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Integrated Application of Organic and Blended Mineral Fertilizers Improves Potato Productivity and Income for Smallholder Farmers in Acidic Soils

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Abstract

Potato (*Solanum tuberosum*) is the world's third most important food crop. However, potato productivity is very low in acidic soils that cover about 50% of the arable land in the world. Therefore, the aim of this study was to evaluate the effect of sole and integrated farmyard manure (FYM) and different types of mineral fertilizers on yield, yield components and economic returns of potato in acidic soils of Ethiopia. Six treatments: 1) Control (without fertilizer), 2) sole application of the recommended NP (RNP) fertilizer (11 kg/ha N and 40 kg/ha P), 3) sole FYM (28.8 t/ha FYM), 4) half dose of recommended NP fertilizer and half dose of the FYM, 5) blended fertilizer formulated as 17.3 kg N, 34.7 kg P_2O_5, 7.41 kg S, 2.23 kg Zn, 0.3 kg B + 100 kg/ha K), and 6) half blended and half FYM, were arranged in a randomized complete block design. The results revealed that potato plants amended with sole blended fertilizer, and integrated FYM, and mineral fertilizers doubled fresh tuber yield as compared to the control. The RNP fertilizer gave the lowest ($\alpha < 0.05$) marketable potato yield of all the fertilizer treatments. Applications of sole blended or integrated FYM and mineral fertilizers resulted in the highest net benefit with acceptable marginal rate of return. Integrated use of FYM and mineral fertilizers is crucial for improved and sustained smallholder potato production in acidic soils. Further studies are required to examine the long-term effects of blended fertilizers on soil properties.

Keywords: Farmyard Manure, Blended Fertilizer, Yield Components, Ethiopia

1. Introduction

Potato (*Solanum tuberosum*) is the world's third most important food crop after wheat and rice (Birch et al., 2012). The mean world potato yield was estimated at 19.5 t/ha in 2016 (FAOSTAT, 2016). Billions of people across the world eat it on a regular basis. Although the crop was mainly produced in Europe and North America, it has become an increasingly important food security crop in many developing countries (Birch et al., 2012; Bradshaw & Bonierbale, 2010). For instance, in Ethiopia the area under potato increased from 62,000 ha to 296,578 ha and production increased from 500,000 tons to 3.6 million tons from 2006 to 2016, respectively (CSA, 2006; CSA, 2016; FAOSTAT, 2016). Potato is a nutritious, high-value, short production cycle crop, which is important for food security and income generation in humid and dry sub-humid agro-ecologies across Africa (Birch et al., 2012; Bradshaw & Bonierbale, 2010; Hirpa et al., 2016).

While acidic soils cover about 30% of the world's total land area and more than 50% of the world's potential arable lands (Guo et al., 2010), potato is one of the major crops with ever increasing coverage in acidic soil (von Uexku ll & Mutert, 1995). However, soil acidity is one of the threatening factors causing low soil fertility and hence reduced crop yields due to aluminum toxicity and phosphorus deficiency (Liu et al., 2008; Zheng, 2010). In Acidic soils, large amounts of P applied as fertilizer could enter into the immobile pools through precipitation reaction with highly reactive Al^{3+} and Fe^{3+} (Hao et al., 2002; Haynes & Mokolobate, 2001). Low inherent soil fertility associated with soil acidity coupled with inadequate use of organic and inorganic fertilizers by smallholder farmers has caused low potato productivity in Africa (ATA, 2014; Druilhe & Barreiro-Hurlé, 2012; Ephrem, 2015; Kefyalew, 2010; Kinyua et al., 2001; Lemaga et al., 2001; Mesfin, 2009; Olanya et al., 2001).

Although fertilizer recommendations based on soil fertility assessments are not common in Africa, the Ethiopian Agricultural Transformation agency (ATA) through its Ethiopian Soil Information System (EthioSIS) project has recently made a national assessment on soil fertility status at district levels to give evidence-based specific fertilizer recommendations (ATA, 2016). For this purpose, EthioSIS gathered and analyzed soil samples from more than 18,000 sites. Accordingly, new blended fertilizers that have nitrogen, phosphorus and Sulphur as basic nutrients and blending them with minor nutrients such as Zn, Cu and B were recommended depending on their deficiencies in the soils of different districts in the country. However, the responses of various crops in terms of yield and economic performances to blended fertilizers have not yet been studied. On the other hand, although smallholder farmers in SSA use traditional soil fertility improvement methods such as manuring, intercropping, compost, crop residue and fallowing to a lesser extent (Place et al., 2003), integrated application of organic and mineral fertilizers is less common. Therefore, this study was initiated to evaluate the effects of sole and integrated applications of mineral fertilizers, either the newly blended or the RNP fertilizers, and farmyard manure on yield, yield components and economic return of potato by smallholder farmers in acid soils of the Ethiopian highlands.

2. Materials and Methods

2.1 Description of the Study Area

This study was carried out in Arbegona district of southern Ethiopia. The study area lies between 6°34'19"-6°47'54"N latitude and 38°35'60"-38°53'36"E longitude (Figure 1). The experimental site is located at about 78 km southeast of Hawassa city, the capital of the Southern region, at an elevation of 2,521 meters above sea level. The study area has a mean annual rainfall of 1400 mm and a mean annual reference evapo-transpiration of 1123 mm (Mekasha et al., 2015). The study area has predominantly Nitosols (Paul, 2016). Major crops grown in the study area include enset (*Enset ventricosum*), potato (*Solanum tuberosum*), maize (*Zea mays*), wheat (*Triticum aestivum)*, field pea (*Pisum sativum*), cabbage (*Brassica oleracea*), carrot (*Daucus carota),* Ethiopian cabbage (*Brassica carinata*), onion (*Allium cepa.)* and Garlic (*Allium sativum*). The average livestock holding of the farm households in the study area was reported to be 17, out of which cattle and sheep shared about 47 and 41%, respectively (Mekasha et al., 2015).

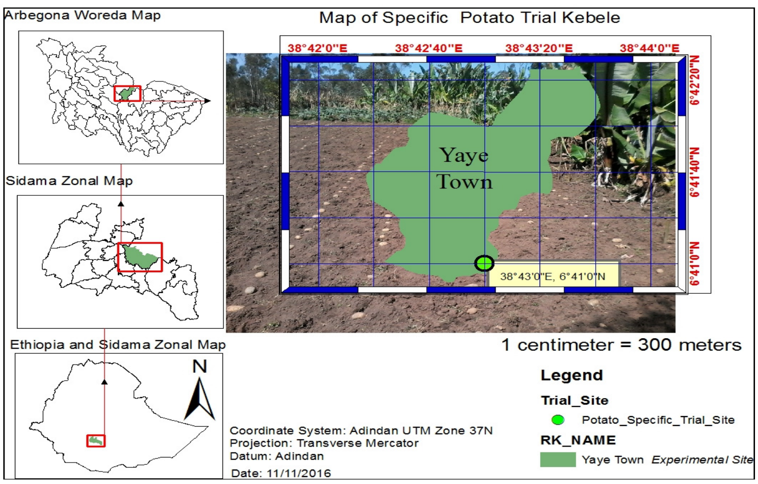


Figure 1. Geographical location of the study site at Arbegona district (locally known as woreda) in the southern Ethiopian highlands

2.2 Experimental Design and Treatments

The field experiment was laid out in a Randomized Complete Block Design (RCBD) with six treatments (Table 1). Each treatment was replicated three times and the experiment was conducted for two consecutive growing seasons. The first experiment was undertaken from December 19/2015 to April 15/2016, while the second from August 24/2016 to December 22/2016. During rain shortage, supplemental surface irrigation was applied evenly to all treatments. A blended fertilizer formulation composed of nitrogen, phosphorus, sulfur, zinc, boron and potassium (NPSZnB+K) was used as it was recommended for the highland acidic soils which have problems of phosphorus fixation and deficiency of micro-nutrients like zinc and boron (ATA, 2016). This blended fertilizer contained 17.3, 34.7, 7.4, 2.2 and 0.3% of N, P_2O_5, S, Zn, and B, respectively.

The amount of decomposed FYM used in the experiment was determined based on the nutrient contents of the widely available dry FYM from cattle in the study area. Therefore, the amount of FYM was estimated based on concentrations of major nutrients (Table 1). The concentrations of N, P and K in the FYM were high substantiating the findings of Hazelton and Murphy (2007) and Landon (2013). The FYM had 28.8% moisture content on average during application, and hence this was used as a correction factor (mcf) for the calculations of nitrogen, phosphorus and potassium contents.

For the field experiments, clean seed potato of the *variety Belete* was planted at a spacing of 75 and 30 cm, between rows and plants, respectively. The plot size was 4 m wide and 3 m long with 1 m spacing. The FYM and inorganic fertilizer were applied on the sides of seed potatoes on ridges and covered with soil to avoid contact. All the recommended rates of P, K, S, Zn and B according to the different treatments were applied at planting, whereas N was applied in split: half at planting and the remaining half at about 35 days after planting.

Table 1. Different sole and integrated organic and inorganic soil amendment techniques that were tested for their effects on potato production by smallholder farmers at Arbegona in the southern highlands of Ethiopia

No.	**Type of treatment**	**Applied Nutrients (kg ha^{-1}) from different fertilizer sources**					
		N	P	S	Zn	B	K
1	Control (without any fertilizer)	0	0	0	0	0	0
2	Recommended NP (RNP)	111	40	0	0	0	0
3	Combined RNP and FYM (each sharing half of the rate)	111	38.5	*	*	*	27.7
4	Sole FYM	111[1]	36.9[2]	*	*	*	55.4
5	Combined Blended and FYM (each sharing half of the rate)	111	38.5	9.78	2.49	0.39	77.7
6	Sole Blended	111	40	19.56	4.99	0.79	100

RNP = recommended nitrogen and phosphorus fertilizer (DAP and Urea); FYM = Farmyard manure; Blended fertilizer = formulated fertilizer from NPSZnB+K; N= Nitrogen, P= Phosphorous, K= Potassium, S= Sulphur, Zn= Zinc, and B= Boron;

**The concentrations of S, Zn and B in the FYM were not analyzed.*

[1]N from FYM calculated based on the recommended dose (111 kg of Nitrogen) considering only N (50%) availability (Kirsten, 2014) from (222 kg N in 28.8 t FYM ha^{-1}). Manure P and K occur mostly in a soluble form similar to the PK in fertilizer (Mengel & Kirkby, 1987; Kirsten, 2014).

2.3 Data Collection and Analysis

2.3.1 Soil and Plant Samples Collection and Preparation

Before the start of the field experiment, twenty surface soil samples (0-20 cm) were taken randomly from the experimental field. The soil samples were composited and prepared for analyses of the soil physico-chemical properties (Table 2) at the soil laboratory of Hawassa University.

During the experimental periods, data on plant height and numbers of stems per hill were recorded. Plant heights were determined at 50% flowering, approximately at about 9 weeks after planting by measuring the length from the base of the plants to the apex. Number of tubers per hill, foliage weight, tuber weights per plant, marketable and unmarketable tubers were determined at harvesting. The characteristics of unmarketable tubers were determined as explained by Fahmy et al. (2008) and Kavvadias et al. (2012). For potatoes and similar root crops, the yield components are number of stems per plant, number of tubers per plant and average tuber weight (Mengel & Kirkby, 1987).

Uniform small pieces of fresh tubers were taken, and tuber dry weights were determined after drying in an oven at 65^0C to a constant weight. Five-hundred-gram fresh weight was used for determination of dry matter content. The harvest index (HI) was computed by dividing the harvestable yield by the total biomass, both on a dry weight basis.

2.3.2 Soil Analysis

Soil parameters including particle size distribution, pH, organic carbon, total nitrogen, available P and K were analyzed following standard laboratory procedures. The composite soil samples were passed through 2 mm sieve for analyses, except for organic carbon and total N where a 0.5 mm sieve was used. A hydrometer method was used to determine the particle-size distribution (Gee & Bauder, 1986). The soil pH was measured using a pH meter in supernatant suspension of a 1:2.5 soil to water mixture as outlined by Sahlemedhin and Taye, (2000). Total nitrogen (TN) was analyzed by wet-oxidation procedure of the Kjeldahal method and available P and K were determined by Bray II method using spectrophotometer and Morgan's extracting solution methods, respectively (Motsara & Roy, 2008).

Soil organic carbon (OC) was determined following the wet oxidation method (Walkley & Black, 1934). Farmyard manure was subjected to pH, OC, TN and available P and K analyses. All the soil analyses were done at the soil laboratory of Hawassa University in southern Ethiopia.

Table 2. Selected chemical properties of the surface soil and farmyard manure used in the experiment at Arbegona in the southern highlands of Ethiopia

Material	Chemical properties				
	pH	OC (%)	TN (%)	Ava. P (mg kg^{-1})	Ava. K ($cmol^{(+)}kg^{-1}$)
Surface soil (0-20 cm)	4.81	2.64	0.21	7.43	0.48
FYM	7.1	11.38	1.082	1831	6.94

2.4 Economic Analyses

Partial budget and marginal rate of return (MRR) analyses were done to determine the economic benefits and make a rational choice among the studied soil amendments for potato production in acidic soils of Ethiopian highland farming system using the procedure developed by CIMMYT (1988). Partial budget analysis evaluates consequences of changes in farm methods that affect only a part rather than the whole farm. It is used as a planning tool to estimate the effect of on-farm profit to a particular change (Berhanu et al., 2012). Partial budget was computed at 10% yield adjusted, multiplied by the mean local farmgate price of $ 30.16 USD per 100 kg of potato at the time of harvest. A dominance analysis was carried out by first listing the treatments. A dominated treatment is any treatment that has net benefits that are less than those of a treatment with lower variable costs (CIMMYT, 1988).

2.5 Statistical Analysis

Data collected on plant parameters were subjected to descriptive statistics, analysis of variance (ANOVA) and correlation analyses using SAS software (version 9.0). Mean separations of the parameters in response to different treatments were made using the Least Significant Differences (LSD) at P = 0.05 level of significance. Pearson-correlation and path coefficients were also analyzed (SAS, 1997).

3. Results

3.1 Physicochemical Properties of the Experimental Soil

The experimental soil was loamy in textural class with 43, 39 and 18% sand, silt and clay particles, respectively. It is very strongly acidic in reaction and the organic carbon content of the soil could be rated as very high (Table 2). On the other hand, the total N and available K contents of the soil were medium whereas the available P was low in accordance with ratings by Landon (2013). The considerably high available P and K values in the FYM (Table 2) revealed that there is ample opportunity to improve soil fertility through applications of FYM.

3.2 Effect of Soil Amendments on Yield and Yield Components of Potato

Fresh shoot biomass, marketable and unmarketable tuber yields were significantly ($P < 0.05$) affected by soil amendments (Table 3). The lowest values of fresh shoot biomass, and marketable and unmarketable tuber yields were obtained from the control plots that were not treated with fertilizers (Table 4). The application of the recommended amount of NP mineral fertilizer did not significantly (P = 0.05) increase fresh shoot biomass in both seasons. The highest value of shoot biomass was obtained from combined use of FYM and mineral fertilizers (recommended NP or blended) or sole application of a blended fertilizer. All the different soil amendment techniques have significantly ($P < 0.05$) increased marketable tuber yield. The highest fresh tuber yield was obtained from combined use of FYM and mineral fertilizers (recommended NP or blended) or sole application of a blended fertilizer.

Plant height and number of tubers per plant were significantly ($P \leq 0.05$) different among the different soil amendments during both experimental seasons (Table 3). The lowest plant height was recorded in the control experiment where there was no application of chemical or organic fertilizers. Combined applications of FYM with blended fertilizer, and FYM with RNP resulted in the highest number of tubers per plant.

Table 3. Effect of sole and integrated organic and inorganic fertilizers on yield and yield components of potato at Arbegona in the southern highlands of Ethiopia

Season	Treatment	Shoot Biomass yield (t/ha)	Marketable tuber yield (t/ha)	Unmarket-able tuber Yield (t/ha)	Tuber Dry Matter (%)	Harvest Index (HI) (%)	Plant Height (PH) in cm	Tuber No/ Hill (TNH)
First (Dec. 19 2015- April 15 2016)	**Control**	15.4(±0.4^{d})	25.6(±1.4^{d})	2.4(±0.1^{c})	20.8(±0.2^{ba})	64.4(±0.6^{d})	55.6(±1.4^{c})	4.9(±0.3^{d})
	RNP	18.2(±1.6^{dc})	38.2(±2.9^{c})	2.1(±0.1^{c})	20.5(±0.1^{b})	69.0(±0.9^{c})	66.9(±1.6^{ba})	6.2(±0.2^{dc})
	RNP + FYM	24.1(±0.9^{a})	54.8(±3.5^{a})	3.2(±0.1^{ba})	21.2(±0.1^{a})	70.6(±0.5^{cb})	64.7(±2.0^{b})	8.9(±1.0^{a})
	FYM	19.1(±0.7^{cb})	45.6(±2.5^{cb})	3.4(±0.1^{ba})	20.7(±0.2^{ba})	71.9(±1.1^{ba})	65.4(±1.6^{a})	7.6(±0.1^{ba})
	Blended + FYM	21.4(±0.8^{ba})	57.7(±2.2^{a})	3.5(±0.2^{a})	21.2(±0.2^{a})	74.1(±1.6^{a})	70.5(±1.3^{a})	8.5(±0.4^{a})
	Blended	22.4(±0.6^{a})	53.4(±2.4^{ba})	3.1(±0.1^{b})	21.1(±0.04^{a})	71.6(±0.4^{b})	65.3(±1.4^{b})	6.9(±0.4^{cb})
	Season 1 Mean± SE	20.1(±1)	45.9(±2.8)	3.0(±0.1)	20.9(±0.2)	70.3(±0.7)	62(±1.5)	7.1(±1.4)
	LSD (0.05)	*3.1*	*8.7*	*0.3*	*0.5*	*2.2*	*4.8*	*1.4*
Second (Aug. 24 2016- Dec. 22 2016)	**Control**	13.6(±0.7^{c})	21.9(±2.2^{d})	2.6(±0.3^{b})	20.8(±0.2^{ba})	59.8(±3.0^{d})	55.7(±1.5^{b}	4.9(±0.3^{c})
	RNP	15.6(±1.4^{cb})	35.9(±4.9^{c})	4.6(±0.7^{a})	20.6(±0.0^{b})	66.3(±2.3^{cb})	67.8(±1.7^{a})	5.7(±0.1^{cb})
	RNP + FYM	21.5(±2.2^{a})	51.8(±4.5^{ba})	5.0(±0.7^{a})	21.1(±0.1^{a})	64.7(±2.5^{c})	64.4(±4.1^{a})	8.7(±1.2^{a})
	FYM	17.2(±1.1^{cba})	40.8(±4.0^{cb})	5.4(±0.6^{a})	20.7(±0.2^{b})	64.6(±2.6^{c})	65.3(±3.8^{a})	7.4(±0.4^{ba})
	Blended + FYM	18.1(±1.3^{ba})	55.1(±3.0^{a})	5.3(±0.2^{a})	21.2(±0.2)	73.3(±0.4^{a})	70.3(±2.4^{a})	8.8(±0.3^{a})
	Blended	18.7(±1.1^{ba})	48.2(±2.7^{ba})	5.8(±0.2^{a})	21.2(±0.2^{a})	68.1(±1.3^{ba})	66.1(±2.6^{a})	7.6(±0.4^{a})
	Season 2 Mean± SE	17.5(±1.4	42.3(±3.7	4.8(±0.5	20.9(±0.1	66.1(±0.9)	64.9(±2.5)	7.2(±0.6)
	LSD (0.05)	*4.4*	*11.6*	*1.6*	*0.5*	*2.8*	*8*	*1.8*
	Season Evaluation							
Mean of the two seasons	**Season 1 Mean± SE**	20.1(±0.5^{a})	45.9(±1.3)	3.0(±0.2^{b})	20.9(±0.1)	70.3(±0.3^{a})	64.7(±2.1)	7.2(±0.5)
	Season 2 Mean± SE	17.5(±0.5^{b}	42.3(±1.3	4.8(±0.2^{a})	20.9(±0.1)	66.1(±0.3^{b})	64.9(±2.1)	7.2(±0.5)
	Combined Mean± SE	**18.8(±0.5**	**44.1(±1.3**	**4.9(±0.2**	**20.9(±0.1**	**68.2(±0.3**	**64.8(±2.1)**	**7.2(±0.5)**
	LSD (0.05)	*1.5*	*3.9*	*0.4*	*0.5*	*1*	*2.5*	*0.6*

Means followed by the same letter(s) with in a column are not significantly different at ($P \leq 0.05$)

RNP = recommended nitrogen and phosphorus fertilizer (DAP and UREA), FYM = Farmyard manure, Blended = formulated fertilizer from NPSZnB+K, and SE=Standard Error in brackets

3.3 Effect of Different Soil Amendments on the Economic Return of Potato

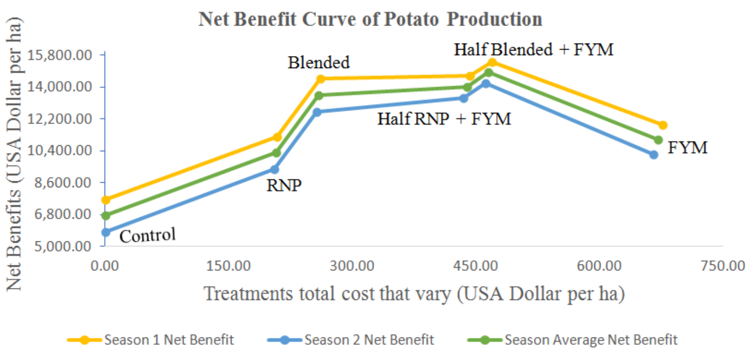
The result of the partial budget analysis revealed that all soil amendments resulted in higher net benefits than the control with respect to the acceptable MRR (Figure 2; Table 4). The dominancy analyses indicated that sole application of FYM could be less profitable due to the increased cost incurred for transportation. The application of combined FYM and blended fertilizer resulted in the highest net benefit followed by combined FYM and RNP fertilizers (Figure 2 and Table 4). For every $1.00 invested in application of FYM combined with blended fertilizer, farmers can expect to recover $1.00, and obtain an additional $31.06 ha^{-1} averaged over two seasons. All the studied soil amendments, except for application of sole FYM, could be economically feasible for potato producing farmers in the study area. The cost of transporting FYM from the homesteads where farmers commonly keep their livestock to the farm plots is high due to its bulkiness.

Table 4. Partial budget and marginal rate of return analyses of potato as influenced by soil amendments at Arbegona in the southern highlands of Ethiopia

Season	Treatments	10% yield adjusted (t/ha)	Total Cost that vary (TCV) ($USA Dollar ha^{-1})	Net Benefits (NB) ($USA Dollar tubers sold (t ha^{-1})	Marginal Rate of Return (MRR %^{1})
First (Dec. 19 2015-April 15 2016)	Control	25.3	0.00	7644.36	
	Recommend NP(RNP)	37.8	208.54	11198.28	1704
	Blended	52.9	261.41	14457.66	6164
	Half RNP and FYM	54.3	442.55	14662.41	113
	Half Blended and FYM	57.1	468.99	15435.33	2924
	FYM	45.1	676.57	11892.53^{D}	
Second (Aug. 24 2016-Dec. 22 2016)	Control	19.71	0.00	5844.66	
	Recommend NP(RNP)	32.31	205.02	9375.96	1722
	Blended	43.38	257.00	12606.52	6206
	Half RNP and FYM	46.62	435.08	13389.28	440
	Half Blended and FYM	49.59	461.07	14243.98	3287
	FYM	36.72	665.15	10223.54^{D}	

$The exchange rate of 1 $ (Dollar) was 21.55 Ethiopian Birr for first season (April, 2016) and 21.92 Ethiopian Birr for the second season (December 2016) trials, respectively ^{D} *indicates the dominated treatments*

RNP = recommended nitrogen and phosphorus fertilizer (DAP and UREA); FYM = Farmyard manure; Blended = formulated fertilizer from NPSZnB+K.



RNP = recommended nitrogen and phosphorus fertilizer (DAP and UREA), FYM = Farmyard manure, and Blended = formulated fertilizer from NPSZnB+K

Figure 2. Net benefit curve (season average) of potato as influenced by soil amendments at Arbegona in Southern Ethiopia

4. Discussions

The strongly acidic soils of the study area might have significantly contributed to P deficiency for potato production. In acidic soils, a substantial percentage of the cation exchange capacity is satisfied by Aluminium ions creating significant Al saturation (Haynes & Mokolobat, 2001). Aluminum oxides have high tendency to adsorb P onto their surfaces and will trigger P fixation. The available P was low in accordance with ratings by Landon (2013). Alemayehu et al. (2017) reported the abundance of Al + Fe-P as a result of variable Al and Fe contents and their reactions with soil P in soils of Hagereselam, close to the study site. The organic carbon content of the soil could be rated as very high in accordance with Hazelton and Murphy (2007). The high OC content of the soil could be attributed to low decomposition rate in very strong acidity as it affects activities of microorganisms (Havlin et al., 1999; Mengle & Kirkby, 1987; FAO, 2015). The highly available P and K values in the FYM (Table 3) revealed that there is ample opportunity to improve soil fertility through sufficient applications of FYM. However, only 18 and 26% of potato farmers in Africa applied FYM to maintain soil fertility (Gildemacher et al., 2009).

Averaged over seasons, application of either blended fertilizer alone or integrated FYM and mineral fertilizers resulted in a 100% increment in marketable tuber yields as compared to the control. The significant increases in tuber yields from the use of FYM alone or combined FYM and mineral fertilizers could be attributed either to the release of limiting essential nutrients from FYM or to the effect of FYM in reducing P adsorption in acidic soils. Manure can change soil pH and improve soil P availability (Shen et al., 2011). Haynes and Mokolobates (2001) stated that organic residues could be used as a strategic tool to reduce the rates of lime and fertilizer P required for optimum crop production on acidic, P-fixing soils.

Tuber dry matter percentage and harvest index of potato differed significantly ($P \leq 0.05$) between the different fertilizer treatments (Table 3). The results agree with a previous study by Ezzat et al. (2011). When the N level and K fertilization increased, the dry matter percentage decreased, which in turn reduced tuber dry matter percentage by increasing tuber water content (Ezzat et al., 2011). Tuber dry matter content and HI increased by 15 and 16% due to application of FYM alone and integrated FYM and blended fertilizer over the control, respectively. This substantiates the findings of Ahmad et al. (2014) who reported that HI increased by 5.5 to 14% due to applications of different levels of sole and combined applications of FYM and inorganic K fertilizer.

The current results in tuber numbers per hill are in line with the findings of El-Khider (2003). Plant height was 26.5% higher in plots treated with half FYM and half blended fertilizers as compared to the control. Das et al. (2015) reported a similar response of potato height on a different variety. The significantly higher effects of combined organic and mineral fertilizers on yield components of potato might be attributed to their complementary effects, whereby the inorganic fertilizers enable the immediate availability of nutrients while the FYM supply nutrients slowly throughout the growing period and improve the soil properties such as soil porosity and reduced soil acidity (Fahmy et al., 2008).

A shortage of one of the essential nutrients can limit crop yields (Lones & Jacobsen, 2001). Under limited soil nutrient conditions, the required nutrients may come from soil reserves, added fertilizer or manure, and crop residues (Kirsten, 2014). Due to the low decomposition rate of organic matter such as FYM, nutrients could be available gradually, thus reducing the risks of immediate loss by leaching and erosion, particularly in high rainfall areas (Mengel & Kirkby, 1987; Kirsten, 2014). Inorganic fertilizers such as DAP, ammonium nitrate and ammonium are considered as acid forming fertilizers (Sommer et al., 2004; Schroder et al., 2011). Thus, integrated use of organic and mineral fertilizers could have a positive influence on reducing soil acidity. The FYM likely enhances mineralization of organically bound P and also desorption of Al + Fe-P in strongly acidic soils by increasing phosphatase activity and microbial biomass in the soil (Takeda et al., 2009).

5. Conclusion

The yield and yield components of potato were significantly affected by different types of fertilizers. Yet, there were differences in yield response to different types of fertilizer treatments. The RNP in the form of DAP and UREA fertilizers resulted in significantly lower potato tuber yields than either sole FYM or integrated FYM and mineral fertilizers. Potato plants grown in soils amended with sole blended fertilizer or integrated FYM and mineral fertilizers increased fresh tuber yield by more than 100% to the control. In general, it can be concluded that the RNP and blended fertilizers alone and their combination with FYM have superior economic yield responses over control. However, the RNP fertilizer resulted in significantly lower marketable yield than either the blended fertilizer or the integrated farmyard manure and mineral fertilizer. Therefore, smallholder potato producers can benefit more if they apply recommended dose of NP fertilizer in combination with FYM depending on their accessibility and ease of applications. In the mixed crop-livestock farming systems where cattle manure could be abundantly available, smallholder farmers should be encouraged to widely utilize FYM together with mineral fertilizers to amend the inherently poor and very acidic soils. Soil acidity being one of the major challenges for smallholder farmers in Africa, further studies are required to examine the short-term and long-term effects of application of sole blended mineral fertilizers and integrated applications of organic and mineral fertilizers in improving the productivity of acidic soils.

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Conflict of interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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