Agronomic and financial benefits of phosphate rock use in acidic soils of Upper Eastern Kenya

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Abstract
A major constraint to crop production in Sub-Saharan Africa is nutrient deficiency, especially phosphorus deficiency. Phosphorus plays a crucial role in photosynthesis but is usually deficient in acidic soils since it is converted to less available forms, affecting crop yields. There is a need to improve phosphorus availability to crops for maximum production. This study assessed the impact of phosphate rock fertilizer application on maize yields, soil chemical composition, and cost-effectiveness in Tharaka Nithi County, Upper Eastern Kenya. We set a field experiment in a randomized complete block design (RCBD) during long rains (SR2017) and Short rains (LR2018) seasons. The treatments were phosphate rock + manure, *Tithonia diversifolia* + phosphate rock, Calcium Ammonium Nitrate (CAN) + Triple Superphosphate (TSP), and a control. Soil samples were collected at a depth of 0-20 cm before and at the end of the experiment for pH, P-sorption, and other soil nutrients determinations. Other auxiliary data collected included labor and input costs besides output prices. The CAN+TSP treatment had significantly higher grain yields, while phosphate rock on its own had the second-lowest than the control treatment ($p<0.05$). We also observed a similar trend in the stover yields. Phosphate rock combined with either manure or *Tithonia diversifolia* led to a significant ($p<0.05$) increase in the phosphorous levels. Sole application of organics increased soil sodium and calcium while iron levels decreased. Other than the control, all treatments significantly lowered the p-sorption levels. However, CAN+TSP had the highest p-sorption while *Tithonia diversifolia* had the lowest. During the LR2018 season, a break-even point was arrived at with all the treatments, and the net benefit was significantly higher at $P<0.05$. Conclusively, the use of phosphate rock, either solely or in combination with organic elements, was found to improve yields, soil chemical composition, P-sorption, and very cost-effective.

Keywords: Phosphate Rock; Agronomic; cost-benefit analysis; maize yields

1. Introduction

Agriculture is a major source of income, employment, and food security in most developing Countries (Olaoye, 2014). The rural population mainly depends on soils and rain for life-supporting agricultural production (Harris & Orr, 2014). Food insecurity is a challenge to many African countries in the face of the 21st century (Smith *et al.*, 2017). This is becoming an alarming issue in Sub-Saharan Africa (SSA), where a decline in food production of at least 3% per capita has been recorded (Khan *et al.*, 2014) due to poor yields. As a result, African countries have resolved to food importation to meet their population's food demand. The decline in soil fertility is increasingly recognized as a significant factor contributing to stagnant per capita food production in SSA (Tittonell & Giller, 2013). Physical, chemical, and biological deterioration is characterized by loss of natural organic material, increased acidity, increased salinity, and increased alkalinity (Wani *et al*., 2011). All these factors result in reduced capabilities of soil to produce goods of value to humans (Nkonya & Mirzabaev, 2016).

Land degradation is highest in Sub-Saharan Africa (SSA) compared to anywhere else globally (Nkonya & Mirzabaev, 2016) and with the broadest yield gaps in maize. In the recent past, the central highlands of Kenya have experienced a decrease in crop yields (Kiboi *et al*., 2017). In Tharaka-Nithi County, a major factor contributing to decreased crop yields for smallholder farmers is P deficiency in the soil (Nziguheba *et al*., 2016). This is worsened by the financial status of most of the county residents (65%) who are poor and lack access to credit facilities. Thus, fertilizer to replenish P is often applied at rates far below the county's recommended levels, as most smallholder farmers cannot afford the high cost of inorganic fertilizer to enable full rate application (Njoroge *et al*., 2018). Intensive use of land without adequate additions of both organic and inorganic fertilizers is another factor leading to soil fertility in the area.

Farmers in Tharaka-Nithi county predominantly use manure to replenish soil fertility (Matusso *et al*., 2014). Studies show that organic residues and manure, apart from improving soil fertility contribute to soil organic matter build-up (Bedada *et al*., 2014), resulting in increased yields. However, poor cattle feeding management and nutrients lost due to poor handling result in manure with low P levels (Castellanos-Navarrete *et al*., 2015). Although manure use is of economic benefit to the smallholder farmers of this region, there is still a challenge of not getting significant amounts of manure from their farms which can be used as farm inputs. To overcome the challenges faced by the smallholder farmers, P levels should be increased to substantial amounts to improve soil conditions and increase crop yields and thus impact the community positively economically.

A good source of P as an alternative to inorganic sources is phosphate rock, and research has proved its use as effective (Qureshi *et al*., 2014). However, phosphate has low solubility, and it is necessary to identify the best management practices for enhancing its availability to crops. The study was carried out to evaluate the impact of phosphate rock fertilizer on maize yields and chemical composition in acidic soils of Tharaka-Nithi County.

2. Materials and Methods

2.1 Description of the Study area

The study was carried out in Kigogo Primary School (S 00°20'07.0"; E 037°36'46.0") in Meru South Sub-county, Tharaka-Nithi County. The altitude of this area is 1526 m above sea level and is located on the Eastern slopes of Mt. Kenya. The county has a bi-modal rainfall pattern, with the long rains running from March to June, and the short rains start in October and end in December. The area has an annual rainfall of between 1200 mm to 1400 mm (Ngetich *et al*., 2014) and an annual average temperature of 20°C (Nderi *et al*., 2015). The soils in this area are humic nitisols well weathered with moderate to high inherent fertility with clay texture (Omenda *et al*., 2021). The main economic activities are agriculture; livestock keeping, and farming of food crops such as bananas (*Musa acuminate*), maize(*Zea mays*), beans (*Phaseolus vulgaris*), sweet potatoes (*Ipomoea batatas*), yams (*Dioscorea alata*), cassava (*Manihot esculenta*) and irish potatoes (*Solanum tuberosum*) while cash crops include tea (*Camellia sinensis),* coffee (*Coffea arabica*), tobacco (*Nicotiana tabacum*) and butternut (*Cucurbita moschata*) (Njue *et al*., 2020).

Experimental design

The experiment was laid out in a Randomized Complete Block Design (RCBD) replicated three times. The plot size was 6 m by 4.5 m with a 1 m wide alley separating plots within a block and a 2 m wide alley left between the blocks. The land was plowed before planting using a hoe. The test crop was maize (*Zea mays*), H516 variety. Manure and *Tithonia diversifolia* were applied into the planting holes before planting. Phosphate rock was applied one week before planting, while CAN+TSP application was done during planting. Each hole had three maize seeds, with a spacing of 0.75 m between rows and 0.25 m within rows, and thinning was done two weeks after emergence to remain with two plants per hole. The experimental plots were kept weed and pest-free, and disease control was observed. The seven treatments each replicated thrice were: (i) manure, (ii) phosphate rock, (iii) phosphate rock + manure, (iv)*Tithonia diversifolia*, (v) *Tithonia diversifolia* + phosphate rock, (vi) CAN + TSP and (vii) Control (Table 1).

Table 1: Treatment description in the field trial

Treatment	**P rate (kg ha^{-1})**		
	From Organic	From inorganic	Total
1. Manure	60	-	60
2. TSP +CAN	-	60	60
3. Control	-	-	-
4. Phosphate Rock	-	60	60
5. *Tithonia diversifolia* +Phosphate Rock	20	40	60
6. Manure+ Phosphate Rock	20	40	60
7. ***Tithonia diversifolia***	60	0	60

TSP= triple superphosphate, CAN=calcium ammonium nitrate.

2.2 Data collection

A composite soil sample was collected in each plot for analysis before the experiment using an Edelman Soil Auger at a depth of 0-20 cm using a zigzag method. The sample bags were clearly labeled to avoid any mix-up of the samples. This was repeated at the end of the field trial. The samples were taken to the laboratory, where they were air-dried and sieved using 2 mm sieve before analysis.

After harvesting, grain and stover yields (above-ground biomass minus grain) were estimated from the net plot and weighed using a digital scale. Maize cob was separated from the stover, sun-dried, and packed in gunny bags for threshing. After this, the moisture content of grains was determined using the moisture meter and recorded. The grain weight was then standardized by adjusting to a per hectare basis at 12.5% moisture content and expressed in t /ha.

Rainfall measurements were taken daily using an automatic rain gauge with 0.2 mm resolution stationed within the field trials. The rain gauge data was read out using HOBO ware Pro Version 3.2.2 and data exported to excel worksheets for further processing.

2.3 Laboratory Analysis

Soil pH was determined in a 1:1 (w/V) soil-water suspension with a pH meter following standard laboratory methods as outlined in Okalebo *et al*. (1993). Other laboratory tests such as available nutrient elements, exchangeable acidity, total C and N, and P-sorption were all carried out following standard laboratory methods as outlined by Okalebo *et al*. (1993).

2.3 Data analysis

Harvest data was managed in MS excel before analysis and subjected to Analysis of Variance (ANOVA) in SAS 9.4. Mean separation was done using the Least Significant Difference (LSD) test at $P \leq 0.05$. Data for soil chemical composition analysis before and after treatments were subjected to t-test and analysis of variance (ANOVA) using the general linear model (GLM) in SAS version 9.4 software and mean separation done using Least Significant Difference (LSD) Test at P=0.05.

For the cost-effectiveness analysis, detailed data on the cost of inputs were collected through a survey of inputs from suppliers in the study area. Time taken for each field operation, including labor cost for land preparation, planting, treatment application, thinning, weeding, pest control, and harvesting, was collected. The average time taken was then calculated and converted into monetary value at 2.49 USD per working day. The partial budget procedure was used for cost-benefit analysis. A rapid market survey was done, and the grain and stover costs were estimated. Maize stovers were used as cattle feed in the area, which was considered as an economic benefit. The net benefit was calculated by subtracting total variable cost from gross benefit for each treatment and benefit to cost ratio calculated as the ratio of net benefit to total variable cost.

3. Results and Discussion

A meteorological drought was experienced during the SR2017 38 days after planting for 80 days, which affected the crop yields greatly (Table 2). Meteorological drought is the absence of rainfall for a period above 28 days during the growing season and is a major challenge in this ecological zone (Kiboi *et al*., 2017). Dry spells, which are also common in the area, expose crops to water stress, as shown in Table 2.

Table 2: Rainfall characteristics of Tharaka-Nithi County during SR2017 and LR2018 Seasons

PARAMETER	**SR2017**	**LR2018**
Start date	12/10/17	03/03/18
Stop date	25/11/17	04/08/18
Length of the rainfall season	46	155
Total rainfall received	608	1200
5 to 10 days	1	2
11 to 15 days	1	2
Above 15 days	0	1
Dry spell seasons	2	5

3.2 **Effects of Phosphate Rock on Grains and Stover Yields**

As indicated in Table 3, there was a significant difference in grain yields was observed in both seasons SR2017 (P=0.005), LR2018 (P<0.05), while stover yields were only significantly different during the LR2018 season (P<0*.05).* In SR2017 season, only CAN+TSP increased both grain yields (92-%) and stover yields (16%) above the control.

During the LR2018 season, CAN+TSP grain yields increased by 188%, followed by sole treatment with *Tithonia diversifolia* at 75% above the control. When manure was used alone as a treatment, an increase of 67% was observed, while treatment with phosphate rock + *Tithonia diversifolia* increased grain yields by 37%. Phosphate rock + manure recorded a grain yield increase of 36% compared to the control (Table 3). Phosphate rock alone gave an increase of 25% lower than when phosphate rock was used in combination with either manure or *Tithonia diversifolia.*

Table 3: Maize grain and stover yields during SR2017 and LR2018 in Kigogo, Tharaka-Nithi County

	SR2017		LR2018	
Treatment	Grain ($t\ ha^{-1}$)	Stover ($t\ ha^{-1}$)	Grain ($t\ ha^{-1}$)	Stover ($t\ ha^{-1}$)
CAN + TSP	0.65[a]	2.14[a]	6.86[a]	7.78[a]
Manure + Phosphate rock	0.14[b]	1.52[a]	3.23[bc]	3.93[b]
Manure	0.15[b]	1.19[a]	4.1[b]	4.20[b]
Phosphate rock	0.19[b]	1.27[a]	3.0[bc]	3.61[b]
Tithonia diversifolia + Phosphate rock	0.1[b]	1.60[a]	3.35[bc]	3.78[b]
Tithonia diversifolia diversifolia	0.17[b]	1.40[a]	4.17[b]	4.60[b]
Control	0.34[b]	1.85[a]	2.39[c]	3.21[b]
P-value	0.005	0.3623	<0.05	<0.05
SED	0.119	0.436	0.676	1.016

TSP= triple superphosphate, CAN=calcium ammonium nitrate. Means with the same letter in each column are not statistically different at p= 0.05.

During the LR2018 season, stover yield had a significant increase almost three times the control (142%) with CAN+TSP, while *Tithonia diversifolia* alone showed a 43% increased followed by manure with a 30% increase. There was a notable increase of 22% above the control when manure was combined with phosphate rock*Tithonia diversifolia,* and phosphate rock had an increase of 18%, while phosphate rock alone gave an increase of 12% (Table 1).

The low grain yields (ranging between 0.1 to 0.65 $t\ ha^{-1}$) during the SR2017 season could be due to the meteorological drought and dry spells experienced during the flowering, grain formation, and grain filling stage. Water is a major constituent of plants' physiological activities, i.e., as a reagent in photosynthesis, affecting plants' productivity (Shittu *et al.*, 2017). Precipitation is a factor that affects agronomic effectiveness by enhancing the plant's ability to utilize available P optimally. For organic matter (*Tithonia diversifolia* and manure) to decompose and provide N for plants during the growing season, good precipitation is required (Nyambati & Opala, 2014). As a result, the crop did not respond well to *diversifolia* and manure either treatments solely or combined with phosphate rock during the SR2017 season. Whereas during LR2018 season, the good rainfalls experience had a positive impact on the organic manure. There was a significant increase in both stover and grain yield compared to the control. The organic inputs (*Tithonia diversifolia* and manure) could retain soil moisture, leading to increased yields during the LR2018 season. The addition of organic inputs contributes to the build-up of SOM, which directly supplies the nutrients necessary for plant growth and indirectly modifies soil physical-chemical characteristics (Adugna & Abegaz, 2016). This is in line with studies carried out by Song *et al*. (2015), who observed that organic inputs increased grain yields.

The highest increase of grain yields with CAN+TSP treatments in both seasons could be attributed to the readily available nitrogen and phosphorus from the inorganic fertilizer. Maize yield doubles when nitrogen fertilizer is applied (Ichami *et al*., 2019) as in treatments with CAN+TSP, where P from TSP was utilized in the same way as P from organic matters. The placement of P fertilizer during the growing season affects P uptake by plants (Arruda *et al*., 2019).

Tithonia diversifolia alone gave a significant high grain increase (75%) associated with its ability to provide nutrient elements such as N, P, and K hence being a good source of plant nutrients (Endris & Dawid, 2015). The high improved soil status leading to increased grain yield can also be due to the ability of the *Tithonia diversifolia* biomass to reduce soil pH and improve biological activities in the acidic soils of Tharaka-Nithi County (Endris, 2019). During the LR2018 season, enough moisture contributed to the rapid decomposing of the biomass, thus improving soil organic matter and other nutrients such as Ca and Mg. This agrees with Mucheru-Muna *et al*. (2014), who reported that the sole *Tithonia diversifolia* realized high grain yields.

Sole manure also showed a significant grain increase of 67%. Studies have shown that treatment with manure as a soil amendment improves soil organic matter, reduces soil bulk density, increases soil porosity, helps maintain soil nutrient balance, improves soil nutrient structure and water holding capacity (Wen *et al*., 2016; Wang *et al*., 2017). These factors improve soil's biological and physical properties, thus increasing plant yields (Mucheru-Muna *et al*., 2014).

3.3 Effects of Phosphate Rock on Soil Chemical Composition

Phosphorus levels were observed to increase over 100% with CAN+TSP, phosphate rock + manure, and phosphate rock +*Tithonia diversifolia.* Sole *Tithonia diversifolia* recorded a significant increase of P by 80% (Table 4). *Tithonia diversifolia* showed a significant decrease in nitrogen (19%) and carbon (25%) (Table 4). Levels of K decreased significantly with CAN+TSP(62%), *Tithonia diversifolia* +phosphate rock (32%), and Manure+phosphate rock (23%). A notable decrease in Mg was also observed with CAN+TSP (59%), Sole phosphate rock (37%), and *Tithonia diversiofolia*+ phosphate rock (36%), as shown in Table 4.

Table 4: Effects of different treatments on pH, total nitrogen, Carbon, Phosphorus, Potassium and Magnesium

Treatments	pH (water)			Total N (%)			Carbon %			P (ppm)			K (%)			Magnesium (%)		
	2017	2018	t-test	2017	2018	t-test	2017	2018	t-test	2017	2018	t-test	2017	2018	t-test	2017	2018	t-test
CAN+TSP	5.51^{a}	5.20^{a}	0.34	0.18	0.15^{ab}	0.46	1.91	1.60	0.39	13.33	229.0^{c}	<0.05*	0.76	0.29	<0.05*	2.44	1.01^{a}	<0.05*
MAN+PR	5.48^{a}	5.64^{b}	0.51	0.16	0.14^{ab}	0.21	1.71	1.36	0.14	10.00	122.0^{b}	<0.05*	0.62	0.48	0.05*	1.86	1.85^{b}	0.06
Manure	5.38^{a}	5.38^{ab}	1.00	0.17	0.15^{ab}	0.40	1.89	1.61	0.21	11.67	36.7^{a}	0.01*	0.76	0.41	0.11	2.48	1.53^{ab}	0.12
PR	5.51^{a}	5.46^{ab}	0.38	0.17	0.14^{ab}	0.32	1.82	1.44	0.38	22.67	54.3^{b}	0.101	0.72	0.42	0.26	2.48	1.56^{ab}	0.03*
TITH+PR	5.34^{a}	5.44^{ab}	0.77	0.14	0.12^{a}	0.41	1.40	1.13	0.39	30.0	227.7^{c}	<0.05*	0.41	0.28	0.05*	2.31	1.61^{ab}	0.03*
TITH	5.65^{a}	5.45^{ab}	0.40	0.16	0.13^{ab}	0.01*	1.70	1.27	<0.05*	16.67	30.0^{a}	0.04*	0.73	0.41	0.06	2.46	1.59^{ab}	0.13
Control	5.54^{a}	5.49^{ab}	0.51	0.16	0.17^{b}	0.83	1.71	1.71	0.99	17.33	41.7^{a}	0.02*	0.78	0.49	0.31	2.70	1.87^{b}	0.99
p-value	0.94	0.45		0.85	0.43		0.80	0.44		0.126	<0.05*		0.48	0.35		0.56	0.14	
SED	0.28	0.19		0.03	0.02		0.34	0.29		6.885	18.9		0.19	0.11		0.40	0.29	

TSP= triple superphosphate, CAN=calcium ammonium nitrate, MAN = Manure PR=phosphate rock, TITH=*Tithonia diversifolia*
SED = Standard Error.
t-test column shows p-value from t-test
* Means there is statistically significant difference at p= 0.05.

A significant decrease in Cu levels was observed with *TitTithonia diversiofolia*+ phosphate rock (55%), followed by sole *Tithonia diversifolia* (47%), *Tithonia diversiofolia* + manure (42%), CAN+TSP (34%), and sole phosphate rock (32%) (Table 5). A notable increase in Fe was observed with CAN+TSP (104%), manure+phosphate rock (35%), phosphate rock(29%), and *Tithonia diversifolia* (19%). Zinc decreased significantly with the sole phosphate rock (32%) as well as Na when sole manure was used (43%) and with CAN+TSP (33%). There was a significant increase in calcium (83%) when phosphate rock+ tithonia was used as a treatment, as shown in Table 5 below. A substantial decrease in p-sorption was observed across all the treatments with a sole application of *Tithonia diversifolia* showing the highest decrease (32%),manure+phosphate rock, sole use of manure, and phosphate rock+ *Tithonia diversifolia as treatments* all showed a reduction of 22%, sole application of phosphate rock (21%). In comparison, CAN+TSP gave the lowest p-sorption at 17%.

Table 5. Effects of different treatments on copper, iron, zinc, sodium, calcium and p-sorption

	Copper (ppm)			Iron (ppm)			Zinc (ppm)			Sodium (%)			Calcium (%)			P-sorption (mg kg^{-1})		
Treatment	**2017**	**2018**	**t-test**	**2017**	**2018**	**t-test**	**2017**	**2018**	**t-test**	**2017**	**2018**	**t-test**	**2017**	**2018**	**t-test**	**2017**	**2018**	**t-test**
CAN + TSP	2.23	1.47	0.05*	17.60	35.97	0.00*	9.76	10.31	0.86	0.42	0.28[a]	<0.05*	1.93	1.47[a]	0.444	1098	913*	0.02
MAN + PR	2.25	1.30	<0.05*	18.70	25.30	0.04*	9.44	7.78	0.55	0.38	0.40[ab]	0.78	1.73	2.90[ab]	0.084	1105	860	<0.05
Manure	2.09	1.26	0.16	17.40	23.67	0.16	10.93	8.10	0.13	0.46	0.26[a]	<0.05*	1.93	1.60[ab]	0.673	1091	853	<0.05
PR	2.16	1.19	0.01*	17.53	22.57	0.01*	11.30	7.74	0.04*	0.34	0.44	0.43	2.07	2.47[ab]	0.444	1069	848	0.01
TITH + PR	2.38	1.07	0.01*	19.83	29.53	0.08	12.23	10.84	0.45	0.40	0.48[b]	0.56	1.80	3.30[b]	0.29	1087	852	0.01
TITH	2.32	1.23	<0.05*	19.03	22.73	0.02*	11.93	10.32	0.70	0.32	0.28	0.42	2.07	1.80[ab]	0.561	1089	744*	0.01
Control	2.27	1.47	0.08	17.27	32.30	0.16	11.63	10.25	0.23	0.36	0.30	0.16	2.13	2.27[ab]	0.422	1027	848	0.07
p-value	0.976	0.66		0.73	0.19		0.75	0.74		0.33	0.10		0.97	0.26		0.93	<0.05	
SED	0.15	0.16		0.32	0.25		1.83	5.67		2.01	2.55		0.47	0.80		70.1	18.1	

TSP= triple superphosphate, CAN=calcium ammonium nitrate, MAN = Manure PR=phosphate rock, TITH= *Tithonia diversifolia*.
SED = Standard Error.
* Means there is statistically significant difference at p= 0.05
t-test column shows p-value from t-test

Increased levels of total P in the soil reported in CAN+TSP treatment could be related to the soluble nature of TSP, allowing it to be fixed and transformed into NaOH-Pi pool, a sink for soluble P, which is unavailable to plants thus large quantities in the soil (Nyambati & Opala, 2014). An increase in total P in the soil by sole manure and *Tithonia diversifolia* could be attributed to the fact that organics improves soil biological activities and reduces soil P adsorption capacities, thus making it available to the plant (Endris, 2019). The general decrease in nitrogen due to *Tithonia diversifolia* could be associated with increased uptake of the nutrients by plants by removing them from the soil hence low nutrient availability. This is in line with other studies (Savini *et al*., 2016; Ademba *et al*., 2015; Mucheru-Muna *et al.,* 2014), indicating that organic fertilizers increase recovery of applied nutrients. Low soil organic carbon observed could be attributed to high SOM decomposition rates resulting in subsequent SOC losses (Ghosh *et al.*, 2016). This is as a result of high temperatures in the tropics increasing microbial activities in the soil (Luambano *et al*., 2015). Soil organic carbon decomposition depends largely on temperature (Zhang *et al*., 2015).

The addition of nitrogen lowers soil base cations but increases non-basic cations (Tian & Niu, 2015), and this was observed with treatments with CAN+TSP; thus, a decrease in Mg, K, and Na was observed with this treatment. A decrease in Mg levels in soil can result from the uptake of the nutrient by plants leading to accumulation in plant tissues (Szczepaniak *et al*., 2016). The decrease in K observed could be associated with acidic soils being inherently low in K or being removed during harvest without any replenishment (Zörb *et al*., 2014). The increase in Ca when phosphate rock+ *Tithonia diversifolia* was used as a treatment is in line with studies that tithonia has the potential of increasing soil Ca (Muchiri, 2014). Reduced levels of Cu and Zn can be associated with heavy metal immobilization with the use of rock phosphate and organics (Zhao *et al*., 2014), while a decrease in Cu is observed with CAN+TSP could be associated with the nutrient leaching to the nearest field trial. High levels of iron could be due to the acidic nature of the soil favoring high concentrations of Fe^{2+} (Tandzi *et al*., 2018).

There was a significant decrease in P-sorption where organic inputs were used solely or combined with phosphate rock, with sole *Tithonia diversifolia* showing the highest decrease (32%). This is in line with Fink *et al*. (2016), who reported that negatively charged functional groups in organic substances could interact with positively charged minerals like iron oxides altering P adsorption sites. This interaction can promote anion adsorption via cation bridges (Fe^{3+}), increasing the specific surface area (SSA) by inhibiting mineral crystal growth (Fink *et al*., 2016); thus, there is increased competition with other anions for adsorption sites, and adsorbed ions are desorbed. As a result, P becomes available in solution form (Nishigaki *et al*., 2019). Sole phosphate rock treatment gave similar results to organic elements such as manure. Phosphorus sorption properties of the soil influence P availability to plants from phosphate rock. Highly acidic soils result in low P-sorption as (Matamwa *et al*., 2018) phosphate rock is reactive in highly acidic conditions even with less than 4.5. The decrease in P-sorption with CAN+TSP can be attributed to the movement of some organic treatments to the trial field where CAN+TSP was applied.

3.4 Cost-benefit analysis

Control had a higher net benefit (USD 45.46) than other treatments in SR2017 (Table 6). During the LR2018 season, the net benefit was significantly higher at $P<0.05$, with the highest net benefit observed with CAN+TSP treatments (USD 1419.8). *Tithonia diversifolia* + phosphate rock gave lower benefits (USD 565.3) than sole use of *Tithonia diversifolia*

(USD 905.6). This was also observed with sole manure application (USD 712.6) versus manure + phosphate rock (USD 574.7).

Table 6: Cost-benefit analysis

Treatment	SR 2017			LR 2018		
	Net Benefit (USD)	BCR (USD)	Return to labour (USD)	Net Benefit (USD)	BCR (USD)	Return to labour (USD)
CAN+TSP	-138.2	-0.33	-2.27	1419.79	2.81	23.14
Manure + Phosphate Rock	-133.2	-0.63	-2.33	574.66	1.66	8.1
Manure	-167.5	-0.7	-2.7	712.63	1.83	8.89
Phosphate Rock	-64.33	-0.43	-1.43	572.4	2.09	10.6
Tithonia diversifolia + Phosphate Rock	-128.47	-0.67	-2.17	565.33	1.67	7.45
Tithonia diversifolia	-27.9	-0.23	-0.43	905.56	3.46	10.34
Control	45.47	0.47	0.93	510.69	2.36	10.26
p-value	<0.05	0.12	0.01	0.01	0.28	0.07
SED	41.96	0.40	0.86	200.99	0.80	4.74

Means with the same letter in each column are not statistically different at p= 0.05

Sole application of *Tithonia diversifolia* gave a high BCR (USD 3.46) as compared to the rest of the treatments. The lowest BCR was reported in manure +phosphate rock (USD 1.66). Sole phosphate rock gave low BCR (USD 2.09) as compared to the control (USD2.36) (Table 6). During the LR2018 season, a break-even point was arrived at with all the treatments. A break-even point is arrived at when a BCR of 1 is achieved, and this determines cost recovery with any new treatment application. During the SR2017 season, there was a significant difference with treatments with phosphate rock and when no input was added (control). However, the two did not reach the break-even point due to the low yields realized in this season. The low yields were a result of low precipitation during this season.

Generally, all the treatments had a positive return to labor (above 1), with CAN+TSP giving the highest return to labor during the LR2018 (USD 23.14) as compared to other treatments. Sole phosphate rock and *Tithonia diversifolia* gave higher returns (USD 10.60 and USD 10.35), respectively, as compared to the control (USD 10.26). Manure and manure+phosphate rock had a low return to labor (USD 8.90 and USD 8.10) as compared to control.

The high net benefit with control in SR2017 could be attributed to the poor yields experienced as a result of the poor rains, while high benefits in LR2018 agree with Mucheru-Muna *et al*. (2007), who reported that no benefits were realized when there were no inputs added to the soil. The high net benefits with sole treatments with organics versus combined with phosphate rock can be associated with the phosphate rock's insoluble nature, which could have hindered the immediate release of nutrients. The highest return to labor with CAN+TSP could result from nutrients in this fertilizer being readily available for uptake by plants. The process of acquiring and application of the treatment is less laborious as compared to organic inputs. A lot of time and human effort was needed from sourcing, transportation to the application of manure thus increasing the cost of production. To determine the profitable use of any fertilizer, one needs to understand fertilizer agronomics which is the yield response, and fertilizer economics which is the cost of inputs versus output (Liverpool-Tasie *et al*., 2017). This is necessary since the decision by farmers to adapt to the nutrient inputs depends on its profitability.

4 Conclusion

A significant impact on the yields, soil chemical properties, and P-sorption was observed where phosphate rock was applied in combination with organic nutrients. The results indicate that phosphate rock combined with organic nutrients can enhance available P in acidic soils. When phosphate rock was combined with organics showed higher yields than when it was applied solely. The combination also improved the soil nutrient composition and decreased P-sorption making phosphorus available to the maize crop. A high return to labor was realized when phosphate rock was used solely than when combined with organics. Sound knowledge of the interaction between phosphate rock and organic inputs in acidic soils is important in combating the challenge of P deficiency in acidic soils. To ensure rational use of phosphate rock with organic inputs, there is a need to consider the soil's condition in terms of soil pH and P-sorption capacities, and soil moisture content.

Acknowledgement

We would like to thank the Kenyatta University Vice-Chancellor's Award-Agronomic and Economic Effects of Phosphate Rock on Acidic Soils in Tharaka-Nithi County, Kenya, for the support accorded to us towards the field trial and laboratory analysis. We appreciate Jotham Mwiti for his technical support during the field trial.

Conflict of Interest

The authors declare no conflict of interest

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