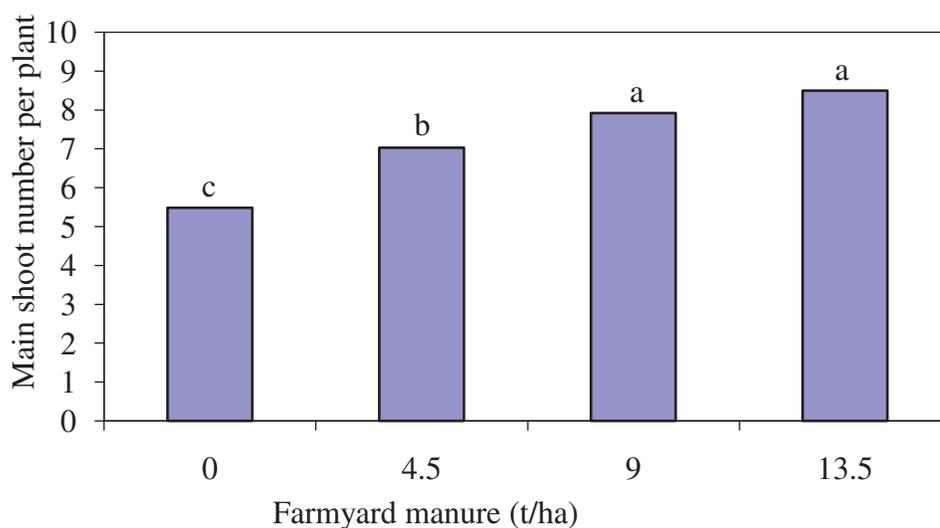
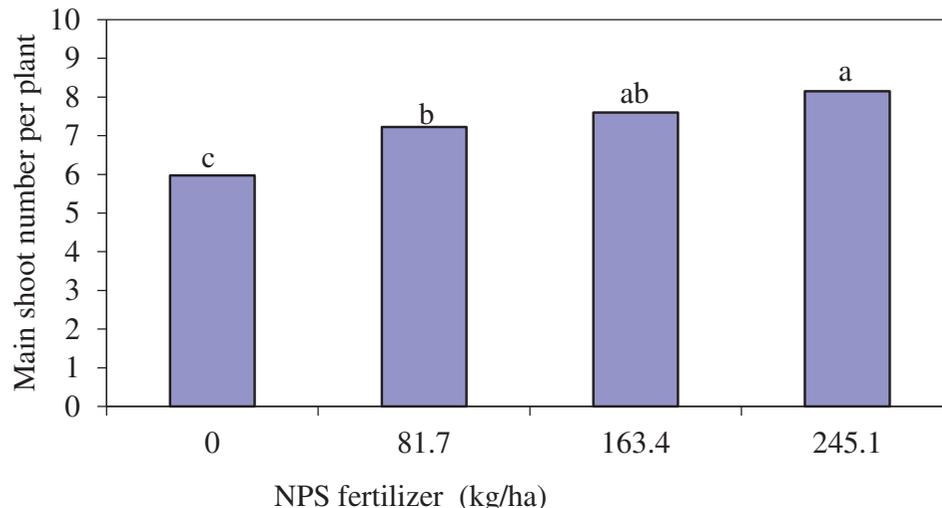


Figure 2. Main stem shoot numbers of potato as affected by NPS fertilizer.

Means followed by the same letter(s) are not significantly different.



chemical, physical, and biological properties of soils (Baia et al., 2018; Girma et al., 2017; Suh et al., 2015). Results obtained in the present study are in agreement with those reported by Ahmed et al. (2015), Alemayehu & Jemberie (2018), Islam et al. (2013) and Masrie et al. (2015).

In contrast to the results of the present study, findings of other researchers demonstrated that shoot number of potato is mostly determined by the genetic makeup, the physiological age, and the size of potato seed tubers rather than mineral nutrients added in the form of fertilizer (De La Guillen, & Del Moral, 1994; Lynch & Tai, 1989).

3.1.3. Days to 50% flowering and physiological maturity of potato

Days to flowering and maturity of potato were highly significantly influenced by the main effects of FYM and NPS fertilizer. However, the interaction of the two factors was not statistically influenced days to flowering and maturity of potato. Potato plants supplied with high rates of FYM has been flowered about 78.83 days after planting while matured 110.42 days after planting (Figure 3). Similarly, plants supplied with high rate of NPS fertilizer (245.1 kg ha^{-1}) flowered and matured about 78.8 and 109.0 days after planting, respectively (Figure 4).

Results of the study clearly showed that application of NPS fertilizer and FYM prolonged flowering and maturity of potato plants, which could be obviously associated with the supply of additional

Figure 3. Days to flowering and maturity of potato as influenced by rate of farmyard manure

Means followed by the same letter(s) in each parameter are not significantly different.

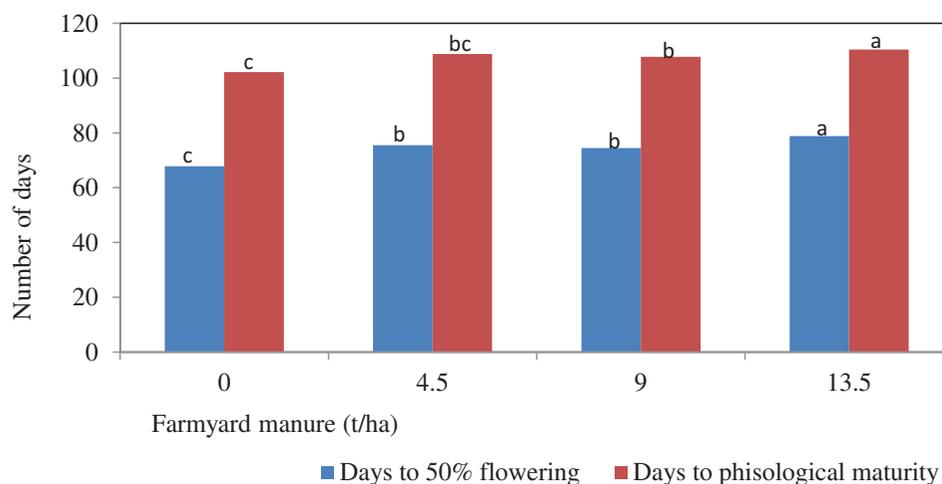
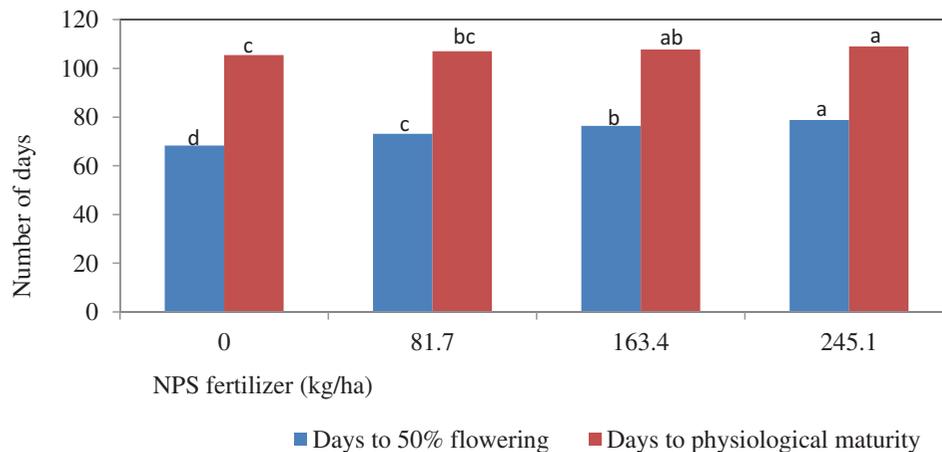


Figure 4. Days to 50% flowering and physiological maturity of potato as influenced by rate of NPS fertilizer.

Means followed by the same letter(s) in each parameter are not significantly different



nutrients, that may promote the vegetative growth of the plants that in turn prolonged flowering and maturity of potato plants. Similar results are also reported by different researchers where application of organic and inorganic fertilizers including NPS fertilizer and FYM prolonged days of flowering and physiological maturity of potato and other vegetable crops (Alemayehu & Jemberie, 2018; Ayichew, Tsegaw, & Dessacha, 2009; Boru, Tsadik, & Tana, 2017).

3.2. Yield of potato as affected by NPS fertilizer and farmyard manure potato

3.2.1. Tuber weight

Mean tuber fresh weight of potato was highly significantly affected by the main and interaction effects of NPS fertilizer and FYM. Combined application of 245.10 kg ha⁻¹ NPS fertilizer and 13.5 t ha⁻¹ FYM recorded the biggest potato tuber, which increased tuber weight by 54.02% compared to tubers recorded without application of NPS and FYM (Table 3).

The results indicated that combined application of NPS fertilizer and FYM up to certain rate increased tuber weight of potato. Further increase in fertilizers however could not significantly increase tuber weight. This could be due to the fact that increasing fertilizer rates also increased main shoot number of potato as indicated in the present study, which possibly creates competition of plants for growth factors that led to restricted assimilate accumulation of potato tubers and thus reduced tuber weight. In agreement with these results, Abebe, Shermari, Thunya, and Oranch (2012) reported high proportion of medium and small-sized potato tubers with increased shoot numbers per plant.

Moreover, research findings also showed that increment of available soil phosphorous up to certain level through application of phosphorous containing fertilizers may increase tuber weights of potatoes. Further increase of available soil phosphorous 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).

3.2.2. Tuber yield of potato

Marketable and total tuber yields of potato were highly significantly affected by the main and interaction effects of NPS fertilizer and FYM. Combined application of 13.5 t ha⁻¹ FYM and 245.1 kg ha⁻¹ NPS fertilizer recorded the highest marketable and total tuber yields of potato which were statistically similar with those yields recorded when 13.5 t ha⁻¹ FYM was combined with 163.4 and 245.1 kg ha⁻¹ NPS fertilizer and when 9.0 t ha⁻¹ FYM was combined with 245.1 kg ha⁻¹ NPS fertilizer as indicated in Table 3.

Similar to the growth parameters, the yield of potato was significantly influenced by the application of NPS fertilizer and FYM. This is obviously associated with the complementary effects of plant nutrients

Table 3. Yield of potato as affected by the interaction effects of NPS fertilizer and FYM

FYM rate (t ha ⁻¹)	NPS rate (kg ha ⁻¹)	Tuber weight (g/tuber)	Marketable yield (t ha ⁻¹)	Total yield (t ha ⁻¹)
0.00	0.00	62.33g	16.63h	18.15i
	81.70	66.67fg	21.67fgh	24.26ghi
	163.40	87.00bc	24.43efg	27.44fgh
	245.10	89.33abc	26.28ef	28.89fgh
4.50	0.00	72.67ef	22.59efgh	24.44ghi
	81.70	87.33abc	26.72def	30.00efg
	163.40	91.33ab	35.17bc	37.22bcd
	245.10	93.33ab	35.63bc	39.26bc
9.00	0.00	76.00dde	19.56gh	20.37i
	81.70	82.33cd	29.22cde	31.67def
	163.40	89.33abc	36.04b	39.26bc
	245.10	94.33ab	38.70ab	42.78ab
13.50	0.00	76.67de	21.78fgh	23.52hi
	81.70	87.00bc	32.96bcd	36.11cde
	163.40	91.67ab	38.26ab	40.74abc
	245.10	96.00a	43.52a	47.04a
P-values		0.0003	0.0019	0.0004
CV (%)		1.901	8.480	6.670
SE ₊		0.671	2.450	2.132

Note: P-values = probability level; CV = coefficient of variance; SE = standard error; means within column followed by the same letter(s) are not significantly different.

available in both fertilizers as well as improved physical, chemical and microbial properties of soils through FYM, which may contribute to growth and development and thus improvement of potato tuber yield as reported by Ahamad et al. (2014), Ahmed et al. (2015) and Suh et al. (2015). Furthermore, sulfur containing fertilizers like NPS may amend the soil pH and thus may improve the availability of micronutrients which in turn increase potato tuber yield.

In agreement with the findings of this study, various researchers reported tuber yield increment when potato plants were applied with combined application of different organic and inorganic fertilizers (Ahamad et al., 2014; Ahmed et al., 2015; Girma et al., 2017; Islam et al., 2013; Najm et al., 2012; Suh et al., 2015). The optimum rates of fertilizers to be applied were however different, which is probably due to the fertility status of the soils, types of fertilizer, and potato varieties used and the environmental conditions of the study areas. Masrie et al. (2015) for instance recommended combined application of 120/92 kg ha⁻¹ N/P₂O₅ with 30 t ha⁻¹ cattle manure for economical production of potato in Northeastern Ethiopia. Application of 100% NPK+ 30 t ha⁻¹ FYM and 100% NPK+ 50 t ha⁻¹ FYM was also recommended by Singh and Kushwah (2006) and Phom et al. (2018), respectively, for higher tuber yield of potato.

3.3. Optimum rates of NPS and farmyard manure for economical production of potato

Variable costs, gross incomes, and associated net return of potato as influenced by different rates of NPS fertilizer and FYM are presented in Table 4 while the marginal rate of returns of potato as affected by the combination of NPS fertilizer and FYM is presented in Table 5 below.

According to the results of the partial budget analysis, which was calculated by subtracting the total variable cost from the gross income of each treatment, combined application of NPS fertilizer, and FYM generally increased the gross income and net benefit of potato at Koga Irrigation Scheme. The highest net benefit was obtained from potato plants supplied with the combination of 13.5 t ha⁻¹ FYM and

Table 4. Variable cost and gross incomes of potato as affected by different rates of FYM and NPS fertilizer in Koga Irrigation scheme

FYM rate (t ha ⁻¹)	NPS rate (kg ha ⁻¹)	Variable cost (Eth Birr)			TVC (Eth-Birr)	MY (t ha ⁻¹)	Gross income (Eth-Birr)	Net benefit (Eth-Birr)	Rank
		FYM	NPS	Labor cost (Eth Birr)					
0	0	0.00	0.00	0.00	0.00	16.63	62,362.5	62,362.50	16
	81.7	0.00	1,143.80	163.40	1,307.20	21.67	81,262.5	79,996.15	13
	163.4	0.00	2,287.60	326.80	2,614.40	24.43	91,612.5	89,079.80	11
	245.1	0.00	3,431.40	490.20	3,921.60	26.28	98,550.0	94,750.95	10
4.5	0	1,687.60	0.00	900.00	2,587.56	22.59	84,712.5	83,323.12	12
	81.7	1,687.60	1,143.80	1063.40	3,894.76	26.72	100,200.0	97,544.27	9
	163.4	1,687.60	2,287.60	1,226.80	5,201.96	35.17	131,888.0	127,965.42	6
	245.1	1,687.60	3,431.40	1,390.20	6,509.16	35.63	133,613.0	128,424.07	5
9	0	3,375.00	0.00	1,500.00	4,875.00	19.56	73,350.0	70,796.25	15
	81.7	3,375.00	1,143.80	1,663.40	6,182.20	29.22	109,575.0	105,754.90	8
	163.4	3,375.00	2,287.60	1,826.80	7,489.40	36.00	135,000.0	129,913.55	4
	245.1	3,375.00	3,431.40	1,990.20	8,796.60	38.70	145,125.0	138,772.20	2
13.5	0	5,062.50	0.00	2,250.00	7,312.51	21.78	81,675.0	77,844.37	14
	81.7	5,062.50	1,143.80	2,413.40	8,619.71	32.96	123,600.0	118,503.02	7
	163.4	5,062.50	2,287.60	2,576.80	9,926.91	38.26	143,475.0	137,111.67	3
	245.1	5,062.50	3,431.40	2,740.20	11,234.11	43.52	163,200.0	155,570.32	1

TVC = Total variable cost; MY = Marketable yield; GI = Gross income
 Notes: Selling price of potato at farm gate = 3.75 Birr kg⁻¹; Cost of NPS fertilizer = 14.0 Eth-Birr kg⁻¹; Cost of FYM = 317.50 Eth-Birr t⁻¹year⁻¹; Labor cost = 75.0 Eth-Birr Man-day⁻¹; 1 USD = 28.50 Eth-Birr.

Table 5. Marginal rate of return of potato as influenced by the combination of different rates of FYM and NPS fertilizer in Koga Irrigation Scheme

FYM (t ha ⁻¹) x NPS (kg ha ⁻¹)		Total Variable cost (Eth-Birr)	Net benefit (Eth-Birr)	Dominance analysis	MRR (%)	Rank
0	0	0	62,362.50		-	-
0	81.7	1,266.35	79,996.15		1,392.5	6
4.5	0	1,389.38	83,323.12		2,704.2	4
0	163.4	2,532.70	89,079.80		503.5	10
9	0	2,553.75	70,796.25	D	-	-
4.5	81.7	2,655.73	97,544.27		6,880.0	2
0	245.1	3,799.05	94,750.95	D	-	-
9	81.7	3,820.10	105,754.90		705.2	8
13.5	0	3,830.63	77,844.37	D	-	-
4.5	163.4	3,922.08	127,965.42		21,779.3	1
9	163.4	5,086.45	129,913.55		4,146.2	3
13.5	81.7	5,096.98	118,503.02	D	-	-
4.5	245.1	5,188.43	128,424.07	D	-	-
9	245.1	6,352.80	138,772.20		699.5	9
13.5	163.4	6,363.33	137,111.67		1,469.5	5
13.5	245.1	7,629.68	155,570.32		1,112.0	7

MRR = marginal rate of return; 1 USD = 28.50 Eth-Birr.

245.1 t ha⁻¹ NPS fertilize (Table 4). The highest marginal rate of return which was calculated by dividing the change in net benefit to the change in variable cost and multiplied with 100 was however obtained from the combination of 4.5 t ha⁻¹ FYM and 163.4 kg ha⁻¹ NPS fertilizer (Table 5). According to CIMMYT (1988), marginal rate of return is calculated after the total variable cost of each treatment was put in increasing order where treatments with 100% marginal rates can be recommend for farmers in developing countries.

4. Conclusion

Combined application of organic and inorganic fertilizers is necessary for sustainable production of crops including potato. Application of FYM and compound NPS fertilizer increased the growth and yield of potato variety “Belete” at Koga Irrigation Scheme where combined application of 13.5 t ha⁻¹ FYM with 245.1 kg ha⁻¹ NPS recorded the highest marketable tuber yield (43.52 t ha⁻¹). Highest marginal rate of return was recorded when the plants were supplied with the combinations of 4.5 t ha⁻¹ FYM and 163.4 kg ha⁻¹ NPS. As the marginal rate of return is higher than 100%, the treatment combination of 13.5 t ha⁻¹ FYM and 245.1 kg ha⁻¹ NPS fertilizer with the highest net benefit is recommended for profitable production of *Belete* variety of potato at Koga Irrigation Scheme, Northwestern highland of Ethiopia. Repeating the research work using various potato varieties at different growing seasons is also recommended.

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Competing interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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