

Effect of Organic and Inorganic Fertilizer Application on Soil Phosphorous Balance and Phosphorous Uptake and Use Efficiency of Potato in Arbegona District, Southern Ethiopia

Tsegaye Girma^{1*}, Sheleme Beyene² and Berhanu Biazin³

¹Southern Agricultural Research Institute (SARI), PO Box 06, Hawassa, Ethiopia

²Hawassa College of Agriculture, Hawassa University, PO Box 05, Hawassa, Ethiopia

³International Livestock Research Institute (ILIR), PO Box 5689, Addis Ababa, Ethiopia

Abstract

Phosphorus is often an important limiting factor for crop yields, and in addition, low soil fertility and crop nutrient imbalances are major obstacles preventing Ethiopian farmers from realizing high agricultural productivity. Effect of the sole and combined application of farmyard manure (FYM) and inorganic fertilizers on tuber yield, nitrogen (N) uptake and use efficiency of Irish potato (*Solanum tuberosum* L.) was assessed in a field experiment carried out in Arbegona district of Sidama zone in Southern Ethiopia. The studied nutrient management practices were control (without fertilizer) and farmyard manure (FYM), recommended N and phosphorus (P), blended (17.3 N₃, 4.7 P₂O₅, 7.41 S₂, 23 Zn0, 3 B within 100 kg) plus potassium (K) fertilizers and combined half FYM and recommended NP and combined half FYM and blended plus K fertilizer. Treatments arranged in randomized complete block design with three replications. The experimental soil was loamy and very strongly acidic, low in organic carbon and available P and medium in total N and available K. Results showed that the applied FYM and inorganic fertilizer individual and in combination were resulted positive N balances. Potato plants amended with sole blended fertilizer, combined half recommended NP and FYM, and combined half FYM and blended fertilizers improved total dry tuber yield and total N uptake more than twofold (100%) as compared to the control. In the amendments, average agronomic and physiological efficiency of N supply and uptake were 48 and 46 kg dry tuber, respectively. Furthermore, 112% of apparent recovery efficiency of N was obtained across the treatments. Soil amendments resulted the highest net benefits with acceptable marginal rate of return (above 100%). Generally, soil amendments either in sole or combined inorganic and organic fertilizers could be considered to improve soil fertility status and potato yield in the study area.

Keywords: Tuber yield; Phosphorous; Nutrient uptake; Use efficiency; Farmyard manure; Combined application; Blended fertilizer

Introduction

Most soils cannot supply all essential plant nutrients in sufficient amounts to support good growth of crops, and hence, the application of fertilizer is one of the most effective means to increase nutrient uptake in crop plants and improve yields [1]. Agriculture and food production are dependent on a phosphorus (P) supply to produce adequate food, fibre and fuel for society [2]. However, P is often an important limiting factor for crop yields, so one of the ways to tackle these issues is improving phosphorus use efficiency (PUE).

According to Vita, Ethiopia has a high potential for potato production with 70% of the 13.5 million ha of arable land suitable for potato cultivation [3]. Furthermore, root crops are good sources of cash and foreign exchange for most smallholder farmers in Ethiopia [4]. However, potato is widely regarded as a secondary non-cereal crop in part because it has never reached the potential that it has in supporting food security. In addition, low soil fertility and crop nutrient imbalances are two major obstacles preventing Ethiopia's farmers from realizing the high agricultural productivity [5].

When fertilizer prices represent a large portion of a producer's costs, it is very important to maximize fertilizer use efficiency. Fertilizer use efficiency by most crops and farming systems is still very poor in most developing countries like Ethiopia. Therefore, improving agronomic efficiency provides both direct and indirect economic benefits and hence larger yield increases can be achieved for a given quantity of fertilizer applied. Integrated nutrient management (INM) by involving the combination of organic manure and fertilizers is an essential tool for balanced fertilization and sustainability of crop production on long term basis [1].

The Southern Nations, nationalities and Peoples (SNNP) region of Ethiopia contributed (22.93%) of the area under potatoes and (38.71%) production to the country's total. Sidama Zone is one of the major potato producing zones in the SNNPR. The farmers in southern Ethiopia use traditional soil fertility improvement mechanisms such as intercropping and farmyard manure application rather than depending only on inorganic fertilizer [4]. However, organic manure alone is not sufficient (and often not available in large quantities) for the level of crop production, the farmer is aiming at. Hence, additional mineral fertilizers must be applied [6]. However, there is a lack of scientific studies to examine the effect of separate and combined applications of organic and inorganic fertilizers in improving nutrient uptake efficiency of potatoes in Sidama highlands. This study, therefore, undertaken in the Arbegona district with the objectives: and (i) to evaluate the effect of sole and combined application of FYM and inorganic fertilizers on soil phosphorous (P) balance (ii) to identify P levels in dry matter accumulation and use efficiency in response to different rate of the applied FYM and inorganic fertilizer.

*Corresponding author: Tsegaye Girma, BSc in Natural Resource Management, Southern Agricultural Research Institute (SARI), PO Box 06, Hawassa, Ethiopia, Tel: +251462206575; Fax: +251462204521; E-mail: elositsseg28@gmail.com

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Materials and Methods

Description of the study area

This study was carried out in Arbegona district of Sidama zone, Southern Ethiopia. The woreda (Arbegona) geographically lies between 6°35'18" to 6°56'37"N and 38°35'60" to 38°53'36"E (Figure 1). The experimental site is located at 74 km east of Hawassa town at geographic coordinate of 06°41' N and 38°43' E with elevation of 2,521 masl. The study area has a mean annual rainfall of 1400 mm and a mean annual reference evapotranspiration of 1123 mm.

According to FAO 1998 soil classification system, the study district has dominantly three soil types of chromic Luvisols, eutric Vertisols and humic Nitisols. However, the trial site is humic Nitisols.

Experimental design and field experimentation

Based on the recommended dose of nitrogen (N) for potato, considering only 50% N availability from FYM, the available N were calculated and treatment setup formulated to the applied full dose of FYM and the combine treatments of half FYM with half of inorganic fertilizers [7]. The field experiment laid out in a Randomized Complete Block Design (RCBD) with five treatments (nutrient management options) and one control (Table 1) replicated three times within a farm. Blended fertilizer formula identified for the woreda containing the most deficient nutrients (NPSZnB+K) selected based on the nutrient map produced [5].

Farm yard manure that was used for the experiment had 28.75% moisture content on average correction factors. Nutrients in FYM other than NPK not considered and 100 kg blended has (17.3 N₂, 4.7 P₂O₅, 7.41 S₂, 23 Zn₀, 3 B within 100 kg) and 100 kg K from (KCl).

The experiments carried out under rain-fed conditions in the season of summer to autumn (Bega to Belg season) of 2015/16. Irish

potato (*Solanum tuberosum L.*) variety of Belete used as a test crop with spacing of 75 and 30 cm between rows and plants, respectively. The total plot size was 3.75 m wide and 3 m long having 1 m space between the blocks. The FYM and inorganic fertilizer banded in an open row on the ridges of the potatoes at 10 cm from the seeds covered by 2 cm layer of soil. The recommended rates of P, and K, S, Zn and B applied at planting, whereas N applied in split: half at planting and the remaining half at about 35 days after planting. FYM, Urea, DAP, KCl and blended (NPSZnB+K) fertilizers were used as sources of the nutrients and applied as banded. First earthing-up or hilling and weeding followed immediately after urea application. The second weeding and hilling done 8 weeks after planting and the plants harvested at maturity.

Data collection and analysis

Soil and plant samples collection and preparation: Before the start of the experiment, twenty surface soil sub-samples (0-20 cm) were randomly collected and composited for laboratory analyses of texture and selected chemical soil properties. After harvest, six surface soil sub-samples collected from each plot (three per ridge and three per row) and a composite made for each treatment.

Tubers dry weights was determined after drying in oven at 65°C to a constant weight. Five-hundred-gram fresh weight used for determination of dry matter content. Uptake of N use efficiency and concentration was done separately for shoots (stems and leaves), roots plus stolon. The nutrient accumulation and partitioning were calculated by multiplying nutrient concentration with the dry matter of the respective plant parts and the uptake of N in economic and by-product of potato plant parts were estimated following the procedure outlined [8,9].

Soil and plant analyses: Determination of particle-size distribution was done by using hydrometer procedure as outlined by Sahlemedhin and Taye. The soil pH was potentiometrically measured using pH meter in supernatant suspension of a 1: 2.5 soil to water mixture.

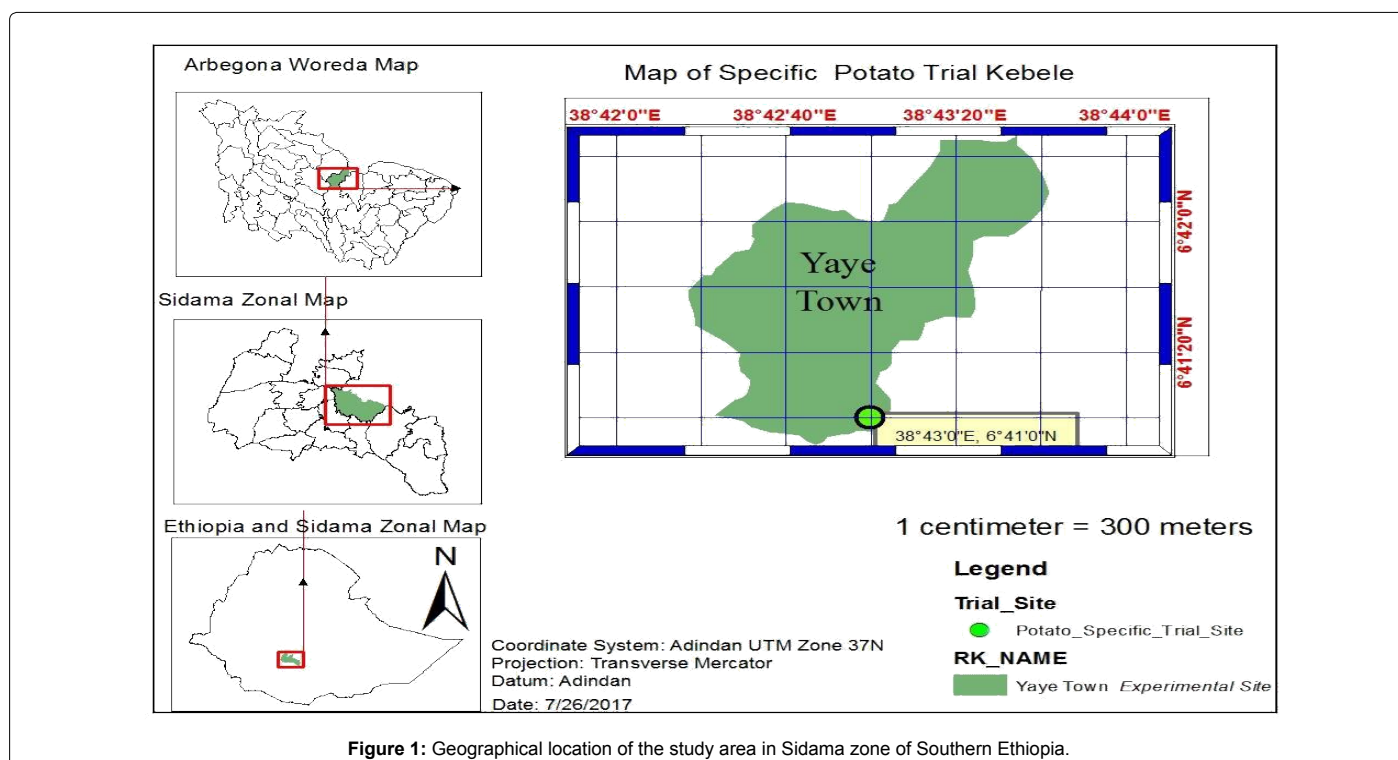


Figure 1: Geographical location of the study area in Sidama zone of Southern Ethiopia.

No	Treatments	Applied Nutrients kg ha ⁻¹ from fertilizer sources					
		N	P	S	Zn	B	K
1	Control	0	0	0	0	0	0
2	Recommended NP (RNP)	111	40	0	0	0	0
3	Half RNP+14.4 t FYM	111	38.5	.*	.*	.*	27.7
4	28.8 t FYM	111*	36.9†	.*	.*	.*	55.4
5	Half Blended+14.4 t ha ⁻¹ FYM	111	38.5	9.78	2.49	0.39	77.7
6	264 kg Blended	111	40	19.56	4.99	0.79	100

RNP=nitrogen and phosphorus, FYM=Farmyard manure and Blended=NPSZnB+, soil treatments (recommended dose of NP, 28.8 t FYM and 264 kg blended fertilizer) and the combined treatments (Half RNP+14.4 t FYM and Half Blended+14.4 t ha⁻¹ FYM); *Those nutrients not analysed; *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 like the PK in fertilizer (Mengel and Kirkby; Kirsten)

Table 1: Treatments set up for potato productivity, nutrient uptake and use efficiency as influenced by soil amendments.

Total nitrogen analyzed by wet-oxidation procedure of the Kjeldahl methods. Available P determined by Bray II method; Available K, determined by Morgan's extracting solution. Soil organic carbon (OC) was determined by the Walkley and Black method the procedure as outlined by Sahlemedhin and Taye. Plant samples subjected to the analysis of total N concentration using the above listed methods for soil N analysis procedure. The oven dried (65°C) plant samples which passed through 200 mesh sieves were used [10].

Calculation of plant nutrient uptakes and efficiencies

The nutrients use efficiencies were calculated by the formulas [2,9,10]

$$\bullet \text{Agronomic efficiency (AE): } AE = (Gf - Gu) / Na \quad (\text{eq. 1})$$

where Gf and Gu are tubers yield from the fertilized and unfertilized plot (kg), respectively and Na is the quantity of nutrient applied (NPK) (kg).

$$\bullet \text{Physiological efficiency (PE): } PE = (Gf - Gu) / (Ntf - Ntu) \quad (\text{eq. 2})$$

where Gf and Gu as described above, and Ntf and Ntu are the nutrient (NPK) (kg) accumulation by (total shoot and tuber) in the fertilized and unfertilized plot, respectively.

$$\bullet \text{Apparent recovery (AR): } AR = (Nf - Nu) \times 100\% / Na \quad (\text{eq. 3})$$

where Nf and Nu are the nutrient accumulation by the total biological yield (shoot and tuber) in the fertilized and unfertilized plot (kg).

•Partial Phosphorous Balances: The assessment of P balances was considering P added from fertilizer as inputs and P taken up by total crop materials (economic and biological yield) as out from the soil system [11,12].

Statistical analysis: Data collected on yields uptake of N and use efficiency in economic and by-product of potato plant parts subjected to analysis of variance (ANOVA). SAS software (version 9.0) was used and the treatments comparison were made with LSD ($P \leq 0.05$) level of significant.

Results and Discussion

Effect of soil amendments on chemical properties

The soil of the study area was loamy textured (Table 2). Loam textured soils are usually considered to be fertile and can hold sufficient available water indicated that such types of soils are often found in mountainous regions and are suitable to grow potatoes. The soil reaction rated as very strongly acidic (Table 2). Analysis of the experimental soil before planting revealed that it was low in OC, medium in total N, low

in available P and medium in K contents in accordance with the rating of the same author for tropical soils (Table 3). Similarly, soil pH and available P of the study area in line that grouped OC contents ranging between 2.00 and 2.99 as very high [5,13,14]. On the other hand, after harvest, available P was significantly ($P \leq 0.05$) higher at application of sole FYM, sole blended fertilizer and their half-combined usage over that of the control and the other amended plots (Table 2). This reveals that applying FYM is important at least partially address the problem of P fixation in the strongly acidic soils of the study area and the consequent low crop productivity due to P shortage.

Partial soil phosphorous balances: Plots treated with RNP and FYM alone had net negative available P balances, while positive available P balances were obtained from all treatments including the control (Table 2). The positive P balance in the control might be attributed both available nutrients replenished in more quantities from the soil exchangeable site as compared to the uptake. Similar findings in net available P balances was reported by [15]. Farm yard manure is a good source of nitrogen, phosphorus and potassium (NPK) and other macro- and micro-nutrients. In long term application of FYM, the nutrient supplying power of the soil is improved, so that treatment with FYM may be superior to an equivalent application of mineral fertilizer. In many soils, the rate of removal of plant nutrients by crops, leaching and denitrification is well more than nutrient release by weathering and mineralization. Potato is a high nutrient feeder. A negative nutrient balance thus resulted unless nutrients supplied in the form of fertilizers or manures to make up the difference [16]. The observed net negative P balances might have been imposed by low P availabilities coupled with high uptake. Loss of phosphorous might have also occurred in plots [7,17].

Effect of soil amendments on P concentration and uptake in different parts of potato

Significant ($P \leq 0.05$) differences in P uptake by potato plant parts were observed due to the use of different amendments (Table 4). The lowest P uptakes in the shoot and tubers were exhibited by the control while significantly higher P uptakes were measured all plants received different treatments. The highest shoot and tuber P uptakes were recorded in plants treated with blended fertilizer alone and half FYM combined with either half RNP or half blended fertilizer over the control and other amendments (Table 5). Similar findings were reported and the differences in uptakes were attributed to the supply of P from the amendments and/or the varietal difference [18-20]. The quantities of P taken up by shoot and tubers were more than double (100%) with applications of sole blended fertilizer, half FYM combined with half RNP and integrated half FYM and blended fertilizer over the control. The uptake of P might have been pronounced by availability of

	Soil pH	OC (%)	TN (%)	Ava. P (mg kg ⁻¹)	Ava. K (cmol (+) kg ⁻¹)	Texture			
	7.1	11.38	0.214	1831	6.94	sand	silt	clay	class
Dry FYM	4.81	2.64	1.082	7.43	0.48	43	39	18	loam
Available Phosphorous (mg kg ⁻¹) After planting									
Before planting	Control	RNP	Half RNP and FYM	FYM	Half Blended and FYM	Blended	Mean	LSD	CV
7.3	4.99 ^b	5.64 ^b	6.14 ^{ab}	10.51 ^a	7.03 ^{ab}	9.82 ^a	7.36	3.7	27.4

*RNP=nitrogen and phosphorus, FYM=Farmyard manure and Blended=NPSZnB+K

Table 2: Selected soil chemical properties before planting and FYM.

Variables	Treatments					
	Control	RNP	Half RNP and FYM	FYM	Half Blended and FYM	Blended
Phosphorus Balance						
Initial soil P kg ha ⁻¹ (a)	14.86	14.86	14.86	14.86	14.86	14.86
P added through fertilizer kg ha ⁻¹ (b)	0	40	36.94	38.47	38.47	40
Total P kg ha ⁻¹ (c)	14.86	54.86	51.8	53.33	53.33	54.86
P uptake kg ha ⁻¹ (d)	20.5	30.1	47.2	37	51.7	50.5
Expected balance kg ha ⁻¹ (e=c-d)	-5.64	24.76	4.6	16.33	1.63	4.36
Actual balance kg ha ⁻¹ (f)	9.98	11.28	21.02	12.28	14.06	19.64
Net P kg ha ⁻¹ gain (+) or loss (-) (g=f-e)	15.62	-13.48	16.42	-4.05	12.43	15.28

*RNP=nitrogen and phosphorus, FYM=Farmyard manure and Blended=NPSZnB+K

Table 3: Partial P balances in soil after harvest as influenced by soil amendments at Arbegona area of Sidama zone, Southern Ethiopia.

Treatments	Dry yield kg ha ⁻¹ total tubers	Phosphorus				
		Concentration (%)			Uptake kg/ha	
		Shoot	Root	Tuber	Shoot	Tuber
Control	5805.5 ^d	0.18 ^c	0.12 ^d	0.30 ^b	3.2 ^c	17.2 ^e
Recommend NP (RNP)	8269.2 ^c	0.22 ^b	0.15 ^c	0.31 ^b	4.6 ^c	25.6 ^d
Half RNP and FYM	12290.2 ^a	0.27 ^a	0.17 ^{ab}	0.31 ^b	9.1 ^a	38.1 ^b
FYM	10161.7 ^b	0.26 ^a	0.16 ^{bc}	0.30 ^b	6.5 ^b	30.5 ^c
Half Blended and FYM	12977.2 ^a	0.28 ^a	0.18 ^a	0.33 ^a	8.5 ^a	43.2 ^a
Blended	11931.3 ^a	0.28 ^a	0.16 ^{ab}	0.35 ^a	9.2 ^a	41.3 ^{ab}
Mean	10239.2	0.25	0.16	0.32	6.9	32.7
LSD (0.05)	1743.1	0.04	0.01	0.01	1.5	4.8
CV (%)	9.4	8.83	6.38	2.5	11.8	8.1

Means followed by the same letter(s) with in a column are not significantly different at (P ≤ 0.05) RNP=nitrogen and phosphorus, FYM=Farmyard manure and Blended=NPSZnB+K

Table 4: Effect of soil amendments on P concentration and uptake in potato plant materials as influenced by soil amendments at Arbegona area of Sidama zone, Southern Ethiopia.

Treatments	Phosphorus (P) Use efficiency		
	AE of P [Dry total tuber yield/ P applied (kg/kg)]	PE of P [Dry total tuber yield/ Total P uptake (kg/kg)]	ARE of P [Total P Uptake/ N applied (%)]
Recommend NP (RNP)	61.6 ^c	252.3 ^{ab}	24.2 ^c
Half RNP and FYM	175.6 ^a	242.3 ^{ab}	72.3 ^a
FYM	113.2 ^b	262.5 ^a	43.0 ^b
Half Blended and FYM	186.4 ^a	229.4 ^{bc}	81.3 ^a
Blended	153 ^{ab}	203.4 ^c	75.0 ^a
Mean	138	237.99	59.16
LSD (0.05)	51.4	28.77	16.64
CV (%)	19.8	6.42	14.94

Means followed by the same letter(s) with in a column are not significantly different at (P ≤ 0.05) RNP=nitrogen and phosphorus, FYM=Farmyard manure and Blended=NPSZnB+K; *Represent the Agronomic efficiency (AE) Physiological efficiency (PE) and Apparent recovery (AR)of nitrogen of potato

Table 5: Effect of soil amendments on P use efficiency of potato as influenced by soil amendments at Arbegona area of Sidama zone, Southern Ethiopia.

K and other micronutrients (S, Zn and B) from the blended fertilizer. Significant (P ≤ 0.05) and lowest P concentration in the shoots and roots of potato were recorded in control plant followed by the plants treated with recommended rate of NP while the remaining treatments exhibited significantly higher concentrations than control and RNP

treatment (Table 4). The highest P concentrations in shoots and roots were obtained from plants treated with sole blended fertilizer and half FYM in conjunction with either half RNP or half blended fertilizer and sole FYM equally recorded the highest P concentrations in shoots.

However, the highest P concentration in tubers was recorded with sole application of blended fertilizer and half FYM and blended fertilizer. The increments in P uptake and concentrations in the plant parts might be attributed to synergistic effects of K and other micronutrients from blended fertilizer. Similar findings were reported by Neshev and Manolov and who observed that the application of K in the form of K_2SO_4 led to increase of P uptake by potatoes [21].

According to Mengel and Kirkby the nutrient content of plant tissue reflects soil availability [16]. The low P uptake and concentrations in plant materials of the control might therefore be attributed to low P availability in the experimental soil; as was also confirmed by soil analysis before planting (Table 2). Additionally, phosphorous availability to plants is determined by the chemical characteristics of the soil and the P fertilizer source [7,22]. Thus, the use of blended fertilizer alone and in combination with FYM could be considered as best source for P availability.

Phosphorous efficiency as influenced by soil amendments

Agronomic Efficiency (AE) of P: Agronomic efficiency of P was significantly ($P \leq 0.05$) lower at application of RNP as compared with all other amendments. The highest values were obtained when half FYM was used in conjunction with either half RNP or half blended fertilizer over RNP. Similar findings on AE of P were reported when P supplied from organic and inorganic sources and the authors stated that AE of P decreased when P fertilization increased [9,20,23].

Physiological Efficiency (PE) of P

Sole application of blended fertilizer resulted in significantly ($P \leq 0.05$) lower phosphorous PE than that of other amendments except the combined application of half FYM with half blended fertilizer. Fertilization with sole FYM increased PE of P by 29% against the plot treated with blended fertilizer. Phosphorous PE in the present study was in agreements with the reports of P level and variety experiments in different cropping system [9,20]. These authors showed that at high P uptake the PE of crops decreases and the PE of P would depend on varieties. Nutrient efficiency of plants depends on: soil factor of production potential, chemical species of the fertilizer used and plant factors of interaction with environmental factor and root microbe [20,22,24].

Apparent Recovery (AR) of P

Lowest apparent recovery of phosphorous at ($P \leq 0.05$) was attained in plots amended with RNP alone. Additionally, plots amended with sole FYM application showed significantly lower ARE of P as compared to those with combined applications of half FYM with half NP, combined half FYM and blended and sole blended fertilization. Phosphorous ARE was improved four times and more than threefold, respectively at application of combined half FYM and blended fertilizer over RNP. Phosphorous ARE is in line with the findings indicate that the level of nutrient fertilization affects the nutrient availability in soil, and at high contents of soil nutrients and their availability more nutrients might be taken up by plants [9,20,23]. It has been reported that variation in ARE is common due to the dissimilarities of cultivars [20,22,23]. These authors have also discussed that depending upon the nutrient absorption power of the crops and their utilization at the biochemical levels, crops may vary in the recovery of the applied nutrients.

Summary and Conclusion

Combined application of FYM with inorganic fertilizer better means to maintain soil P balance as the same time resulted significantly

the highest tuber yield. Potato plants grown in soils amended with sole blended fertilizer, half FYM combined with RNP and half FYM and blended fertilizers improved dry tubers yield and total P uptakes more than twofold (100%) as compared to the control. In the amendments, on average agronomic efficiency of 138 kg dry tubers kg^{-1} was attained for P supply. In the same way, physiological efficiency of 238 kg dry tubers kg^{-1} was attained for P uptake. Furthermore, apparent recovery of 59% across treatments was obtained from P supply. The recoveries of and K was above 100%, indicating that the nutrients were depleted from the soil reserve, and the importance of K management. Generally, soil amendments either in sole or combined inorganic and organic fertilizers could be considered to improve soil fertility status and potato yield in the study area. In the mixed crop-livestock farming system of the Sidama highlands, where livestock is an important component of their livelihood, cattle manure is abundantly available. Hence, they should be encouraged to utilize widely FYM to amend the inherently poor and very acidic soils. Further researches need to be undertaken to replicate the study in a wider spatial and temporal aspects.

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