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Tanzanian Bat Guano as an Alternative Source of Phosphorus for Organic Rice Production

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Many tropical and subtropical soils are low in phosphorus. This is partly because of excessive weathering, high phosphorous (P) fixation rates, and low P levels in soil parent materials. Continuous removal of P from soils by crops, coupled with limited application of P fertilizers, is also among the contributing factors for low P in soils. *Phosphorus is among the most limiting macronutrient in rice (Oryza sativa* L.) production. This study was *conducted to evaluate the suitability of bat guano collected from Kisarawe* (BGK-A and BGK-B) *and Sukumawera caves (BGS) in Tanzania*. The screen-house experiment at the Sokoine University of Agriculture was designed as a 4 × 6 factorial experiment conducted as a randomized complete block design (RCBD). Guano and triple superphosphate (TSP) were used as standard fertilizer at six P application rates. The yield of rice in response to applied TSP was comparable to applied guano but in the order TSP > BGK-A > BGS > BGK-B. All parameters increased with an increase in applied amounts of P from guano and TSP. Besides this study revealed the significant ($P = .05$) interaction between P sources and P rates on plant height (PH), micronutrient concentration and dry matter (DM). The study showed the correlation between grain yield (GY) and other crop components of dry matter (DM), the number of panicles (NP), Panicle height (PAH), plant height (PH) and number of tillers (NT). A significant and positive correlation was found for the GY-DM ($r = 0.58$, $P = .05$), GY-PAH ($r = 0.65$, $P < .001$), and GY-NT ($r = 0.420$, $P = 0.1$). But strong positive

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correlation was found between GY-PH (*r = 0.76, P* < *.001*) and GY-NP (*r = 0.84, P* < *.001*). It was concluded that studied guanos can be used as an alternative source of P, especially for smallholder farmers.

Keywords: Bat guano; grain yield; phosphorous; rice response; yield components.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the second most important food and commercial crop in Tanzania after maize (*Zea mays* L). Fifty percent of Tanzanian farming households depend on rice as a staple food, source of employment and income. Tanzania is among the top rice producers in Africa. The country ranks fourth after Nigeria, Egypt and Madagascar [1], producing 3 million tons annually [2]. The total area under rice cultivation in Tanzania is 1,199,875 ha, which represents 31 % of Tanzania's cultivated land [2]. The average rice yield in Tanzania ranges from 1 to 1.5 tons ha^{-1} because of factors, such as declining soil fertility, drought, insect-pest damage, disease infestations, and poor agronomic practices [3,4]. Soil fertility decline is probably the most limiting factor in rice production. The use of inorganic fertilizers has not been very successful because of various factors, e.g., high and unaffordable prices of fertilizers, non-availability of materials when required, and lack of knowledge about appropriate fertilizer application [5,6]. Consequently, most smallholder farmers cultivate their rice fields without or with minimal application of industrial fertilizers. Low rice yields, coupled with population increase, warrants research on the use of less costly alternative fertilizers.

Despite the local availability of bat guano in Tanzania, little information is available on its use as P fertilizer for rice production. Appropriate application rates and timing of guano application for optimum P uptake in rice production are also not known. This study was conducted to investigate the response of rice to bat guano used as an alternative source of phosphorous for rice production.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted in a screen-house at Sokoine University of Agriculture Department of Soil and Geological Sciences. The screen-house is located at Latitude 06°51' S, and Longitude 37°39' E, at an elevation of 550 m above sea level.

2.2 Soil Sampling and Analysis

A bulk sample of surface soil (0-20 cm depth) was collected from the Soil and Geological Sciences experimental field which is located at Latitude 06°85' S, and Longitude 37°65' E, at an elevation of 550 m above sea level. A random sampling method was used where surface soil samples were collected in two diagonals and thoroughly mixed into a composite sample for a pot experiment. Collected soil was air-dried, crushed and sieved through an 8-mm sieve for pot experiment and representative sub-samples were further ground to pass through a 2-mm sieve for physical-chemical characteristics determination. Particle size distribution was determined by the hydrometer method after dissolving the soil sample in sodium hexametaphosphate solution [7]. Soil textural class was determined by using USDA textural class triangle [8].

Soil pH was determined using a glass electrode pH meter in 1:2.5 (soil: water suspension) [9]. Electrical conductivity was measured in 1:2.5 (soil: water suspension) by using a conductivity meter [9]. Organic carbon was determined via the Walkley and Black method using wet oxidation with potassium dichromate [10]. Total N was determined by the micro-Kjeldahl digestion procedure, followed by distillation [11]. Available P was extracted using the Olsen method [12] and determined by the ascorbic acid colorimetric method [13]. Cation exchange capacity (CEC) was determined by using the neutral ammonium-acetate saturation method (NH_4OAc, pH 7), followed by Kjeldahl distillation. Exchangeable K, Ca, Mg and Na were determined from the ammonium-acetate filtrates by Atomic Absorption Spectrophotometer [7]. Laboratory analyses revealed that experimental soil was sandy clay with neutral pH and medium total N and available P (Table 1). The soil had adequate essential micronutrients and exchangeable cations, except Zn which was deficient.

2.3 Design of the Pot Experiment

The experiment was carried out as a 4 × 6 factorial experiment using a randomized complete block design (RCBD). The first factor was P sources with four levels, namely, bat guano from Kisarawe cave A (BGK-A), bat guano from Kisarawe cave B (BGK-B), bat guano from Sukumawera cave (BGS) and triple superphosphate (TSP) used as standard fertilizer for comparison. The second factor was six rates of P application: absolute control, 0, 10, 20, 40, and 80 mg P kg^{-1} soil (Table 2). The experiment was replicated three times.

2.4 Set- up of the Pot Experiment

A bulk soil previously sieved through 8 mm was used to test rice response to various P sources and rates in the pot experiment. Four kilograms of soil were weighed and placed into each pot previously labeled according to the treatment to be applied. After weighing the soil, the respective amount of each P source required to supply the prescribed P rate was weighed using a chemical balance and thoroughly mixed with the soil on a polyethylene sheet. To avoid cross-contamination of treatments, different sheets were used to mix soils receiving different P sources and the lowest rate of each P source was mixed first, followed by subsequent higher rates. Nitrogen was uniformly applied in the form of urea ($CO (NH_2)_2$) was uniformly applied at a rate of 400 mg N kg^{-1} in two splits to all pots (except absolute controls) [14,15,16] and zinc was applied at a rate of 2.5 mg Zn kg^{-1} soil as zinc sulfate ($ZnSO_4$) [17]. Only N and Zn were applied because of their insufficient amounts in the soil.

Table 1. Physico-chemical properties of the soil used in the experiment

Parameter	SI-unit	Value	Rating	Reference
pH (H_2O)		7.2	Normal	Msanya et al. 2001
EC	mS/cm	561	Normal	Msanya et al. 2001
OC	%	11.05	Very High	Landon, 1991
Total nitrogen	%	0.48	Medium	Landon, 1991
Available phosphorus	mg/Kg	6.59	Medium	Landon, 1991
Calcium	cmol (+) Kg^{-1}	7.97	Medium	Msanya et al. 2001
Sodium	cmol (+) Kg^{-1}	3.98	Very High	Msanya et al. 2001
Magnesium	cmol (+) Kg^{-1}	5.12	High	Msanya et al. 2001
Potassium	cmol (+) Kg^{-1}	6.07	Very High	Msanya et al. 2001
Cation Exchange Capacity	cmol (+) Kg^{-1}	20.2	Medium	Msanya et al. 2001
Copper	mg kg^{-1}	3.79	Sufficient	Landon, 1991
Zinc	mg kg^{-1}	1.61	Deficient	Landon, 1991
Iron	mg kg^{-1}	133.98	Sufficient	Landon, 1991
Manganese	mg kg^{-1}	98.80	Sufficient	Landon, 1991
Particle size:				
Sand	%	49.3		
Clay	%	41.1		
Silt	%	9.6		
Textural class	Sandy Clay			FAO, 2006

Table 2. P rates used in pot experiment

P rate (mgP kg^{-1})	Equivalent rate of each P source applied (mg kg soil^{-1})			
	BGK-A	BGK-B	BGS	TSP
0^a	0	0	0	0
$P_0{}^b$	0	0	0	0
P_{10}	0.47	0.57	1.16	0.2
P_{20}	0.94	1.14	2.32	0.4
P_{40}	1.88	2.28	4.64	0.8
P_{80}	3.76	4.56	9.28	1.6

[a,] *Without addition of any external source of nutrients (Absolute control)*

[b,] *All nutrients were applied to recommended levels except P*

After mixing with fertilizers, the soil was re-filled in the pots and equilibrated to about 90% of field capacity by using tap water. After 24 hours of equilibration, eight rice seeds (*Oryza sativa* L.) variety SARO-5 were planted and irrigation was done to maintain soil moisture around field capacity for the first 21 days. On the 21st day after germination, the rice plants were thinned to four plants per pot, and the soil was submerged to mimic the recommended water supply for low-land rice culture. Weeding was done by uprooting all emerging weeds to keep the crop free from weed competition. The second split of N was applied during panicle initiation.

2.5 Physiological Data Collection

Physiological data for rice response as determined by P sources and rates were collected from initial stages of growth, vegetative, maturity, and harvesting. The parameter assessed were plant height (PH) and panicle height (PAH) measured by using a tape measure, number of tillers (NT), tissue nutrient concentrations, dry matter yield (DM), number of panicles (NP), and grain yields (GY). On the parameters of NT, PAH, PH and NP the data were collected at the 28th, 56th and 84th day after sowing. This interval of time was recommended due to a similar study held by [18] in the phosphorous release from bat guano which gave out P to be progressively increased with time from 28 days and reached its peak at 84-112 days of incubation. As well as justified by [19,20,21] in their studies of incubation methods of fertilizers in soils.

When the crop was at the booting stage, one plant was cut close to the soil surface from each pot by using sharp scissors for tissue nutrient analysis and the remaining three plants were maintained in each pot to maturity. Above-ground plant parts harvested at the booting stage were thoroughly washed using distilled water, oven-dried at 55 ^{o}C for 72 hours to constant weight, and ground to pass a 0.5 mm sieve. Ground plant materials were digested by dry ashing at 600 ^{o}C in a muffle furnace and allowed to cool. After cooling, the ash sample was diluted in a 6N HCl and the digest was filtered for determination of P, K, Fe, Zn, Cu, and Mn. In the digests, P was determined following a colorimetric procedure [13], K was determined by Flame Emission Spectrophotometer [22], whereas Fe, Zn, Cu, and Mn were determined using Atomic Absorption Spectrophotometer [7]. Nitrogen in-ground plant samples were determined by the Macro-Kjeldahl method [23]. When the remaining plants reached maturity, the average number of panicles per plant was recorded and harvested, and rice grain yield was determined by weighing the grains harvested from each pot.

2.6 Data Analysis

Collected data were subjected to analysis of variance using GenStat Discovery Edition 14 software [24]. Treatment means separation was done via Duncan's New Multiple Range Test at the 5% probability level. Correlations between grain yield and other crop components were carried out using Analysis Tool Pak in MS Excel (Microsoft 2010).

3. RESULTS

3.1 Effect of P Rate on Number of Tillers and Plant Height

The effect of P rates on the number of tillers and plant height is presented in Table 3 and the ANOVA for plant height and the numbers of tillers are presented in Tables 4 and 5, respectively. There was a significant effect of P rates ($P < 0.05$) on the number of tillers and plant height on the 28th, 56th, and 84th days after sowing for all P sources.

3.2 Interaction Effect of P Sources × P Rates on Number of Tillers and Plant Height

There was no significant interaction effect of P sources and P rates on the number of tillers for all treatments. However, significant interaction effects of P sources and P rates ($P < 0.05$) were observed on plant height (Table 6). Plant height increased gradually with an increase in the number of days after sowing. The tallest plants (53, 105, 119.5 cm) were observed in pots receiving 80 mg P kg^{-1} of soil from TSP at 28 days as well as from BGK-A at 56 and 84 days after sowing, respectively. A higher increase in plant height was observed in plants that received TSP than those received guano (BGKA) on the 28th day after sowing.

3.3 Effects of P Sources, P Rates and their Interaction on Plant Tissue Nutrient Concentrations

3.3.1 Effects on macronutrients concentration

There was no significant effect of P sources and interaction of P sources × P rates ($P < 0.05$) on macronutrients concentrations in plant tissue (Table 7). Only P rates showed a significant effect on tissue macronutrients concentrations (Tables 8 -10).

Table 3. Effects of P rates on number of tillers and plant height at various growth stages

Treatment (mg kg^{-1})	Number of tillers			Plant height (cm)		
	28 day	56 days	84 days	28 day	56 days	84 days
AbsC	4.6 ab	4.9 a	4.92 a	44.8 a	54.0 a	78.1 a
P 0	4.2 a	16.1 b	19.6 b	47.0 b	90.3 b	104.2 b
P 10	4.7 b	17.8 bc	21.2 bc	47.1 b	92.1 bc	107.4 c
P 20	4.6 b	17.3 bc	21.0 bc	48.7 bc	94.1 c	110.0 d
P 40	4.8 b	17.8 bc	20.9 bc	48.8 bc	97.5 d	112.2 de
P 80	49 b	18.7 c	22.8 c	50.7 c	98.2 d	112.9 e
Mean	4.6	15.43	18.4	48	87.7	104
CV (%)	10.8	17.6	14.9	5.1	3.8	2.9
LSD (0.05)	0.41	2.23	2.26	2	2.8	2.4

Means in the same column followed by the same letter(s) are not significantly different at 5% level of probability according to Duncan New Multiple Range Test. Means in each column analyzed separately

Table 4. ANOVA table for plant height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	61.882	30.941	3.51	
Block.*Units* stratum					
P_Source	3	164.20	54.734	6.21	0.001
Rate_mg_kg_1	5	10367.28	2073.456	235.19	<.001
P_Source.Rate_mg_kg_1	15	498.80	33.253	3.77	0.001
Residual	46	405.54	8.816		
Total	71	11497.69			

Table 5. ANOVA table for number of tillers

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	8.361	4.181	0.55	
Block.*Units* stratum					
P_Source	3	17.264	5.755	0.76	0.522
Rate_mg_kg_1	5	2683.236	536.647	71.01	<.001
P_Source.Rate_mg_kg_1	15	94.819	6.321	0.84	0.634
Residual	46	347.639	7.557		
Total	71	3151.319			

Table 6. Effects of interaction between P sources and rates on Plant height

P-Source	Rates (mg kg^{-1})	Plant height (cm)		
		28 days	56 days	84 days
BGK-A	AbC	45.75 abcd	58.50 b	77.4 a
BGK-A	0	45.83 abcde	91.50 defgh	103.0 bc
BGK-A	10	46.67 abcdef	95.00 ghijk	107.3 cdef
BGK-A	20	49.33 cdefg	97.67 hijkl	111.2 efghi
BGK-A	40	49.33 cdefg	100.50 klm	113.3 ghi
BGK-A	80	51.00 fg	105.00 m	119.5 j
BGK-B	AbC	43.83 a	51.67 a	78.1 a
BGK-B	0	47.17 abcdef	91.33 defgh	104.7 bcd
BGK-B	10	49.00 bcdefg	94.00 efghij	107.3 cdef
BGK-B	20	46.33 abcdef	95.83 ghijk	110.0 defgh

P-Source	**Rates (mg kg^{-1})**	**Plant height (cm)**		
		28 days	**56 days**	**84 days**
BGK-B	40	47.00 abcdef	99.50 jklm	112.7 fghi
BGK-B	80	51.00 fg	102.67 lm	116.0 ij
BGK-S	AbC	44.33 ab	52.83 ab	77.3 a
BGK-S	0	47.00 abcdef	90.67 defg	104.3 bcd
BGK-S	10	45.33 abcd	92.33 defghi	106.7 cde
BGK-S	20	48.67 abcdefg	94.67 fghijk	109.3 defg
BGK-S	40	48.3 bcdefg	98.33 ijkl	111.0 efghi
BGK-S	80	47.67 abcdef	89.33 defg	100.7 b
TSP	AbC	45.17 abc	52.83 abcd	79.79 a
TSP	0	47.83 abcdef	87.83 de	105.0 bcd
TSP	10	47.33 abcdef	87.00 d	108.3 cdefg
TSP	20	50.50 efg	88.33 bef	109.5 defg
TSP	40	50.17 befg	91.50 defgh	112.0 efghi
TSP	80	53.00 g	95.67 ghijk	115.3 hij
Mean		48	87.69	104
CV %		5.1	3.8	2.9
LSD (0.05)		4	5.5	4.9

Means in the same column followed by the same letter(s) are not significantly different at 5% level of significance according to Duncan New Multiple Range Test. Means in each column analyzed separately

Table 7. Effects of P- rates on macronutrients tissue concentrations

P-rates (mg kg^{-1})	**Macro nutrients (%)**		
	N	**P**	**K**
Absc	0.927 a	0.115 a	22.09 a
P 0	1.761 b	0.120 a	42.22 bc
P 10	1.791 b	0.137 a	42.80 bc
P 20	1.901 b	0.144 a	37.47 b
P 40	1.872 b	0.178 a	41.26 bc
P 80	1.902 b	0.231 a	44.17 c
Mean	**1.71**	**0.15**	**38.33**
CV (%)	**11**	**83.4**	**17.6**
LSD (0.05)	**0.754**	**0.106**	**5.56**

Means in the same column followed by the same letter(s) are not significantly different at 5% level of significance according to Duncan New Multiple Range Test. Means in each column analyzed separately

Table 8. ANOVA table for P%

Source of variation	**D.F.**	**S.S.**	**M.S.**	**V.R.**	**F PR.**
Block stratum	2	0.04209	0.02104	1.27	
Block.*Units* stratum					
P_Source	3	0.07321	0.02440	1.47	0.234
Rate_mg_kg_1	5	0.11513	0.02303	1.39	0.245
P_Source.Rate_mg_kg_1	15	0.19773	0.01318	0.80	0.675
Residual	46	0.76157	0.01656		
Total	71	1.18973			

Table 9. ANOVA table for N%

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	0.20833	0.10416	2.95	
Block.*Units* stratum					
P_Source	3	0.24816	0.08272	2.34	0.086
Rate_mg_kg_1	5	8.91303	1.78261	50.45	<.001
P_Source.Rate_mg_kg_1	15	0.93213	0.06214	1.76	0.072
Residual	46	1.62551	0.03534		
Total	71	11.92715			

Table 10. ANOVA table for K%

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	613.24	306.62	6.71	
Block.*Units* stratum					
P_Source	3	167.57	55.86	1.22	0.312
Rate_mg_kg_1	5	4104.43	820.89	17.97	<.001
P_Source.Rate_mg_kg_1	15	1053.71	70.25	1.54	0.131
Residual	46	2101.71	45.69		
Total	71	8040.65			

Table 11. Effects of P- sources on micronutrients tissue concentrations

P- sources	Micro nutrients (mg kg^{-1})			
	Cu	Fe	Zn	Mn
BGK-A	9.16 a	171.5 a	15.40 b	482.2 b
BGK-B	10.38 ab	189.8 a	8.97 a	362.0 ab
BGS	11.29 bc	155.9 a	9.20 a	362.5 ab
TSP	12.96 c	170.3 a	11.03 ab	298.2 a
Mean	10.9	171.9	11.15	371.48
CV (%)	27.5	31.8	69.9	55
LSD (0.05)	2.02	36.72	5.23	137.15

Means in the same column followed by the same letter (s) are not significantly different at 5% level of significance according to Duncan New Multiple Range Test. Means in each column analyzed separately

Table 12. ANOVA table for Cu

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	27.728	13.864	1.53	
Block.*Units* stratum					
P_Source	3	138.770	46.257	5.10	5.10
Rate_mg_kg_1	5	36.810	7.362	0.81	0.548
P_Source.Rate_mg_kg_1	15	124.549	8.303	0.91	0.554
Residual	46	417.547	9.077		
Total	71	745.404			

Table 13. ANOVA table for Fe

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	5782.	2891.	0.97	
Block.*Units* stratum					
P_Source	3	10413.	3471.	1.16	0.336
Rate_mg_kg_1	5	26017.	5203.	1.74	0.145
P_Source.Rate_mg_kg_1	15	86859.	5791.	1.93	0.044
Residual	46	137771.	2995.		
Total	Total	266842.			

3.3.2 Effects on micronutrients concentration

There was a significant effect ($P < 0.05$) of all P sources, P rates and P source × P rate interactions on rice plant tissue micronutrients concentrations (Table 11-13).

3.4 Effect of P Sources, P Rates and P Sources × P Rates on Number of Panicles and Panicle Height

3.4.1 Number of panicles per plant

P sources and the interaction of P sources × P rates had no significant effect on the number of panicles per plant while P rates showed a significant ($P < 0.05$) effect on the same parameter (Tables 14 -15).

3.4.2 Panicle height

There was no significant effect of P sources and the interaction of P sources × P rates on panicle height. Nevertheless, P rates significantly ($P < 0.05$) increased panicle height (Table 14 and 16).

3.5 Effect of P Sources, P Rates and P Sources × P Rates Interaction on Dry Matter and Grain Yield

3.5.1 Effect on dry matter yield

P sources showed a significant effect ($P < 0.05$) on dry matter yield (Table 17-18) furthermore there was a significant effect ($P < 0.05$) of P rates and the interactions of P sources versus P rates on dry matter yield. Significantly higher dry matter yield was recorded in plants receiving TSP while BGK-A and BGS ranked next to TSP with statistically similar dry matter yields. BGK-B resulted in the lowest dry matter yields. The highest dry matter yield was recorded in pots treated with TSP, followed by BGK-A and BGS, and lastly BGK-B.

Table 14. Effects of P-rates on number of panicle plant $^{-1}$ and panicle length

Treatment	Number of panicles plant^{-1}	Panicle length (cm)
AbsC	3.00 a	19.18 a
P 0	12.92 b	23.30 b
P 10	13.00 b	23.47 b
P 20	13.75 c	23.58 b
P 40	14.42 c	23.68 b
P 80	15.25 d	24.18 b
Mean	12	22.90
CV (%)	7.5	4.3
LSD (0.05)	0.7	0.80

Means in the same column followed by the same letter(s) are not significantly different at 5% level of significance according to Duncan New Multiple Range Test. Means in each column analyzed separately

Table 15. ANOVA table for number of panicles per plant

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	9.5278	4.7639	5.90	
Block.*Units* stratum					
P_Source	3	6.7778	2.2593	2.80	0.050
Rate_mg_kg_1	5	1227.4444	245.4889	304.06	<.001
P_Source.Rate_mg_kg_1	15	16.8889	1.1259	1.39	0.190
Residual	46	37.1389	0.8074		
Total	71	1297.7778			

Table 16. ANOVA table for Panicle height

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	4.3047	2.1524	2.26	
Block.*Units* stratum					
P_Source	3	6.4466	2.1489	2.25	0.095
Rate_mg_kg_1	5	204.6782	40.9356	42.93	<.001
P_Source.Rate_mg_kg_1	15	12.0603	0.8040	0.84	0.627
Residual	46	43.8587	0.9534		
Total	71	271.3485			

Table 17. Effects of P- sources on dry matter and grain yield

P-source	Dry matter yield	Grain yield
	g pot $^{-1}$	
BGK-A	31.11 b	92.20 a
BGK-B	28.44 a	90.24 a
BGS	31.11 b	93.93 a
TSP	33.17 c	94.64 a
Mean	31	92.75
CV (%)	6.9	10.4
LSD (0.05)	1.4	6.49

Means in the same column followed by the same letter(s) are not significantly different at 5% level of significance according to Duncan New Multiple Range Test. Means in each column analyzed separately

Table 18. ANOVA table for Dry matter

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	42.194	21.097	4.66	
Block.*Units* stratum					
P_Source	3	202.278	67.426	14.88	<.001
Rate_mg_kg_1	5	344.611	68.922	15.21	<.001
P_Source.Rate_mg_kg_1	15	293.056	19.537	4.31	<.001
Residual	46	208.472	4.532		
Total	71	1090.611			

Table 19. ANOVA table for Grain yield

Source of variation	D.F.	S.S.	M.S.	V.R.	F PR.
Block stratum	2	123.95	61.97	0.66	
Block.*Units* stratum					
P_Source	3	208.59	69.53	0.74	0.531
Rate_mg_kg_1	5	91173.42	18234.68	195.09	<.001
P_Source.Rate_mg_kg_1	15	2813.17	187.54	2.01	0.036
Residual	46	4299.46	93.47		
Total	71	98618.59			

Table 20. Effects of P- rates on shoot dry matter yield and grain yield

Treatment	Shoot dry matter yield	Grain yield
	g pot $^{-1}$	
Absc	27.42 a	13.85 a
P 0	29.00 a	101.94 b
P 10	31.25 bc	105.56 bc
P 20	32.83 cd	106.36 bc
P 40	30.75 b	113.74 cd
P 80	33.92 d	115.06 d
Mean	31	92.75
CV (%)	6.9	10.4
LSD (0.05)	1.7	7.9

Means in the same column followed by the same letter (s) are not significantly different at 5% level of Significance according to Duncan New Multiple Range Test. Means in each column analyzed separately

Table 21. Simple correlation coefficients for grain yield and yield components

Characters	Grain yield (g)	Dry matter yield (g)	Number of panicles/plant	Panicle height (cm)	Plant height (cm)	Number of tillers
Grain yield (GY)	1					
Dry matter yield (DM)	0.413*	1				
Number of panicles/plant (NP)	0.945***	0.488**	1			
Panicle height (PAH)	0.844***	0.346*	0.809***	1		
Plant height (PH)	0.909***	0.469**	0.910***	0.857***	1	
Number of tillers (NT)	0.869***	0.460**	0.918***	0.788***	0.872***	1

*Statistically significant effects are indicated: ***, P < 0.001; **, P < 0.05; *, P < 0.1*

3.5.2 Effect on grain yield

The result showed no significant ($P < 0.05$) difference in rice grain yield on account of P sources (Tables 17 and 19).

3.5.3 Effects of P rates on dry matter and grain yield

Shoot dry matter yield significantly ($P < 0.05$) increased with increasing P application rates (Table 20).

3.6 Correlation between Grain Yield and Other Crop Components

We assessed the association between rice yield and other agronomic traits. We found that associations between grain yield and other crop components were dependent. The grain yield per plant (GY) showed a positive and significant relationship with dry matter yield (DM), the number of panicles (NP), panicle height (PAH), plant height (PH,) and the number of tillers (NT) (Table 21). Positive correlation was observed for the GY-DM ($r = 0.41$, $P < 0.1$), GY-PAH ($r = 0.84$, $P < 0.001$), and GY-NT ($r = 0.87$, $P < 0.001$). On the other hand, strong positive correlation was found between GY-PH ($r = 0.91$, $P < 0.001$) and GY-NP ($r = 0.95$, $P < 0.001$).

4. DISCUSSION

4.1 Pot Experiment Visual Assessment of Rice Growth

Germination of seeds started the seventh day after sowing, and the germination was 100% in all Pots. The deposits of some salts were observed on the surface of soils, which implied that the soil from the experimental site had a saline property. The deficiency of nitrogen started to be observed in absolute control pots during the 21st day after sowing by showing yellow coloration of the leaves and in other pots, it was observed during the 42nd day after sowing where it was controlled by adding a second split of N (200 mg N per pot). Pots with bat guano from Kisarawe cave A (Plate 1) showed darker green color in leaves than bat guano from Kisarawe cave B (Plate 2), Sukumawera (Plate 3), and TSP fertilizer (Plate 4) during the vegetative growth stage. Also, the higher number of tillers and height of the leaves were observed plants treated with TSP, BGK-A, BGS, and lastly with BGK-B at a rate of 80 mg P kg^{-1}. The first flower was observed in a pot treated with BGK-A at a rate of 80 mg P kg^{-1} on the 81st day. The latest flowering and maturation of rice grain was observed on absolute control treatment.

Plate1. Rice response to applied guano from Kisarawe cave A (BGK-A) in reproductive stage: from absolute control, 0, 10, 20, 40 and 80 mg/Kg P under screen house condition

Plate 2. Rice response to applied guano from Kisarawe cave B (BGK-B) in reproductive stage: from absolute control, 0, 10, 20, 40 and 80 mg/Kg P under screen house condition

Plate3. Rice response to applied guano from Sukumawera cave (BGS) in reproductive stage: from absolute control, 0, 10, 20, 40 and 80 mg/Kg P under screen house condition

Plate 4. Rice response to applied guano from TSP fertilizer in reproductive stage: from absolute control, 0, 10, 20, 40 and 80 mg/Kg P under screen house condition

4.2 Grain and yield Components Responses to Soil-Applied with Bat Guano

Data presented in Table 3 revealed that the number of tillers increased gradually after thinning up to the maximum tillering stage (around 56 to 84 days after sowing). At this stage, the main culm was difficult to distinguish tillers from the main/original rice plants. Generally, rice plants produce 2 to 5 panicle bearing tillers per plant [25]. The lowest number of tillers per plant (4.92) was recorded in an absolute control because of insufficient nutrients in the soil which limited plant growths.

The highest number of tillers (22.83) was recorded on the 84th day after sowing in treatments receiving P at a rate of 80 mg P kg^{-1} (Table 3) and no additional tillers formed thereafter. The increase in the number of tillers could be attributed to increasing phosphorus application rate to 80 mg P kg soil as reported in other studies [26,27]. Moreover, the highest number of tillers was recorded around 80thdays and no more tillers formed thereafter. This concern could be because of the high rate of mineralization at the mid-period of the study also at that time all plant parts haste to make sure that grains are formed. In most cases, rice tillering begins around 40 days after sowing and can last up to 120 days [28]. Root elongation is the physiological function of P in soil [29], consequently, the availability of P sources in the soil might influence the formation of more roots and increase the number of tillers.

A higher increase in plant height observed in plants that received TSP than those receiving guano (BGK-A, BGK-B, and BGS) on the 28th day after sowing (Table 4) could be attributable to faster P release from TSP which is in mineral and soluble form as compared to guano in which most of its P is in organic form and undergoes gradual release [30]. The shortest plants (43.83, 51.67, and 78.1 cm) at 28th, 56th, and 84th days respectively were recorded in absolute control implying that a positive increase in plant height was attributed to availability as influenced by P application [31]. Furthermore, in absolute control, the deficiency of nutrients could be the source of slow uptake of nutrients which cause stunted growth of rice shoots. The highest P rates of 80 mg P kg^{-1}soil resulted in the highest number of panicles per plant (Table 7) due to an increased supply of P and other nutrient elements in rice [32]. Moreover, the formation of the higher number of panicles could be attributed to the adequacy of other factors such as solar radiation, temperature, and moisture contents reported to have a direct effect on panicles [33] This observation is supported by the lowest number of panicles recorded in absolute control treatments. These results are further supported by findings reported by [34-36].

Moreover, the longest panicle (24.18 cm) was recorded in plants that received the highest P rate (80 mg P kg^{-1} of soil) while the shortest panicle (19.18 cm) was recorded in absolute control indicating a positive effect of P application on panicle height. Many studies showed that panicle development is closely associated with preliminary plant growth which produces good vigor of traits such as leaf emergence rate [37-40]. [41,42] also reported that tillering increases the number of panicles in rice. On the other hand; [43] and [44] reported that reducing the number of tillers and panicle height with increasing stem size can increase the potential yield of rice.

In rice grain yield is determined by plant height, growth period, tillering ability, panicle height, grains per panicle, number of panicles per plant or per unit area, filled grains per panicle, and 1000-grain-weight [45-47]. In this study, it was found that rice grain yield from pots applied to these three types of guano was similar to that of TSP (Table 16). Despite potentially harmful materials such as cadmium, fluoride, uranium, and lead that are associated with several bat guano. There are fewer toxic elements found in these studied guanos. It was found to have only lead material in a trace amount of less than 0.01% [18]. So, they can serve as an alternative P source in organic rice production where industrial fertilizers are not available or acceptable. Moreover, the effectiveness of guano as a source of P is supported by the findings reported by [48] in their study of the effect of bat guano on some yield parameters of wheat.

4.3 Dry Matter Yield and Nutrient Concentrations of Rice Treated with Bat Guano

4.3.1 Dry matter yield

Significantly higher dry matter yield was recorded on plants receiving TSP, followed by BGK-A and BGS which ranked next to TSP with statistically similar dry matter yields and plants treated with BGK-B had a significant difference in dry matter yields (Table 16). This implies that bat guano was as effective as TSP when all P sources were applied at the same rates based on total P contents.

The highest dry matter yield was recorded in pots treated with TSP, followed by BGK-A and BGS and lastly BGK-B. This may be because of more P available from TSP, as P is more soluble from TSP than from bat guano. The differences in P availability from the two types of bat guano (BGK-A and BGK-B) may be attributed to both the nature of food eaten by a bat, geology of the caves, and other environmental conditions that can also account for differences in dry matter yields observed from sources of the two bat guanos.

Conversely, the lowest dry matter yield recorded in BGK-B could also be triggered by the excessively acidic nature of this guano as compared to the other two guano. According to [49], the acidic condition tends to impair absorption of Ca, Mg, and P. It can also increase solubility and toxicity of Al, Mn, and Fe hence reducing the availability of P in soil. Also, he reported that the inhibition of phosphorus uptake and absorption by Al has a drastic effect on the growth of plants include dry matter yield, this statement supports the proneness of low dry matter yield in treatments treated by BGK-B. Similarly, [50] reported that one of the major consequences of acidification is a decline of basic cations such as Ca^{2+} and Mg^{2+}, leading to potential deficiency of these cations for plant growth. Furthermore, at low pH, the bioavailability of Ca may be restricted because of the antagonistic effects of soluble Al. With increasing soil acidification, smaller amounts of Mg^{2+} remain in exchangeable form because of a reduction in negative charge. Since Mg^{2+} is a poor competitor with Al^{3+} and Ca^{2+} for the exchange sites hence it accumulates in the solution and becomes leached.

4.3.2 Nutrient concentrations of rice treated with bat guano

In Table 7 on P rates, only K showed significant effects ($P < 0.05$) in macronutrients analyzed. This could be attributable to the high level of K present in soil (Table 1) and that added from guano during the study. [51] reported that guano contains K which can be released at medium to fast rates within the soil. There was no significant difference ($P < 0.05$) of N and P tissue concentrations on P rates since N was applied at the same rate in all treatments except absolute control and P was applied based on total P contained in the guano source. NPK tissue concentrations were higher on the application rate of 80 mg P kg^{-1} (Table 7). This reveals that the synergistic interaction of plant nutrients influences the higher use of nutrients in a plant. [52] reported that higher K levels in plant tissue increase N uptake and lower K levels decrease the N uptake resulting in low N concentrations in plant tissue. This observation is because a high level of exchangeable K in soil solution improves the N use efficiency of the plant. On the other hand, there was no significant difference in P tissue concentrations in all P rates. This could be due to the reason that the level of P availability in the test soil was medium hence the soil was responsive enough to external P sources. Tissue P concentration (0.23 %) determined in the shoots of rice plants treated with external P sources at the rate of 80 mg P kg^{1} was the above critical range of 0.16% as reported by [17] indicating that P supply at this rate was adequate for rice plants. Similarly, N and K were above the critical range (1.8 – 2.5%) and 1.6 % respectively [17, 53] henceforth there was no limit of rice response to applied P.

On the other hand, all P sources had a significant effect ($P < 0.05$) on plant tissue concentrations of micronutrients (Table 12). This observation could be attributed to the release of micronutrients from the guano as analyzed earlier before sowing.

4.4 Correlation between Grain Yield and Other Crop Components

This study confirmed a positive correlation between rice grain yield and other crop components namely DM, NP, PAH, PH and NT hence these can be successfully used as indicators or determinants of rice grain yield as previously reported by other researchers [54-56]. Results clearly showed a positive association between rice grain yield and crop components mentioned in the above statement. It was found that rice grain yield increased with NP, PAH, and PH while the increase in DM and NT was associated with low grain yield. This gave an impression that NP as the most important agronomic character in rice was influenced by NT produced [57]. Moreover, NP was higher due to the genotype of the rice cultivar SARO 05 (TXD 306) which was used as a test crop. As reported by [58] and [59], SARO 05 is a high-yielding cultivar that produces large NT, NP, and high DM. Moreover, the correlation between PH and GY was strong and positive this is because of the constructive interaction of the genotype and the environment [60]. This study further showed that PAH was high in rice and was associated with high yield. It observed that large PAH was influenced by many spikelets formed per panicle which were associated with higher grain filling proportion.

5. CONCLUSIONS

Rice response to TSP was comparable to that of bat guano from Kisarawe and Sukumawera of Tanzania. Rice yield increased progressively with increasing P levels to the maximum application rate of 80 mg P kg^{-1}. Thus, the three studied bat guano are effective as TSP in improving rice yields. Nevertheless, these results are based on screen-house condition (controlled environment), thus need to be further tested under field conditions to evaluate how rice responds to guano. Field-based results will make it possible to generate recommendations on the use of guano as an alternative P source for rice.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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