ASSESSMENT OF BAT GUANO AS SOURCE OF NUTRIENTS FOR RICE PRODUCTION

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EXTENDED ABSTRACT

Rice production in Tanzania is generally low and continuing to decline partly due to low soil fertility. Smallholder farmers are continuing cultivating in the same area with little or without use of fertilizer due to limited access to costly industrial fertilizers. This trend results into continuous mining of plant nutrients such as phosphorous (P) and other essential nutrients elements which are needed by rice for growth and development; and consequently decline in soil fertility and hence rice production. The country has several bat guano deposits, but none of them are adequately exploited as alternative source of plant nutrients and soil amendment to improve the soil properties because of lack of information on their potential suitability. This study, therefore, aimed to evaluate the agronomic potential of selected bat guano for enhancing soil fertility and improving rice production. Selected bat guano in Tanzania were studied in a laboratory incubation experiment for 112 days to assess P release patterns and establish the pick periods of P mineralization in Department of Soil and Geological Sciences (DSGS) laboratory. Guanos used in this study were from Kisarawe cave A (BGK-A), Kisarawe cave B (BGK-B) and Sukumawera cave (BGS) with 8.55, 7.03 and 3.45 % total P, respectively. Guano from each deposit was mixed with soil at varying rates of 0, 10, 20, 40 and 80 mg P 200 g^{-1} soil. The incubation experiment was arranged as a 3x5 factorial experiment in randomized complete design (RCD) with three replications. In addition to incubation experiment pot experiment was setup to evaluate the response of rice to selected bat guano as a source of phosphorous. The experiment was carried out in a screen house at Sokoine University of Agriculture (SUA). The experiment was a 4 × 6 factorial in a Randomized Complete Block Design (RCBD) replicated three times. The treatments were three bat guano from Kisarawe cave A (BGK-A), cave B (BGK-B), and Sukumawera (BGS) and Triple Super Phosphate (TSP) as standard fertilizer all at six application rates (absolute control, 0, 10, 20, 40 and 80 mg P kg^{-1} soil). Bat guano was supplemented with urea ($CO\ (NH_2)_2$) which was applied at a rate of 400 mg N kg^{-1} and zinc sulphate ($ZnSO_4$) was applied at a rate of 2.5 mg Zn kg^{-1}. Rice SARO variety (TXD 306) was grown as a test crop.

From the incubation experiment, results showed gradual increase of extractable/available P from 28 days to 84 days followed by a decrease in P release up to 112 days of incubation. In all days of incubation there was a highly significant interaction effect of P-sources and application rates ($P < 0.05$) on P released from guano applied at the rate of 80 mg kg^{-1}. The soil pH showed a very strong negative correlation with phosphorus released ($r > 0.8$) from the first day to 112th days of incubation.

The pot experiment results indicated that there was a significant ($P < 0.05$) effect of all three guano and standard P fertilizer (TSP) on dry matter accumulation at maturity in the order TSP > BGK-A > BGS > BGK-B. There was a significantly ($P < 0.05$) higher effect of P at 80 mg P kg^{-1} for all P sources on dry matter accumulation at maturity. Interaction effect of P sources and P rates was highly significant ($P < 0.05$) on dry matter accumulation at maturity. Plant physiological parameters (number of tillers, plant height, panicle height and number of panicles per plant), as well as rice grain yield were also significantly higher for plants receiving 80 mg P kg^{-1} for all P sources. Positive correlation between grain yield and other yield components was observed indicating better crop response to P sources and P rates applied. Both incubation and pot experiment results indicated guano to have similar effect to TSP in releasing P for rice; hence the potential for application as alterative P source. It was further observed that at application rate of 80 mg P kg^{-1} of guano, the studied guanos would release adequate phosphorous for plant growth.

Because these results were obtained under controlled environment field trials are recommended to evaluate the response of rice and other crops to soil applied guano for meaningful recommendations to farmers.

DECLARATION

I, Asha Ally Hatibu, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

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LIST OF ABBREVIATION AND SYMBOLS

Al	Aluminium
Ca	Calcium
Ca^{+2}	Calcium ion
cm	Centimeter
Cmol (+) kg^{-1}	Centimole (+) per kilogram
Cu	Copper
CV	Coefficient of Variation
EC	Electrical Conductivity
et al	and others
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
K	Potassium
LOI	Loss on ignition
LSD	Least Significant Difference
Mn	Manganese
mS/cm	millisiemens per cm
MSc	Master of Science
N	Nitrogen
$\underline{N}$	Normality
Na	Sodium
℃	Degrees Celsius or Centigrade
OC	Organic Carbon
P	Phosphorous
Pb	Lead

Pd	Palladium
pH	Potential Hydrogen
PhD	Doctor of Philosophy
PTEs	Potentially Toxic Elements
RCBD	Randomized Complete Block Design
RLDC	Rural Livehood Development Company
Rh	Rhodium
S	Sulphur
Si	Silicon
Sn	Tin
Sr	Strontium
SUA	Sokoine University of Agriculture
Ti	Titanium
TSP	Triple Super Phosphate
USDA	United States Department of Agriculture
Zn	Zinc

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

The word guano originates from the Andean indigenous language which refers to as accumulated excrement of seabirds, seals or cave-dwelling bats (Sedgwick, 1990; Gomero, 1991). Guano was manure collected by Andean people from small islands of Peru for use as soil amendment for over 1500 years ago (Cushman, 2013). Some indigenous people in Peru and Chile used the thick deposits of seabird excrement, which they called “huanu,” to fertilize their crops (Foster and Clark, 2009).

In Tanzania, bat guano deposits are found at Sukumawera in Southwest Tanzania near Mbeya, Buzuruga in Mwanza region, Amboni caves in Tanga region, and Kisarawe caves in Coastal region as well as at Lantham, Haitajwa and Manapwani caves in Zanzibar Islands. The Kisarawe caves, that were originally used to produce Kaolin minerals, are said to harbour three million bats producing one ton of guano per day (Juma, 2001). Bat guano deposits of Sukumawera in Mbeya are located in caverns in horizontal travertine formations, and some 3223 tons of bat guano were excavated from these caves from 1934 to 1954 for direct agricultural application especially for farmers near the caves areas (Spurr, 1957). A reinvestigation of the bat guano deposit at Sukumawera revealed easily accessible resources with concentrations of between 26 and 37% P_2O_5 (Harris, 1981). Apart from Sukumawera, to date there is no adequate information about the potential of bat guano from other regions although there are many places where bat guano deposits are found in Tanzania which could be used as source of phosphorous (P) for crops such as rice. In Morogoro town, bat guano is found at Mji Mpya along the river Morogoro but its deposit is small and inconsistence and is small due to washing out of bat guano and leaching of nutrients caused by the river floods.

Mlay and Sagamiko (2008) reporetd about the use of Kisarawe bat guano in the improvement of the nutritive value of poor quality roughage fed to ruminants in Tanzania but not for food crop production purposes. Also Andrew (2016) conducted a pot experiment using bat guano from Kisarawe and Sukumawera as soil amendment for maize growth under acidic soils. In this study, maize poorly responded to bat guano due to the fact that the bat guano and soil used were acidic, which led to unavailability of some macro and micronutrients and low microbial activities.

Rice (*Oryza sativa*) is a grain crop, and most widely consumed staple food for a large proportion of the world's human population, especially in Asia. According to FAO (2012), rice as an agricultural commodity ranks the third after sugarcane and maize in terms of world production. In Tanzania, rice is the second most important food and commercial crop after maize, providing employment from production to marketing stages. Thus, rice provides income and food security for Tanzanian households. Tanzania ranks the second largest rice producer among the Southern Africa countries just after Madagascar (Kafiriti *et al.,* 2003). However, rice yields in Tanzania are very low. Yield average only 1.8 t ha^{-1} due to a number of factors among them being inability of the farmers to afford high fertilizer costs and prevailing low soil fertility (MAFC, 2009). Many smallholder farmers use farmyard manure, compost and crop residues as nutrient sources but the available quantity is generally small relative to the needs, and these materials often have alternative uses such as for fodder, thatch and fuel (Rware *et al.*, 2017). There is thus a need of looking for alternative sources of organic materials for use as organic fertilizers. Organic fertilizers are very useful in paddy soil systems since they favour soil fertility maintenance and contribute in building-up of organic matter in soils.

Bat guano is among the organic fertilizers which are rich in nutrients especially P and N nutrients. Studies conducted elsewhere indicate that rice responds to bat guano as fertilizer when it is incorporated into the soil in not less than 90 days prior to harvest (Mutters and Thompson, 2009). Buliga (2010) reported that farmers in Madagascar who have applied guano mad fertilizer have noted an increase in quantity and quality of crops and also fertility of the soil improved, and plant resist to diseases. The study further reported that guano mad gave better response to rice when applied at seedling or at transplanting, and yielded up to 6 tons ha^{-1} compared to 2-3 tons ha^{-1} with other traditional fertilizers. In Tanzania however, the agronomic potential of bat guano is scantly known although there are a lot of bat guano in many areas of the country. The studies using bat guano as fertilizers have not covered many cash and food crops including rice. Thus this study aimed to assess the agronomic potential of selected bat guano in Tanzania as source of nutrients for rice production.

1.2 Problem Statement and Justification of the Study

An increase in Tanzanian population from 44 million to 57 million by 2017 (National Bureau of Statistics, 2016), limited access and high cost of industrial fertilizers led to continuous cultivation in the same area with little or without use of fertilizers (Buresh *et al*., 1997). This trend has led in continuous nutrient mining from the soil and decline of soil fertility and crop yields. Business Monitor International Research (2016) reported an increase in rice consumption in Tanzania from 2012 to 2020 while its production is declining. Use of inorganic fertilizers has been advocated over a number of years for improving soil fertility and consequently crop yields. Their use however is limited due to many factors including unaffordable prices by many small scale farmers, knowledge of application (time, quantity and amount) and type to be used. These limitations made only few farmers to use inorganic fertilizers. This justifies the need for exploiting other and affordable fertilizers such as bat guano which could improve soil fertility and hence rice yields while minimizing risks of environmental pollution associated with chemical fertilizers. Guano deposits are found in several places of Tanzania and are continuously being deposited by bats thus they are renewable. However, little information is known on their quality as organic fertilizer, chemical composition, nutrient release patterns and their response to crops on soils amended with these materials. Furthermore, their potential as fertilizer for crop production including rice scantly known.

In most places in Tanzania rice is grown on slightly alkaline soils and bat guanos are acidic in nature. Application of bat guano to alkaline soils will decrease the soil pH and make the soils become slightly acidic and suitable for rice production. However, it is not known the optimum amounts of bat guano that will give better rice response. The chemical composition of bat guano depends on types of fruits and insects eaten by bat as well as maturity of bat guano and composition of the host rock. Hence, there is the need to determine their chemical and physical properties of bat guano before it is recommended for use as organic fertilizer.

This research was therefore intended to investigate the physical-chemical properties, nutrient release patterns and the potential of bat guano collected from Kisarawe and Sukumawera caves as organic fertilizer in rice production.

1.3 Objectives

1.3.1 Overall objective

The overall objective was to evaluate the agronomic potential of bat guano collected from Kisarawe and Sukumawera caves as soil amendment and source of nutrients for rice production.

1.3.2 Specific objectives

i. To determine physico-chemical properties of bat guano collected from Kisarawe and Sukumawera caves with respect to organic fertilizer applications
ii. To establish the nutrient release patterns of bat guano as influenced by soil physical-chemical properties, and
iii. To evaluate rice responses to soil applied with bat guano collected from selected deposits in Tanzania.

1.4 Organization of the Dissertation

Chapter one is the general introduction. It provides theoretical background information of this study as presented above. Chapter two is on general literature review with respect to bat guano and rice. Chapter three covers the study of phosphorous release from selected deposits Tanzanian bat guanos. In addition, total elemental compositions of Kisarawe and Sukumawera bat guano and physic-chemical properties of the experimental soils collected for incubation experiment were determined.

Chapter four covers the Screen house study designed to assess the response of rice from bat guano as alternative source of phosphorus compared to TSP as standard fertilizer.

Chapter five covers general Discussions from the findings of phosphorous release from bat guano collected from selected deposits during incubation experiment and from Pot experiment.

Chapter six presents general Conclusions and Recommendations. Key issues concluded include physical chemical properties of bat guano and soil used during the study, P release patterns from bat guano during incubation and application time on soil during cropping. Also, conclutions are on comparison between bat guano and TSP in respect to rice responses.

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CHAPTER TWO

2.0 GENERAL LITERATURE REVIEW

2.1 Importance of Bat Guano

In agriculture and horticulture, bat guano is reported to be useful in a number of ways, such as fertilizer material due to high contents of nitrogen (N) and phosphorous (P) (Gillieson, 1996; Furey and Racey, 2016), soil building material, fungicide, control of nematocide as well as compost inoculants (Allocati *et al.,* 2016; Keleher and Sara, 1996; Boyles *et al.,* 2011).

Bat guano typically contains 2-6% total nitrogen, 1.5-10% available phosphoric acid and 1.5-10% soluble potassium (Sikazwe and Waele, 2004). The concentrations of N, P and K in some bat guano meet the 5% N P K composition set as criteria for any material to qualify as a fertilizer (FAO, 2006). High concentrations of primary macronutrients in bat guano can make it a useful fertilizer, especially for lawns. In addition to these major nutrients, bat guano is also reported as source of secondary macronutrients and micronutrients required for healthy plant growth. It has been reported to contain 3.5-9% Ca, 1.5-8% Mg, 0.4-0.8% Mn, 0.2-0.5% Cu, 0.5-1.3% Fe, and 0.2-0.4% Zn (Sikazwe and Waele, 2004; Sridhar *et al.,* 2006). Bat guano is also reported to have pH (water) values of 4-5.6 a range which could allow it to work as a soil conditioner for calcareous soils and thus improving both nutrient supply and rhizosphere environment (Sikazwe and Waele, 2004; Sridhar *et al.,* 2006).

Bat guano like other organic fertilizers, improves soil physical properties especially soil structure, and hence its porosity, aeration, infiltration and water holding capacity, which influence the soil biological and chemical fertility status. Bat guano is not easily leached and thus its benefits to the plants and soil are much more sustainable than those of most inorganic fertilizers (Sothearen *et al.*, 2014). Microbes in bat guano have been reported to have bioremediation capabilities and thus, can aid in cleansing soil contaminants and toxicities (Dowd, 2016). The microbes can also improve soil structure, porosity, aeration and water-holding capacity (Dowd, 2016). With respect to the benefits explained, bat guano is an important source of nutrients for farmers practicing organic farming especially small scale farmers leaving nearby guano deposits. In such cases, it can be used for indoor and outdoor crops as well as for hydroponic crop production.

2.2 Plant Nutrients and Organic Matter Content of Bat Guano

Nutrient contents of bat guano is a function of various factors including the geographical location where the bats and hence guano is found, bat specie, guano age, type and form of caves where bats live and type of diet taken by bats (Bhat *et al.*,1990; Korine *et al.*, 1999). Studier *et al.* (1991) during summer roosting period analyzed Nitrogen (N), Sodium (Na), Calcium (Ca), Magnesium (Mg), Iron (Fe) and Potassium (K) levels in faeces of some neotropical bats and reported that N levels were markedly higher while Na levels were marginally higher in faeces of carnivores and omnivores than in frugivores. Ca levels were higher and K levels were lower in faeces of insectivores. Also the study reported that total Fe levels in faeces of frugivorous species were marginally lower than in carnivores or omnivores, while Mg concentrations was imbalanced in all feeding habits. The study concluded that N, K and Mg appeared to be adequate for bats of all feeding habits. Ross (2003) and Timothy *et al.* (2004) reported that bat guano contained high NPK content which help to improve soil quality and provide nutrients for plant growth. Sridhar *et al.* (2006) analyzed N, P, and K in bat guano. The study showed higher total N levels than P contents. The NPK was higher in fecal pellets than in humus guano with the ratio of 7.9:2.4:1.1 and 5.7:2.2:0.9, respectively. In comparing with other animal manures (poultry, cow and sheep manures) Mathur *et al.* (1990) reported that bat humus guano was higher in

N and organic carbon was lower resulting in narrow C/N ratio, while P was more than in cow and sheep manures.

Emarson and Rork (2007) reported 84.3, 88.4 and 88.8% organic matter in guano produced by bats feeding on insects, blood and fruits, respectively. Studies by Shahack-Gross *et al. (*2004) conducted in Israel reported organic matter contents of 60% and 53-65% in guano produced by bats feeding on fruits and insects, respectively. From India, Sridhar *et al.* (2006) reported 45.6% organic matter contents in insectivorous bat guano. In addition to variations due to bat species, the diets and geographical regions, organic matter content of guano deposit also varies with depth where the topmost centimeters (usually partially decomposed) have the highest organic matter contents. Organic matter contents declines with depth, and is generally completely decomposed within the top few meters (Shahack-Gross *et al.,* 2004; Bird *et al.,* 2007; Wurster *et al.*, 2007). Upon decomposition of organic material in the deposit, much of the carbon is consumed and N is released. The remaining, largely acidic, guano materials interact with weathered material in the cave to form new largely phosphatic, authigenic (secondary) minerals with other elements such as Aluminum (Al), Potassium (K) and Iron (Fe) from the guano (Giurgiu and Tămaş, 2013; Shahack-Gross *et al.,* 2004).

2.3 Effect of Guano on Soil pH

Decu (1981, 1986) observed that there is variation in pH between fresh and old guano deposits. Harries (1970), reported that fresh guano is commonly basic, with the pH varying according to the volume of urine deposited with faeces. Fresh guano commonly had a pH of 8.5 - 9.0 that rapidly became acidic (5.0 - 5.5) with age and depth, although the centre of guano piles had a stable pH of around 4. Barrett (2008), reported that guano contains high concentrations of nitrogen (N). The study explained that higher N concentration lowered soil pH over a long period of time because of building up of N levels in the soil. On the other hand, the acidification of soil due to exchangeable bases (Na, Ca, K and Mg) present in guano is very small causing the pH of soil to remain fairly constant. In a different way, Eghball (2002) and Iyamuremye *et al.* (1996), reported that fairly the addition of manure can cause an increase of pH in soil. Ayers *et al.* (2015), also reported that water birds soils have higher pH due to less accumulation of guano and contain less N, P and metals.

2.4 Comparison of Guano with Chemical Fertilizers

Both chemical and organic fertilizers provide plants with NPK (Bokhtiar and Sakurai, 2005; Chen, 2006), which respectively give plants their green color; promote root and flower development, and the growth of stems. The main difference between bat guano and chemical fertilizers is the rate and state in which minerals are made available to plants. Plants absorb nutrients as mineral salts that have been dissolved in water (Barber and Walker, 1963). The NPK elements derived from chemical fertilizers are immediately available to plants in an unfixed state. This often makes it difficult for plants to use volatile elements like N that volatilize before being fully absorbed (Zapata, 1995) and can lead to overdose of NPK, burning of plant roots and harmful effects to beneficial microorganisms. On the other side, organic fertilizers such as bat guano contain nutrients which must first be decomposed and mineralized by microorganisms in the soil (Sun *et al.*, 2004). These processes fix the minerals in the soil and making it easier for plants to receive, absorb and use them in amounts and proportions of NPK not more than they are needed. Furthermore, the use of guano based fertilizers enhances soil structure and its ability to maintain moisture, while the use of chemical fertilizers leads into hard, poor structured and acidic soils with an impoverished texture (Lal, 1989). Indeed, most chemical fertilizers have no secondary elements and micronutrients such as Ca, Zn, Cu, and Mg which facilitate the different metabolic processes, stabilization and maintenance of soil pH (Hänsch and Mendel, 2009). In addition, using bat guano as fertilizer is said to make plants and fruits both taste better and longer life than when using chemical fertilizers (Buliga, 2010). Also, bat guano fertilizers are considerably cheaper than chemical fertilizers. Chemical fertilizers have potential of causing environment pollution as through runoff they can enter into lakes, rivers and leach into the water (Förstner and Wittmann, 2012). Organic fertilizers such as bat guano can also pollute sources of water, but on a much smaller scale.

Soil physical and chemical properties influence nutrient release patterns of organic residues added to the soil. Knowledge of nutrient availability from added organic residues in different soil types will be valuable for efficient nutrient management and in maintaining synchrony between nutrient release and plant uptake. In the past, several researchers have studied the beneficial effects of guano as sources of nutrients in soils (Fenolio *et al.,* 2006). The use of organic ameliorants such as guano had been reported to enrich the soil with organic matter which improve soil physical properties such as water infiltration, aeration and tilth, react with clay minerals and reduce P sorption characteristics of the soil thereby making more P available for plant use (Hue, 1991).

2.5 Crop Responses to Soils Applied Bat Guano

Bat guano applications enhance plant growth and provide the increment in stem circumference and height (Sothearen *et al.,* 2014). Many trials done by researchers suggested that only small amounts of bat guano are required to enhance the efficiency of plant growth mostly 0.1, 0.5 and 1 g per 20 g of soil (Sridhar *et al.,* 2006; Shetty *et al.,* 2013). Moreover, amending the bat guano with other organic manure such as farm yard manure, green manure, bio-slurry, etc. in appropriate ratios may increase availability of nutrients and help overcome the nutrient deficiencies so as to improve crop production (Sridhar *et al.*, 2006). Ciancio *et al.* (2014), reported the accumulation of grain yield and dry matter production in maize and beans fields on application of manure.

Sridhar *et al*. (2006) reported on the efficiency of humus-like bat guano in crop production by observing the response of finger millet (*Eleusine coracana*) and legume (*Phaseolus mungo*) to different rates in weight applied in the red loamy soil. Both crops, in soil amended with bat guano at the ratio of 20:1 showed the highest shoot length, total dry matter, N content and N uptake. The shoot length, total dry matter, N content and N uptake in both crops were significantly higher on treatment 20:1 than that of control.

Shetty *et al.* (2013) studied the effect of bat guano on the growth of *Vigna radiata* (mung bean) seedlings using bat guano from semicarnivorous bats. The guano came from two different geographical locations (Varanga and Yennehole) applied in different ratios (soil: guano; 20:1, 20:0.5, 20:0.1) and in two types of soil (Autoclaved and Non-autoclaved). Plant growth assay indicated that guano from Yennehole was found to be better compared to that from Varanga. Amendment of both types of soil with bat guano from both locations showed good growth at soil: guano ratio of 20:0.5, with higher rates gave poor response.

2.6 Potential Challenges Facing the Use of Bat Guano as Organic Fertilizer

The use of bat guano as organic fertilizer has many challenges including, hazardous health effects to the farmers who use bat guano as organic fertilizer. High risk of infection can develop severe histoplasmosis (Taylor *et al.*, 2005; Santos *et al.*, 2013; Allocati *et al.*, 2016). Rather than containing micronutrients such as Zn, Fe, Mn and Cu (Sikazwe and Waele, 2004; Sridhar *et al.* 2006), bat guano is the source of heavy metals like Cd, Co, Ni and Pb which can result in serious negative consequences, such as the loss of ecosystems and of agricultural productivity, the deterioration of food chain, contamination of water resources, economic damage, and serious health problems in humans and animals (Aydin *et al.*, 2010).

Most of bat guanos are naturally acidic in nature (Shahack-Gross *et al.*, 2004; Rebollo *et al.*, 2008), and when applied to acidic soils will lead to low crop productivity due to toxicity of Fe, Al and Mn. Also variability in their chemical composition, age, diet and chemical contents of country rock can change the composition of bat guano. Thus, before its application bat guano need to be thoroughly analyzed, tested and validated in farmers fields using different soil types, crops and bat guano application rates.

2.7 Factors Affecting Phosphorus Fixation in Soils

Bat guano contains high P contents, when applied in soil P is relatively stable as it is immobile when compared to N (Sahrawat, 1983; Covert, 1999). To a certain extent, lack of P mobility is due to limited solubility of P compounds in the soil (Von Wandruszka, 2006). Hydrous oxides of Fe and Al fix phosphate through adsorption on their surfaces. The less the crystalline of such compounds the more the fixing capacity of phosphates because of greater surface area. Beauchemin and Simard (1999) reported that soil pH has a profound influence in which soluble P becomes fixed in soil in form of H_2PO_4 or HPO_4^{-} ions. At acidic pH values of less than 6, the $H_2PO_4^{-}$ phosphate ions react with Al and Fe to form less soluble compounds (Fig. 2.1). At alkaline pH values greater than pH 7.5, the HPO_4^{2-} phosphate ions tend to react quickly with Ca and Mg to form less soluble compounds (Hoque, 1981). Other nutrients especially micronutrients tend to be less available when soil pH is above 7.5, and are optimally available at a slightly acidic pH from 6.5 to 6.8. Molybdenum (Mo) appears to be less available under acidic pH and more available under moderately alkaline pH. Organic matter affect P fixation because organic acids produced during their decomposition fallout to solubilize phosphates and other phosphate bearing minerals consequently phosphate fixation is lowered. Temperature contributes in P fixation as it increases the solubility of phosphatic compounds such as apatites, as it speeds up the chemical reactions of P mineralization and microorganism activities are increased. Jones and Wild (1975), reported that low organic matter and low biological activity in the soil can affect buffering capacity of OM. Furthermore, through buffering organic matter retains plant nutrients and prevents them leaching to deeper soil layers, where microorganisms are responsible for the mineralization and immobilization of N, P and S through the decomposition of organic matter (Duxbury *et al.*, 1989).

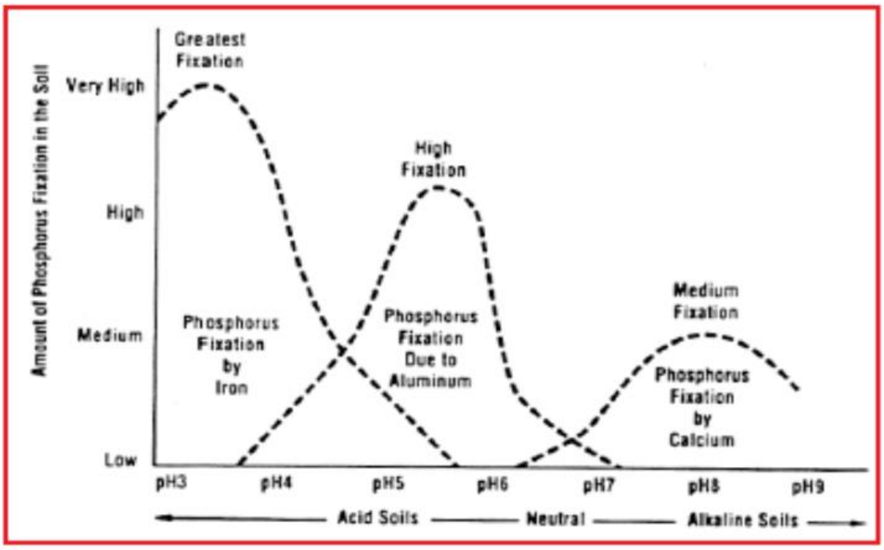

Figure 2.1: Phosphorus availability across pH ranges

(Source: California Fertilizer Association, 1995)

2.8 Phosphorous Interaction with Other Nutrients

In plants, the nutrient interactions are generally measured in terms of growth response and change in concentration of nutrients (Fageria, 2001). Interactions of P with other essential nutrients in crops have been documented in many research studies. Sumner and Farina (1986) reported that P has positive significant interaction with N absorption and plant growth. P interaction with N are both involved in vital plant functions such as photosynthesis, protein formation, and symbiotic N fixation (de Groot *et al.*, 2003; Hernández *et al.,* 2009; Bhardwaj *et al.,* 2014). Weisany *et al.* (2013) reported that during nodulation, P supply is needed in high quantities. When legumes dependent on symbiotic N receive an inadequate supply of P, they may also suffer from N deficiency.

On the other hand, it has also been reported that cytokinin (phytohormones that promote cell division) levels may also offer a possible explanation for a decrease in N uptake at low P levels (de Groot *et al.*, 2003). Cytokinin levels in root exudate (Dhillon, 1978; Menary and Van Staden, 1976) and shoot material (Horgan and Wareing, 1980; Kuiper *et al.,* 1988; Thorsteinsson and Eliasson, 1990) were shown to decrease upon P levels. Other researchers reported that decreasing of cytokinin levels might cause a decrease in nitrate reductase activity within the plant cell (Bueno *et al.*, 1994; Gaudinová, 1990; Lu *et al.,* 1992). Moreover, P has positive interactions with Mg since Mg is activator of kinase enzymes that activates most reactions involving phosphate transfer (Fageria, 2001). Higher inputs of P in soil decrease Zn diffusion rates and finally enhance immobilization of Fe to take place. Smilde (1973) reported positive interaction between P and Mn.

2.9 Phosphorous in Submerged Anaerobic Soils

Amer *et al.* (1991) reported that in submerged soils, P is not directly involved in oxidation-reduction reaction which take place in the soil but it is affected by the changes associated with anaerobiosis process (life in the absence of oxygen). However, submergence usually increases the availability of P in soil and up take by flooded crops such as rice (Savant, 1964; Patrick *et al.,* 1985; Oliver *et al.,* 2011). The increase in P availability to rice under flooded conditions involves the reduction of ferric (Fe^{3+}) phosphate to ferrous (Fe^{2+}) phosphate and the release of P from insoluble to soluble Fe and Al compounds and some dissolution of Ca phosphates when CO_2 levels in the soil solution is very higher (Snyder and Slaton, 2002). In addition, P uptake in flooded alkaline soils improves because of the liberation of P from Ca and calcium carbonate resulting from the decrease in pH. The formation of insoluble calcium phosphate is favoured when the pH is high (Fageria *et al.,* 2011).

2.10 Phosphorus Deficiency and Its Symptoms in Plant

P deficiency is a common problem in many soils of East Africa (Nziguheba *et al.,* 1998). P deficiency symptoms can appear at all stages of plant growth but in young plants it is more prevailed. The initial overall symptom of P deficiency is slow, weak, and stunted growth of the plant. Since P is relatively mobile in plants and can be transferred to sites of new growth, symptoms of dark to blue-green coloration and can appear on older leaves of some plants when P is not sufficient. Under severe deficiency, purpling of leaves and stems also may appear (Blevins, 1999). Lack of P can cause delayed maturity and poor seed and fruit development (Uchida, 2000). In rice and other grass plants, P deficiency does not always show a distinct purple colour. Symptoms may be observed in seedling rice as severe stunting, small diameter stems, and lack of tillering. The dark green colour of deficient leaves can vary to light green or yellow, and in low temperatures, leaf colours become lighter (Tiwari, 2001).

2.11 Importance of Phosphorous in Crop Quality

P is required by crop plants for many physiological and biochemical functions. P uptake varies among rice varieties (Choudhury *et al.,* 2007). This variation is dependent on soil fertility and rice variety (Choudhury *et al*., 1992; Choudhury and Khanif, 2002). Fageria *et al.* (2013) reported that at harvest, P uptake was higher in grains compared to shoots, implying that P is very important element in improving crop yields.

P stimulates root development necessary for plant to get nutrients from the soil. The roots are also necessary for the anchoring of plant. When the roots are well developed, they are able to penetrate the soil and absorb all the nutrients required by the plant for growth. P improves crop quality in terms of many crop aspects (Mullins, 2009). For root crops such as carrots, onions and beets, tuber crops like sweet potatoes, Irish potatoes and cassava, their quality are influenced by P contents. In nutrition of the crop, P is processed in the leaves and then stored or transferred to other parts of the plants, and is responsible for crop maturity at the right time. Crop that lack P take time to mature and hence bear few fruits or seeds which are poor in quality. P deficiency can also delay the ripening of crops which can set back the harvest, risking the quality of the produce. In addition, it reduces the fruits yield and the grain size consequently the crop quality will be affected (Kalra, 1997; Munson, 1997). Plants with P deficiency have high chance of being infested by diseases because most of the plants components made by P. Furthermore, P reduces grain drying expense, increase sugar content, increase proportion of marketable yield, better feed value, and improved drought resistance (Obaid-ur-Rehman *et al.*, 2007).

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CHAPTER THREE

3.0 ASSESSMENT OF PHOSPHOROUS RELEASE FROM BAT GUANO WITH RESPECT TO THEIR USE AS ORGANIC FERTILIZERS IN CROP PRODUCTION

ABSTRACT

Bat guano collected from Kisarawe cave A, Kisarawe cave B and Sukumawera in Tanzania were studied in a laboratory incubation experiment for 112 days to assess the phosphorus (P) release patterns and establish the pick periods of P mineralization. The total P contents of bat guano from Kisarawe cave A (BGK-A), Kisarawe cave B (BGK-B) and Sukumawera (BGS) were 8.55, 7.03 and 3.45 % respectively. The bat guano from each deposit mixed with soil at varying rates of 0, 10, 20, 40 and 80 mg P 200 g^{-1} soil. The incubation experiment was arranged as a 3x5 factorial experiment in randomized complete design (RCD) with three replications. Results showed a gradual increase of P availability from 28 days to 84 days of incubation; followed by a slow decrease up to the 112th day of incubation. P release (availability) from the studied guano was in the order of BGK-B < BGS < BGKA indicating higher potential of bat guano from Kisarawe cave A as an alternative P source for crop production. P-source and application rate had a significant interaction effect ($P < 0.05$) on P release at all incubation intervals when P was applied at 80 mg P kg^{-1} soil. The soil pH showed a very strong negative correlation ($r > 0.8$) with P released in the soil throughout the incubation period. It was concluded that P release from the three bat guano deposits in soils is gradual and reaches the pick in almost three months after application. Thus, in order to make effective utilization of P released from bat guano, it should be applied at least two months before planting. This will ensure that P will be readily mineralized and available in soil to be taken up by plant.

Keywords: Bat guano, Phosphorus release, Incubation, soil pH

3.1 Introduction

Phosphorus (P) is an essential plant nutrient required for optimum crop growth (Grant *et al.,* 2001). In crop production it is the second most limiting nutrient element after nitrogen (N) (Ross and Middleton, 2013). Phosphorus plays vital roles in almost all plant processes including energy transfer, phosphate held as a part of the chemical structures of adenosine diphosphate (ADP) and adenosine triphosphate (ATP). It is the source of energy that drives the large number of chemical reactions within the plant including phosphorylation process (Marschner, 2011).

In photosynthesis, P utilizes light energy in the presence of chlorophyll to combine carbon dioxide and water into simple sugars, with the energy being captured in form of ATP which is available as an energy source for the many other reactions that occur within the plant. Through genetic transfer, P is a vital component of the substances that are building blocks of genes and chromosomes which involve in carrying genetic code from one generation to the next (Sharpley *et al.,* 1999).

Also P is involves in transportation of nutrients through the plant cells (Sharpley *et al.,* 1999). In cereal crops such as rice, P increases panicle number, seed-setting rate and grain weight (Usman, 2013; Tian *et al.,* 2017). Moreover, it stimulates tillering and often hastens maturity (Alkurdi, 2014; Sundaresh and Basavaraja, 2017). Phosphorous improve crop health and reduce the incidence and severity of many fungal diseases such as powdery mildew (Marschner, 2011; Huber and Graham, 1999; Dordas, 2009). Bat guano as organic fertilizer can release P in soil and supplied in plants, hence improve crop productivity. Therefore, this study aimed to assess P release from bat guano with respect to their use as organic fertilizers in crop production.

3.2 Materials and Methods

3.2.1 Geological settings of bat guano deposits

3.2.1.1 Kisarawe bat guano deposits

Kisarawe bat guano deposits are found in Kisarawe district, 25 km west of Dar-es-Salaam City (Appendix 1). The site is located at 38° 78'E / 7° 20'S. Annual total rainfall amount and annual temperature of the area as recorded at Julius Nyerere International Airport (JNIA) meteorological weather station from 2010 up to 2017 are showed in Figure 3.1. In the period from 1950 to 1970 the caves were used for mining kaolinite mineral and thereafter were abandoned. After abandoning the mining activity bat slowly colonized the caves till today, where there are millions of bats permanently leaving as their home. The parent material of the caves is kaolinitic sandstone. The sandstone hosting bat guano is surrounded to the north and western side by clay bound gravels and to the eastern side by superficial white buff sands (Appendix 1).

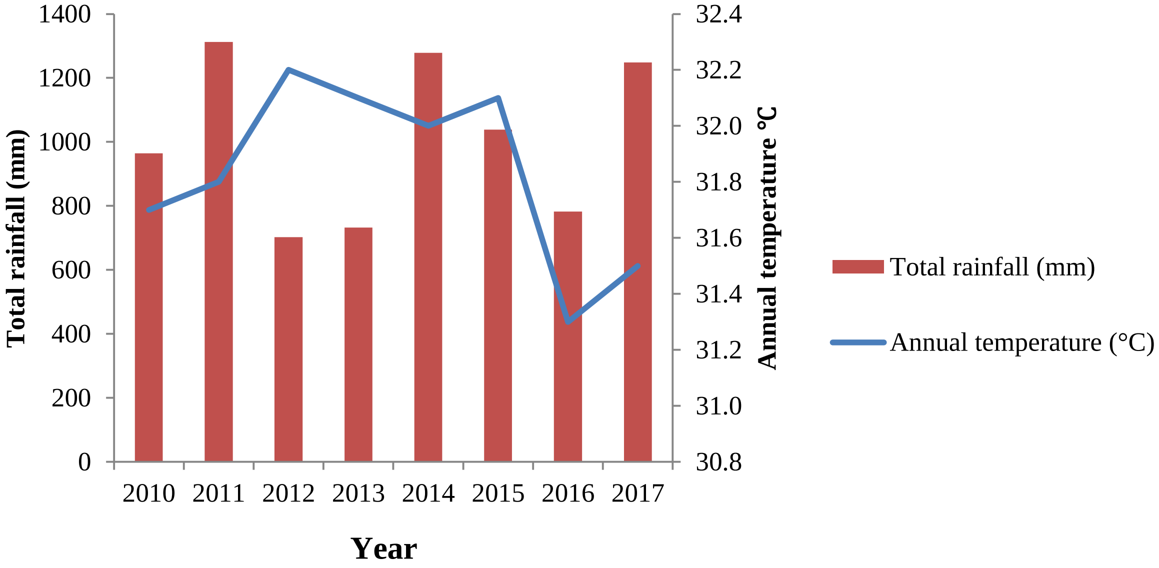


Figure 3.1: Kisarawe annual rainfall and temperature data (2010-17)

Data Source: Julius Nyerere International Airport (JNIA) Meteorological Station.

3.2.1.2 Sukumawera bat guano deposit

Sukumawera guano deposit is found at Majimoto village near the river Songwe, in Songwe district. The site is located at 33° 22'E / 8° 89'S. Annual total rainfall amounts and annual temperature of the area as recorded at Mbimba Mbozi Meteorological Weather Station from 2010 up to 2017 are showed in Figure 3.2. The cave is made of travertine (carbonate rock) within the parent rock which is dominated by mainly Precambrian garnet biotite gneiss (Appendix 2).

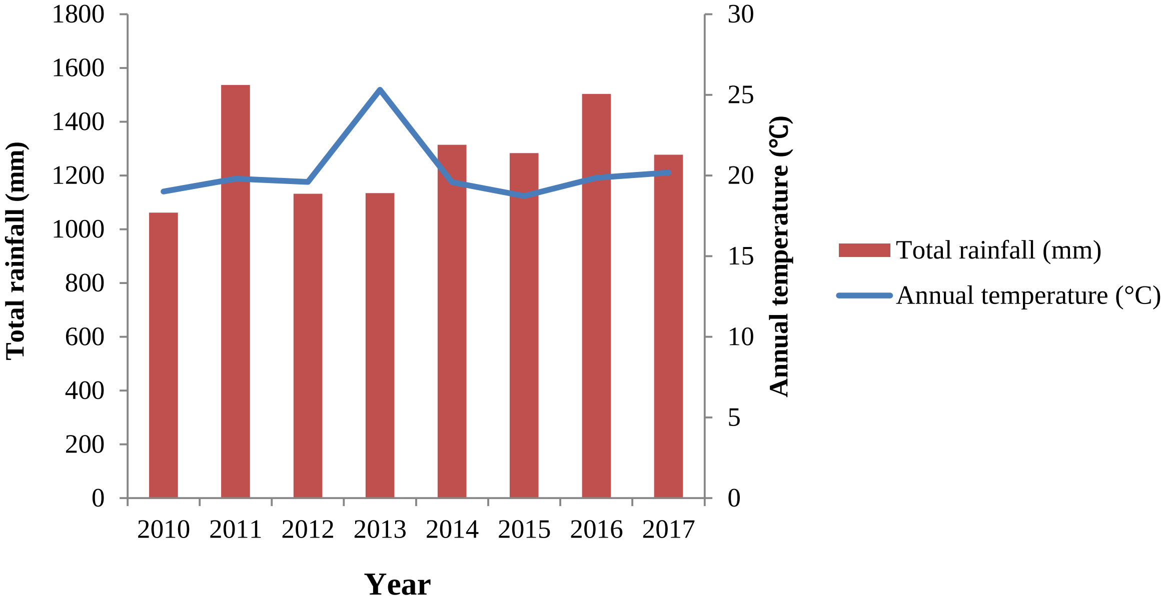


Figure 3.2: Sukumawera annual rainfall and temperature data (2010-17)

Data Source: Mbimba, Mbozi Meteorological Station.

3.3 Sampling and Analysis of Bat Guano

Three composite samples of guano were randomly collected from Kisarawe caves (A and B) and Sukumawera guano deposits. The samples were air-dried in a glasshouse and sieved to pass through a 0.5 mm sieve, labeled and packed in bags and transported for determination of all total elemental composition presented in bat guano at Geological Survey of Tanzania (GST) laboratory by using X-ray Fluorescence (XRF01) pressed powder without binder. The analysis was done by using *Minipal Analytical Software*. While other samples sieved through 2 mm sieve and transported to the Soil and Geological Sciences laboratory at Sokoine University of Agriculture (SUA), Morogoro Tanzania for determination of physical properties including moisture content (MC) and loss on ignition (LOI), chemical properties determined were pH, Electrical conductivity (EC), organic carbon (OC) and total N as described by Okalebo *et al.* (2002) and Moberg (2001).

3.4 Soil Sampling and Analysis

A bulk soil sample was collected at 0-20 cm depth from the Soil and Geological Sciences experimental field, using the random sampling method in two diagonals. The soil was air dried, crushed and sieved through a 2 mm sieve for physical and chemical analysis. Particle size distribution was determined by the hydrometer method after dispersing soil sample in sodium hexametaphosphate solution (Jember, 2011). Thereafter, the corresponding soil textural class was determined by using USDA textural class triangle (FAO, 2006). The pH of the soil was determined using a glass electrode pH meter in 1:2.5 (soil: water suspension) (Warncke and Brown, 1998). Electrical conductivity was measured in 1:2.5 (soil: water) by using conductivity meter (Warncke and Brown, 1998). Organic carbon was determined by Walkley and Black method using wet oxidation by potassium dichromate (Nelson and Sommers, 1996). Total N was determined by the micro-Kjedahl digestion procedure followed by distillation (Okalebo *et al.*, 2002). Available P was extracted using extraction procedure described by Olsen (1954) and determined by ascorbic acid-colorimetric method using a Spectrophotometer (Kuo, 1996). Cation exchange capacity (CEC) was determined by using neutral ammonium-acetate saturation method (NH_4OAc, pH 7) followed by Kjeldahl distillation method. Exchangeable K, Ca, Mg and Na were determined from the ammonium-acetate filtrates by Atomic Absorption Spectrophotometer (Jember, 2011).

3.5 Experimental Design

The experiment was designed as a 3 x 5 factorial experiment laid down in the Completely Randomized Design (CRD) replicated three times. It consisted of two factors which were three P-sources from Kisarawe A, Kisarawe B and Sukumawera deposits at five different levels of application (Table 3.1). Bat guano mixed thoroughly with soil, the mixture was incubated in plastic containers covered with aluminum foil at the top to avoid aeration and covered with cotton wool at the bottom to avoid leaching. It was placed on the laboratory bench at $25^{\pm}$ 1^{o}C for 112 days. Incubation moisture was maintained around 50% of field capacity by adding a predetermined amount of distilled water.

Table 3.1: P rates used in an incubation experiment

P rate (mgP kg^{-1})	**Level of P applied from each source (mg P 200 g soil^{-1})**		
	BGK-A	**BGK-B**	**BGS**
P_0	0	0	0
P_{10}	0.023	0.028	0.06
P_{20}	0.046	0.056	0.12
P_{40}	0.092	0.112	0.24
P_{80}	0.184	0.224	0.48

3.6 Data Collection

After every 28 days, 5 g sample of the incubated mixture was collected by using sterilized spatula for picking and cotton wool for cleaning and analyzed for pH in a 1:2.5 (soil:water) suspension (Warncke and Brown, 1998) and P was extracted by the Olsen extraction method (Olsen *et al.,* 1954), followed by quantification of extractable P using ascorbic acid colorimetric method (Kuo, 1996).

3.7 Statistical Analysis

Analysis of variance was performed on extractable P determined at different intervals of incubation, using GenStat Discovery 15th edition Software. Treatment means were separated using Duncan New Multiple Range Test at the 5% of probability level.

3.8 Results and Discussion

3.8.1 Physico-chemical properties of the experimental soil used in the incubation experiment

The initial physico-chemical properties of the soil used in the incubation study are as presented in Table 3.2. According to Landon (1991), the soil was slightly alkaline with pH of 7.2. Most plant nutrients are optimally available to plants between 6.5 to 7.5 pH (McCauley *et al.*, 2009). Landon (1991) explained that when the pH is low, P could be fixed by Al, Fe and Mn and it could be insoluble when it is higher and can cause calcium inhibition. The texture of the soil was sand clay. The soil texture could influence the availability of P which is mineralized after the amendment of soil with bat guano.

The electrical conductivity (EC) of the soil was 561 mS/cm. According to Msanya *et al.* (2001) is categorized as normal. Kim *et al.* (2007) reported that under anaerobic condition EC has a tendency of showing positive correlation with phosphorus concentrations. The organic carbon (OC) of the soil was rated as very high while total N was medium (Landon, 1991) Olsen extractable P was relatively higher than the critical value for deficiency (4.25 mg P kg^{-1}) as reported by Jones *et al.* (1982). Moreover, Msanya *et al.* (2001) reported that Olsen extractable P higher than 6 mg P kg^{-1}is regarded as medium.

Table 3.2: Chemical and physical properties of soil collected for the incubation experiment

Parameter	**SI-unit**	**Value**	**Rating (Msanya *et al.*, 2001; Landon 1991)**
pH (H_2O)		7.2	Normal
EC	mS cm^{-1}	561	Normal
OC	%	11.05	Very High
Total nitrogen	%	0.48	Medium
Olsen Available phosphorus	mg kg^{-1}	6.59	Medium
Calcium	cmol (+) kg^{-1}	7.97	Medium
Sodium	cmol (+) kg^{-1}	3.98	Very High
Magnesium	cmol (+) kg^{-1}	5.12	High
Potassium	cmol (+) kg^{-1}	6.07	Very High
Cation Exchange Capacity	cmol (+) kg^{-1}	20.2	Medium
Particle size			
Sand	%	49.3	
Clay	%	41.1	
Silt	%	9.6	
Textural class			Sand Clay

3.8.2 Total elemental compositions of Kisarawe and Sukumawera bat guano

Table 3.3 shows the result of the total elemental composition of Kisarawe and Sukumawera bat guano used in this study. The results showed relatively higher total P (8.55%) from BGK-A than BGK-B (7.03%) and BGS (3.45%). Andrew, (2016) reported total P content of Kisarawe bat guano in the range of 7 - 15% P. In Zambia Sikazwe and Waele (2004) reported similar levels of total P (8.41%) for bat guano collected from Kapongo cave

Higher P concentration in Kisarawe caves A and B could be due to high accumulation of daily fresh bat faeces (Zapata, 1995). Total P content determined in Sukumawera guano of 3.45% was lower and different from P content of 20 - 41% previously reported by Andrew (2016) using guano from the same deposit/caves. Such differences could be due to decomposition of bat guano followed by gradual leaching of nutrients including P (Zapata, 1995; Bird *et al.,* 2007; Cleary *et al.,* 2017).

Table 3.3: Total elemental compositions of Kisarawe and Sukumawera bat guano

Element	**Guano type (%)**		
	BGK-A	**BGK-B**	**BGS**
Al	5.82	11.11	Trace
Si	4.21	10.11	2.34
P	8.55	7.03	3.45
S	7.49	4.25	2.87
K	11.04	6.34	3.98
Ca	6.70	4.92	45.67
Ti	0.36	1.98	0.35
Mn	7.36	1.40	0.31
Fe	2.71	4.41	4.70
Zn	1.25	0.86	0.38
Sr	0.09	0.10	1.23
Pd	0.11	0.14	0.05
Cu	0.04	0.05	0.03
Pb	< 0.01	0.01	< 0.01
Zr	0.01	0.03	0.01
Sr	0.01	0.01	0.21
Rh	0.062	0.07	0.03

Potassium (K) is among major nutrient elements required by plants. The total K in guano from Kisarawe cave A was found to be higher (11.4%) compared to that obtained from Kisarawe cave B (6.3%) and Sukumawera cave (4.0%). Other nutrient elements contained in guano include calcium which was higher in guano from Sukumawera deposit (45%) than the other two deposits. This could be due to high Ca contents in parent material of the cave. The parent material of Sukumawera cave is mainly composed of gneiss and travertine; the rocks which contain amphibole, pyroxene and calcite minerals (Hallimond, 1947).

Total Manganese in the three bat guano was low, which are similar to the findings reported by Andrew (2016). Furthermore, total S in the three bat guano was also low. The data reported by Andrew (2016) was contrary to these findings. Andrew (2016) reported higher total S in Kisarawe and Buzuruga caves. Other elements (Pb, Pd, Rh,Ti, Sr, and Zr) apart from Si and Al were found relatively smaller in amounts in the three deposits suggesting that application of guano as organic fertilizer is safe and can't be associated with high risks of PTEs accumulation in the soil environment.

3.8.3 Physico-chemical properties of bat guano used in the experiment

Table 3.4 shows some physic-chemical properties of bat guano used in these studies. The physical chemical properties assessed include pH, electrical conductivity (EC), moisture content (MC), loss on ignition (LOI), organic content (OC) and Total nitrogen. The pH of Kisarawe bat guano from caves A and B was quite different. Cave A was slightly acidic with a pH of 6.1, while pH of cave B was extremely acid (4.3) (Landon, 1991; Msanya *et al.,* 2001). The pH of guano from caves A and B were different although these guanos are from the same geographical location but found in different caves. Their differences could be caused by high amount of organic matter in cave B which was 60% compared to 45% in cave A. This could be due to high acidity reserve in guano which has high OM. Fageria and Baligar (2008) reported that soil which has high organic matter has greater capacity of holding hydrogen ions; therefore it has high ability of reserving acidity. Moreover, McCauley *et al.* (2009) explained that cation and anion exchange capacity are largely determined by the charges of the SOM which are influenced by pH. High amounts of organic matter typically have higher cation exchange capacity (CEC), that is, are able to bind more cations such as calcium or potassium, aluminum and hydrogen ions which have a tendency of lowering pH.

The pH values of bat guano from Kisarawe caves A and B were similar to those reported by Andrew, (2016). Bat guano from Kisarawe caves A and cave B both had very high content of organic carbon (21.5 % and 28 %, respectively). The OC results of bat guano from Kisarawe caves were slightly lower than that from Sukumawera cave (35.10 %). Moisture content of bat guano from Sukumawera was higher compared to that of Kisarawe cave A and cave B. Guano from Kisarawe cave A had higher LOI of 26.23% compared to that of Kisarawe cave B (7.7%) and Sukumawera deposit (15.88%). Total N from both deposits was nearly the same with that from Sukumawera and Kisarawe B deposits being slightly higher than that of Kisarawe cave A. This difference could be due to their slightly higher OC content.

Table 3.4: The physico-chemical properties of Kisarawe and Sukumawera bat guano

Parameter	**Guano type**		
	BGK-A	**BGK-B**	**BGS**
pH (water)	6.1	4.3	6.3
ECe (mS cm^{-1})	17.77	3.28	28.53
OC (%)	21.45	27.95	35.10
MC (%)	14.55	19.71	21.69
LOI (%)	26.23	7.7	15.88
Total N (%)	4.08	5.51	5.57

3.8.4 Effect of incubation time on P release

The P released determined as Olsen available P during incubation for 112 days depicted in Fig. 3.3. P releases were in three regions; the first region was fast release of P and was immediately after day 0 to day 56. The second region was slow release which was from day 56 to day 84. And in the third region P release was decreased from day 84 to day 112. The results were in line with those reported by Nafiu (2009) and Kaloi *et al.* (2011). Both studies reported increase in available P followed by decrease in the release of P. Akhtar and Alam (2001) in their study showed that as the time of incubation increases the P availability in soil decreases for both organic and inorganic P sources due to rapid microbial immobilization of the added sources (Bünemann *et al.*, 2012).

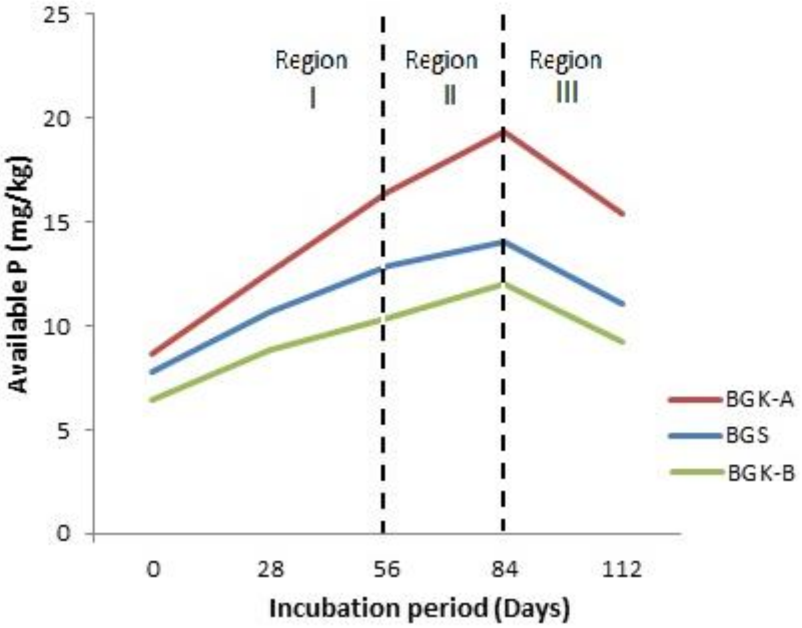


Figure 3.3: P release from different bat guano at varying incubation interval.

3.8.5 Effect of P- rates and interaction between P-sources and rates on P release

The P release significantly increased with increasing application rates of P- sources (Table 3.5). For all three P sources, application of 80 mg kg^{-1} resulted into highest level of P release. These findings are similar to those of Kaloi *et al.* (2011). They reported that phosphate release increase significantly with increase in initial phosphorus levels and decreased with increasing incubation period. The P released was significantly ($P < 0.05$) higher for BGK-A followed by BGK-B and BGS (Fig. 3.4).

Table 3.5: Effect of P-rates on P release at varying incubation intervals

P-rates (mg kg^{-1})	**Days of incubation**				
	0	**28**	**56**	**84**	**112**
P0	5.02 a	4.98 a	5.21 a	5.6 a	5.45 a
P10	6.99 b	10.26 b	13.43 b	14.85 b	11.17 b
P20	7.85 c	10.92 c	14.59 bc	16.58 c	12.94 c
P40	8.77 d	12.01 d	15.40 c	18.55 d	14.31 d
P80	9.40 e	14.16 e	17.55 d	20.22 e	15.60 e
Mean	7.61	10.46	13.24	15.16	11.89
CV %	4.8	4.5	11.4	4.2	5.7
F-pro	<0.001	<0.001	<0.001	<0.001	<0.001

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.

Furthermore there was highly significant ($P < 0.05$) interaction effect between P-sources and rates on P released in soil (Table 3.6). The overall mean results showed significantly higher P release ($P < 0.05$) from BGK-A and BGS at the rate of 40 and 80 mg kg^{-1} as compared to P released from equivalent rates of BGK-B. These differences could be due to variations in their pH. BGK-A and BGS were slightly acidic while that of BGK-B was very strongly acidic (Table 3.4). According to Havlin *et al.* (2005) fertilizers with lower pH prevent P availability in soil due to P fixation.

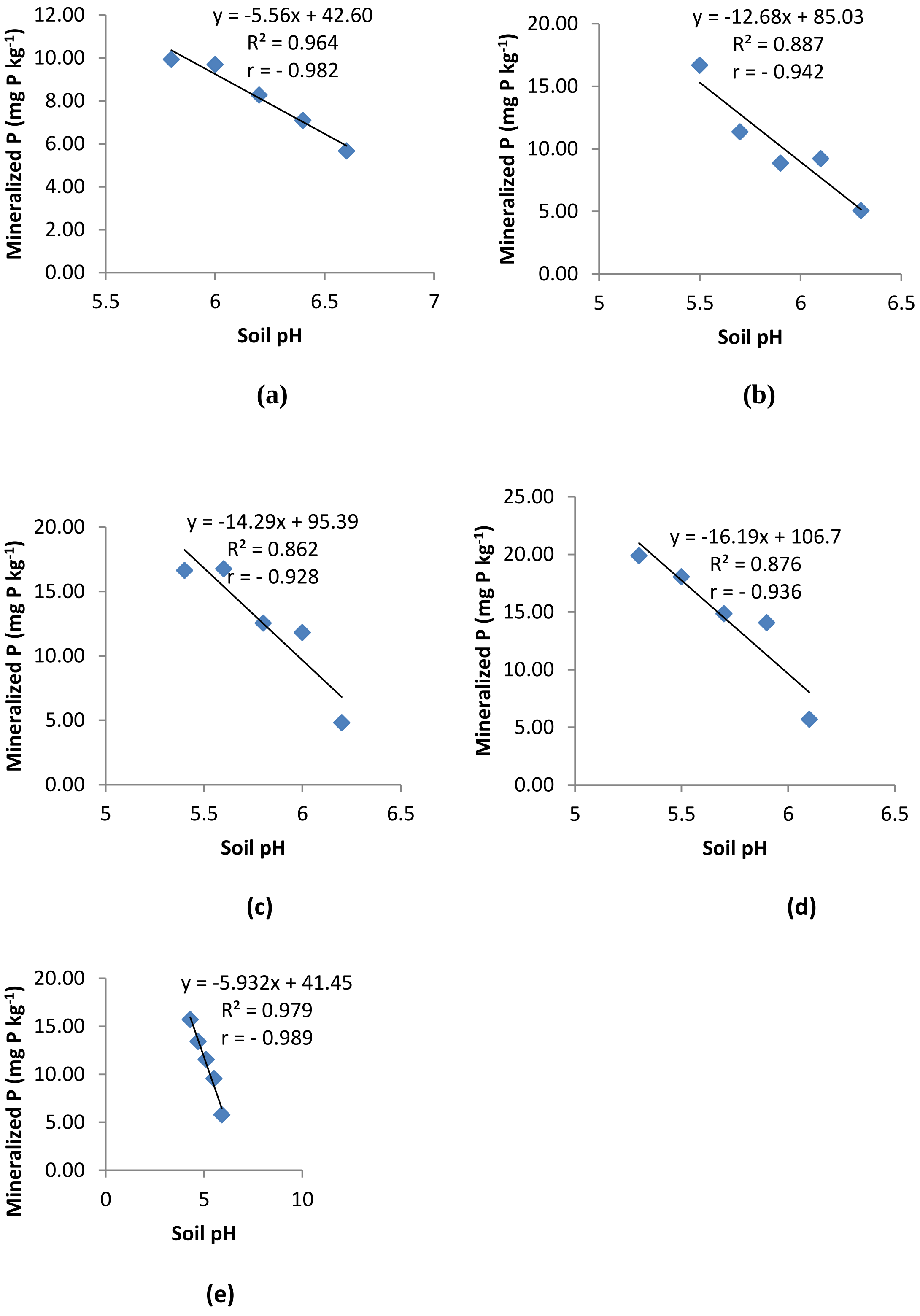
Table 3.6: Interaction effect of P-sources and rates on P released at varying incubation intervals

P-Source	Rates (mg kg^{-1})	Days of incubation				
		0	**28**	**56**	**84**	**112**
BGK-A	0	5.28 ab	5.18 a	5.79 a	5.50 ab	5.19 a
BGK-A	10	8.82 f	13.68 f	17.93 e	20.47 g	16.31 fg
BGK-A	20	9.30 fg	14.14 f	18.81 e	22.02 h	17.44 g
BGK-A	40	9.61 gh	14.48 f	19.13 e	23.69 i	18.66 h
BGK-A	80	10.09 h	15.36 g	20.54 e	25.41 j	19.28 h
BGK-B	0	4.65 a	4.76 a	4.74 a	6.23 b	6.15 a
BGK-B	10	5.59 b	8.21 b	10.69 b	11.35 c	7.70 b
BGK-B	20	6.38 c	9.01 bc	11.18 bc	13.07 d	9.59 c
BGK-B	40	7.25 e	10.40 d	12.18 bcd	12.73 d	10.79 d
BGK-B	80	8.12 e	11.78 e	13.10 bcd	14.66 e	11.88 d
BGS	0	5.12 ab	5.01 a	5.11 a	5.07 a	5.02 a
BGS	10	6.54 c	8.88 bc	11.66 bc	12.73 d	9.50 c
BGS	20	6.54 c	9.60 c	13.79 cd	14.66 e	11.80 d
BGS	40	7.88 e	11.14de	14.90 d	17.33 f	13.47 e
BGS	80	10.01 h	15.32 g	19.01 e	20.30 g	15.65 f
Mean		7.61	10.46	13.24	15.16	11.89
CV %		4.8	4.5	11.4	4.2	5.7
F-pro		<0.001	<0.001	0.003	<0.001	<0.001

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.

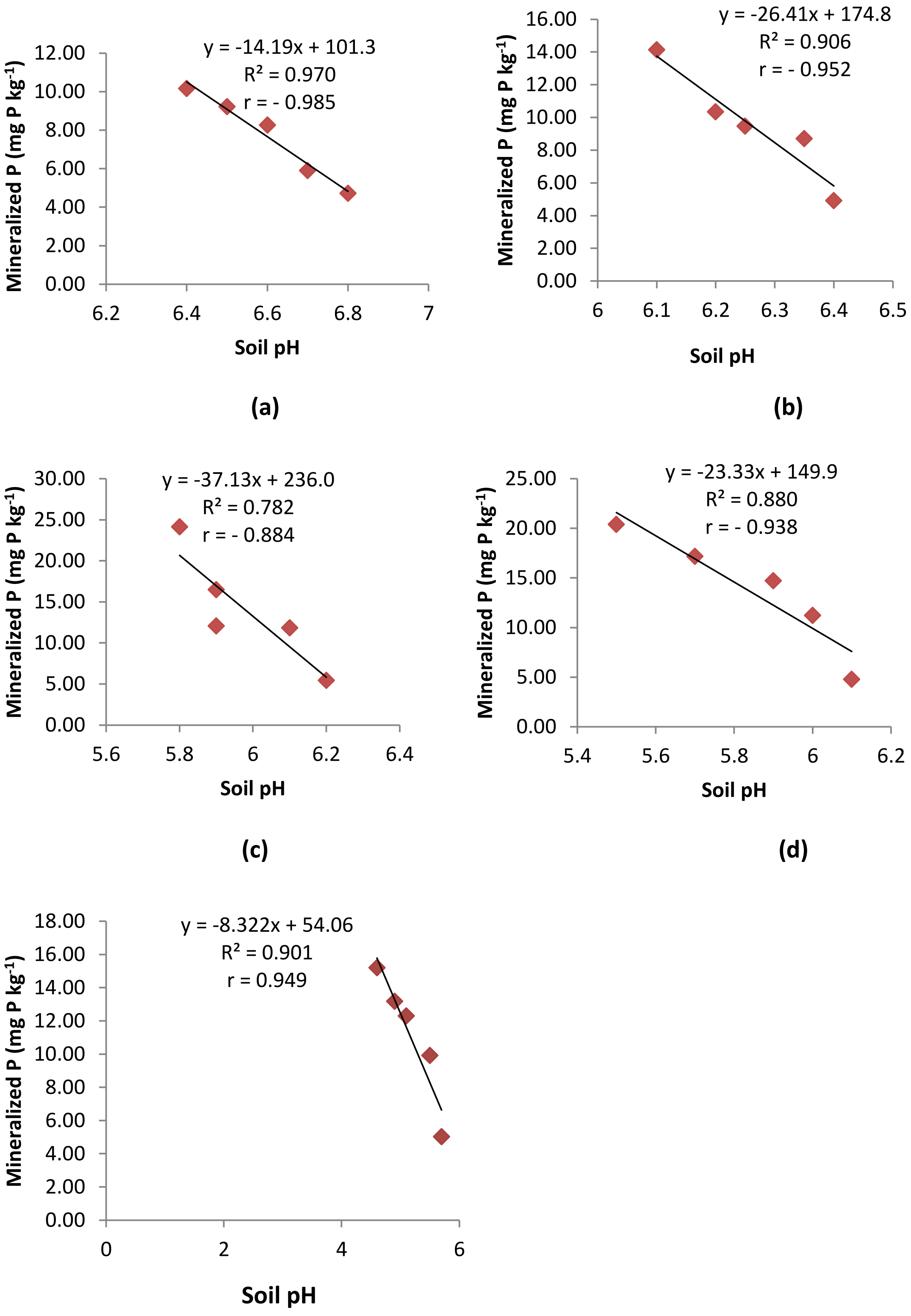
3.8.6 Effect of pH on P release

The pH of the soil was correlated with the release of phosphorus in soil from 0 day to 112 day of incubation. The results of soil pH showed a very strong negative correlation with phosphorus released (r > 0.8) as shown in Figures 3.4- 3.6. The results are in agreement with the findings of Boukhalfa-Deraoui *et al.* (2015) who reported negative correlation between available P and pH values of soil. In BGK-A the correlation was highest in day 112 (r = -0.982) and lowest in day 56 (r = -0.928) (Fig. 3.4 e, c). In BGK-B the correlation was highest in day 0 (r = -0.985) and lowest during day 56 (r = -0.884) (Fig. 3.5 a, c). Similarly in BGS, result showed that correlation was highest in day 0 (r = -0.998) and lowest in day 56 (r = -0.943) (Fig. 3.6 a, c). These results showed that as the pH decrease in moderately and slightly acid soil, the P availability increases. These results are in line with observations made by Hossain *et al.* (2014) and Goundar *et al.* (2014). These results were also in agreement with findings by Goundar *et al.* (2014). Goundar *et al.* (2014) reported that phosphorus availability is higher in moderately acidic soil. Moreover, in this study, the pH decreased as the rate of guano increases probably due to acidic nature of the guano. This finding is supported by Anderegg and Naylor (1987) who reported the addition of organic sources to soils may result in pH changes due to microbial activity during residue breakdown. Also, Boukhalfa-Deraoui *et al.* (2015) reported that contribution of phosphorus fertilizers can cause the decrease of the pH values in soils.



(a) **(b)** **(c)** **(d)** **(e)**

Figure 3.4: Correlation of P released from BGK-A at a rate of 0, 10, 20, 40 and 80 mg P kg^{-1} with pH at (a) day 0, (b) day 28, (c) day 56, (d) day 84 and (e) day112 of incubation

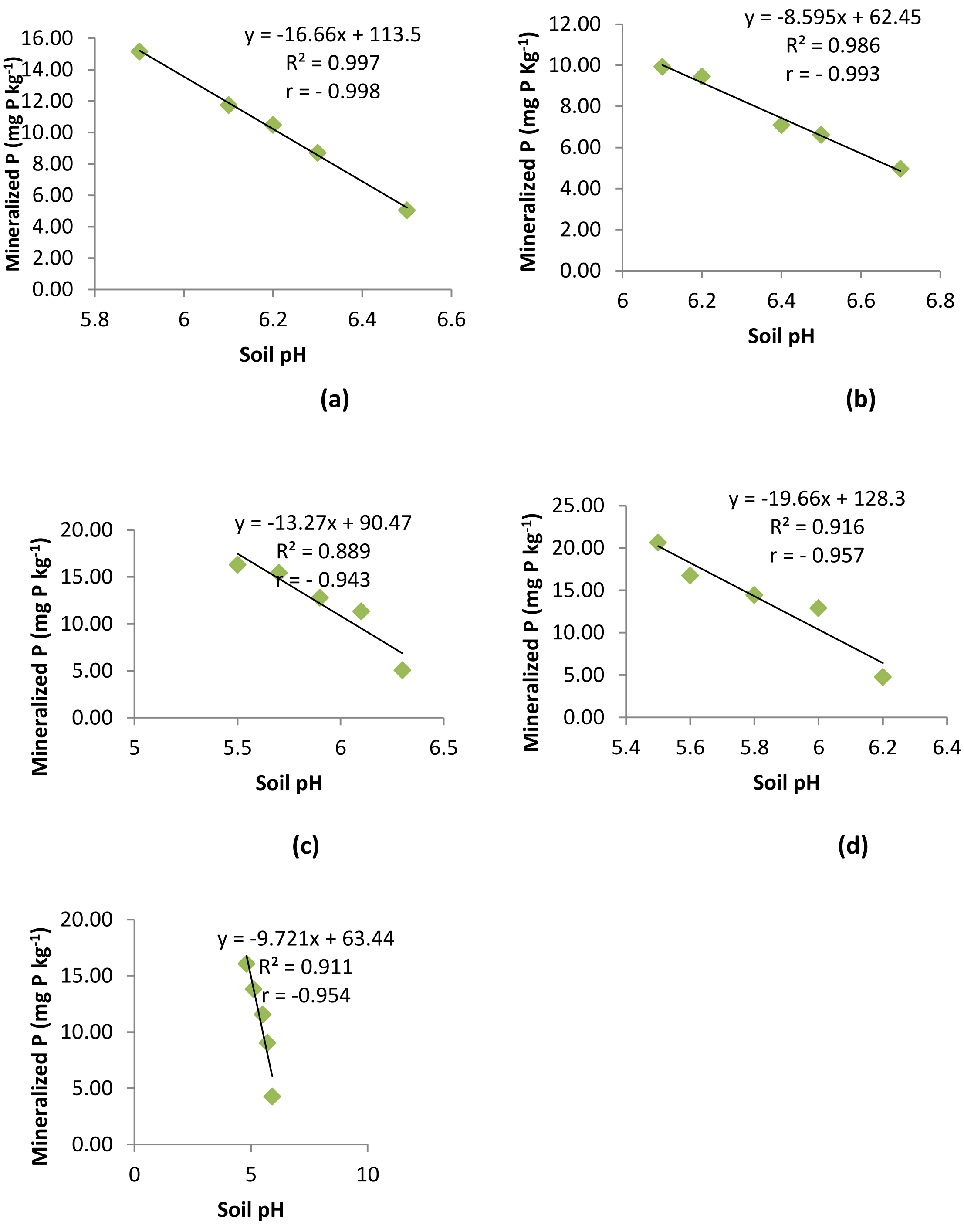


(a) (b)

(c) (d)

(e)

Figure 3.5: Correlation of P released from BGK-B at a rate of 0, 10, 20, 40 and 80 mg P kg^{-1} with pH at (a) day 0, (b) day 28, (c) day 56, (d) day 84 and (e) day112 of incubation



(a) (b)

(c) (d)

(e)

Figure 3.6: **Correlation of P released from BGS at a rate of 0, 10, 20, 40 and 80 mg P kg^{-1} with pH at (a) day 0, (b) day 28, (c) day 56, (d) day 84 and (e) day112 of incubation**

3.9 Conclusions

Guano from Kisarawe cave A decomposed more rapidly in the soil and released more available P than BGK-B and BGS. In all three P sources, application rate of 80 mg kg^{-1} resulted into the highest level of P release at 84 days of incubation. Furthermore the study found a negative correlation between P release from guano and pH of soil. These results implied that P released from guano could be much more available for plant uptake when applied earlier during planting especially for annual crops.

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CHAPTER FOUR

4.0 BAT GUANO CAN SERVE AS ALTERNATIVE SOURCE OF PHOSPHORUS FOR ORGANIC RICE PRODUCTION IN TANZANIA

ABSTRACT

Many tropical and subtropical soils are low in phosphorus contents. This is partly due to excessive weathering, high P fixation 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 contents in soils. Low P contents in soils limits crop yields of most crops including rice. This study was therefore conducted to evaluate the suitability of bat guano as alternative sources of P in Tanzania. A screen house experiment was conducted at Sokoine University of Agriculture using bat guano from Kisarawe caves A and B (BGK-A and BGK-B) and Sukumawera (BGS) using rice as a test crop. The experiment was designed as 4 × 6 factorial experiment in Randomized Complete Block Design (RCBD) using three bat guano and triple super phosphate (TSP) as standard fertilizer. Six P rates were compared. Results obtained indicated that rice response to applied TSP was higher than three bat guano, and the response was in the order TSP > BGK-A > BGS > BGK-B. All parameters increased with the increase in applied amounts of P from bat guano and TSP. Positive correlation between grain yield and other yield components was observed indicating better crop response to fertilizer application rates. It was concluded that the studied bat guanos can be used as alternative source of P if available in rice production at a recommended rate of 80 mg P kg^{-1} soil.

Keywords: *Rice response, Phosphorous, Bat guano*

4.1 Introduction

Rice (*Oryza sativa* L.) is the second most important food and commercial crop in Tanzania after maize. Fifty percent of Tanzanian farming households depend on rice as staple food, source of employment and income. Tanzania is the second largest producer of rice in Southern Africa after Madagascar producing 818 000 tons (USDA, 2007). Total area under rice cultivation in Tanzania is 681 000 ha which represents 18 % of Tanzania's cultivated land. About 71 % of the rice produced in Tanzania is grown under rain fed conditions. Irrigated land represents 29 % of the total land under rice, most of which is in small village level traditional irrigations (RLDC, 2009).

The average yield of rice is very low, ranging from 1 to 1.5 tons ha^{-1} due to different factors including declining soil fertility, drought, pests and diseases and use of poor agronomic practices (RLDC, 2009; Lu *et al.*, 2015). Declining of soil fertility is probably the most limiting factor in rice production. Inorganic fertilizers as ameliorating approach has not been very successful due to various factors like high and unaffordable prices of fertilizers, unavailability of materials on time when required and knowledge of applying. Due to these factors, most farmers depend on natural fallows to improve their soil fertility. But due to population increase natural fallows are no longer useful, hence other approaches of improving soil fertility need to be tested and evaluated.

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

4.2 Materials and Methods

4.2.1 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 elevation of 550 m above sea level.

4.2.2 Soil sampling and analysis

A bulk sample of surface soil (0-20 cm depth) was collected from Soil and Geological Sciences experimental field which is located at Latitude 06°85’ S, and Longitude 37°65’ E, at elevation of 550 m above sea level. Sampling method used was a random sampling method in two diagonals. Collected soil was air-dried, crushed and sieved through 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 dispersing soil sample in sodium hexametaphosphate solution (Jember, 2011). Soil textural class was determined by using USDA textural class triangle (FAO, 2006).

The pH of the soil was determined using a glass electrode pH meter in 1:2.5 (soil: water suspension) (Warncke and Brown, 1998). Electrical conductivity was measured in 1:2.5 (soil: water) by using conductivity meter (Warncke and Brown, 1998). Organic carbon was determined by Walkley and Black method using wet oxidation by potassium dichromate (Nelson and Sommers, 1996). Total N was determined by the micro-Kjedahl digestion procedure followed by distillation (Okalebo *et al.*, 2002). Available P was extracted using Olsen method (Olsen, 1954) and determined by the ascorbic acid colorimetric method (Kuo, 1996). Cation exchange capacity (CEC) was determined by using 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 (Jember, 2011). The soil was sandy clay with neutral pH and medium total N and available P (Table 4.1). The soil had adequate essential micronutrients and exchangeable cations except Zn which was deficient.

Table 4.1: 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^{-1}	561	Normal	Msanya *et al.,* 2001
OC	%	11.05	Very High	Landon 1991
Total nitrogen	%	0.48	Medium	Landon 1991
Available phosphorus	mg kg^{-1}	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

4.3 Design of the Pot Experiment

The experiment was carried out as a 4 x 6 factorial experiment laid down in Complete Randomized Block Design (CRBD). 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 Super Phosphate (TSP) used as standard fertilizer for comparison. The second factor was P application rate which was six levels of P application (absolute control, 0, 10, 20, 40 and 80 mg P kg^{-1} soil) based on P content of each source, whereby the amount of bat guano applied gave the same amount of P rate (Table 4.2), and the experiment was replicated three times.

Table 4.2: 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	AbC	AbC	AbC	AbC
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

AbC, Absolute control, [b], All nutrients were applied to recommended levels except P.

4.4 Setting 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 was weighed and placed into each pot (72 pots in total) before P application and the pots were labeled according to treatments 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. In order 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 were mixed first followed by subsequent higher rates. Nitrogen was uniformly applied in the form of Urea ($CO (NH_2)_2$) at a rate of 400 mg N kg^{-1} in two splits to all pots (except absolute controls) (Semoka and Mnguu, 2000; Fageria *et al.,* 2011; Mbaga, 2015) and zinc was applied at a rate of 2.5 mg Zn kg^{-1} soil as zinc sulphate ($ZnSO_4$) (Kalala *et al.,* 2017). Only N and Zn were applied due to their insufficient amount in soil.

After mixing with fertilizers the soil was re-filled in the Pots and equilibrated to about 90% of field capacity by using tape water. After twenty four hours of equilibration eight rice seeds (*Oryza sativa* L.) var 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 and the second split of N was applied during panicle initiation.

4.5 Physiological Data Collection

Physiological data for rice responses as affected by P sources and rates were collected from vegetative, maturity to harvesting stage. The parameter assessed are plant height measured by using tape measure, number of tillers, tissue nutrient concentrations, dry matter yield, number of panicles and grain yields were recorded. When the crop was at booting stage, one plant was cut close to soil surface from each Pot by using sharp scissor for tissue nutrient analysis and the remaining three plants were maintained in each Pot to maturity. Above ground plant parts harvested at 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 using macro furnace and allowed to cool.

After cooling down, 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 (Kuo, 1996), K was determined by Flame Emission Spectrophotometer (Thomas, 1982), while Fe, Zn, Cu and Mn were determined using Atomic Absorption Spectrophotometer (Jember, 2011). Nitrogen in ground plant samples was determined by Macro-Kjeldahl method (Chapman and Pratt, 1961). When the remaining plants reached the 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.

4.6 Data Analysis

Collected data was subjected to Analysis of Variance using GenStat Discovery edition 4 Software. Treatment mean separation was done by using Duncan New Multiple Range Test at the 5% probability level. Correlations between grain yield and other yield components were carried out using Analysis Tool Pak in MS Excel (Microsoft 2007).

4.7 Results and Discussion

4.7.1 Effect of P rate on number of tillers and plant height

The effect of P rates on number of tillers and plant height was as presented in Table 4.3. There was a significant effect of P rates ($P < 0.05$) on number of tillers and plant height at the 28th, 56th and 84th day after planting for all P sources.

Table 4.3: Effects of P rates on number of tillers and plant height at various growth stages

Treatment	Number of tillers			Plant height (cm)		
(mg kg^{-1})	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.

The number of tillers increased gradually after thinning up to the maximum tillering stage which ceased around 56 days after sowing. At this stage, the main culm was difficult to distinguish from the tillers and rice plants generally produce 2 to 5 panicle bearing tillers per plant (Moldenhauer and Slaton, 2001). The lowest number of tillers per plant (4.92) was recorded in absolute control due to insufficient nutrients in soil which limited the growth of plants. These results conform to those reported by Usman (2013). The highest number of tillers (22.83) was counted at the 84th day after planting in treatments receiving P at a rate of 80 mg P kg^{-1} (Table 4.3) and no additional tillers formed thereafter. The increase in number of tillers could be due to increasing phosphorus application rate. This observation is supported by Alam *et al.* (2003) who reported that the increase of single super phosphate (SSP) level from 0 to 150 mg P kg^{-1} of soil significantly increased the number of tillers per plant and grain yield over the control. Similar response of rice to increasing P supply was reported by Cralle *et al.* (2003), Babu *et al.* (2001) and Fioreze *et al.* (2012). Grant *et al.* (2001) attributed an increase in number of tillers to increase in amount of roots and the capacity of phosphorus absorption. This observation is in line with the physiological functions of P in plants and suggests a positive response of rice to P application. The results for plant height are in agreement with Razaq *et al.* (2017) who reported a positive relationship between P level and growth of the plant. Several other researchers found a positive effect of P application on the growth of different plant species (Verma *et al.,* 1996; Pandey *et al.,* 2006; Waraich *et al.,* 2015; Hudai *et al.,* 2007; Cicek *et al.,* 2010).

4.7.2 Interaction effect of P sources verses P rates on number of tillers and plant height

There was no significant interaction effect of P sources and P rates on number of tillers for all treatments. However, significant interaction effects of P-sources and rates ($P < 0.05$) were observed on plant height (Table 4.4). Plant height increased gradually with increase in number of days after sowing. The tallest plants (53, 105, 119.5 cm) were observed in pots receiving 80 mg P kg^{-1} from TSP at 28 days as well as from BGK-A at 56 and 84 days after sowing, respectively. Higher increase in plant height observed in plants received TSP than those received guano (BGKA) at the 28th day after sowing could be due 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 (Nkongolo, 2016). 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 P application. These results are in line with the observation of Ojobor *et al.* (2014) who reported that plots treated with manure were significantly taller than the control. The results are in conformity with those reported by Babu *et al.* (2001) and Hossaen *et al.* (2011) on interaction of P sources and rates.

Table 4.4: Effects of interaction between P sources and rates on number of tillers and 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
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.

4.7.3 Effects of P sources, P- rates and their interaction on plant tissue nutrient concentrations

4.7.3.1 Macronutrients

There was no significance effect of P sources and interaction of P sources versus P rates ($P < 0.05$) on macronutrients tissue concentrations. On P rates, only K showed significance effects ($P < 0.05$) (Table 4.5). This could be due to high level of K present in soil (Table 3.2) and that added from guano during the study. Penhallegon (2003) reported that guano contains K which can be released on 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 on the same rate in all treatments except absolute control and P was applied based on total P contained in guano source. NPK tissue concentrations were higher on application rate of 80 mg P kg^{-1} (Table 4.5). The results are comparable to that observed by Myint *et al.* (2010) who reported that N, P and Mg were higher in a maximum application rate of the treatment during their study. On the other hand, the results agreed with that Kemp (1983) who reported that increasing N concentration in soil can increase or decrease K concentration in the plant tissue depending on K level. Also, Fageria (2001) reported that higher K level increased N uptake and lower K level decreased the uptake of N in plant tissue. Furthermore, higher level of K in soil solution allows more efficiency on the use of nitrogen. On the other hand, there was no significance difference of P tissue concentrations in all P rates. This could be due to effective uptake of P from the P sources to be taken up by rice crop (Choudhury *et al.,* 2007). Furthermore P tissue concentration (0.23 %) in rice shoot at the rate of 80 mg P kg^{1} was above critical range of 0.16% as reported by Kalala *et al.* (2017). Similarly, N and K were above the critical range (1.8 – 2.5%) and 1.6 % respectively (Wallihan *et al.,* 1974; Dorbermann and Fairhust, 2000; Kalala *et al.*, 2017).

Table 4.5: Effects of P- rates on macronutrients tissue concentrations

P-rates	**Macro nutrients (%)**		
(mg kg^{-1})	**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.

4.7.3.2 Micronutrients

There was significant effect ($P < 0.05$) of all P sources on micronutrients tissue concentrations in rice shoots (Table 4.6). Nevertheless P rates and interaction of P sources and P rates had no significant effects. This could be due to preexisting of micronutrients in guano which was analyzed earlier before planting. Still the results are supported by Sikazwe and Waele (2004) and Sridhar *et al.* (2006). They reported that guano contain 3.5-9% Ca, 1.5-8% Mg, 0.4-0.8% Mn, 0.2-0.5% Cu, 0.5-1.3% Fe, and 0.2-0.4% Zn.

Table 4.6: 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.

4.8 Effect of P Sources, P Rates and P Sources Versus P Rates on Number of Panicles and Panicle Length

4.8.1 Number of panicles per plant

P-sources and the interaction of P-sources × rates had no significant effect on number of panicles per plant while P rates showed significant ($P < 0.05$) effect on the same parameter (Table 4.7). The highest rates of 80 mg P kg^{-1} provide the highest number of panicles per plant; this is due to supply of P and other nutrient element in rice. The statement supported by Yoseftabar (2013), who reported that the higher application of P increases the number of panicles in rice. The lowest number of panicles was recorded in absolute control treatments. The results conform to those reported by Amanullah (2016).

4.8.2 Panicle length

There was no significant effect of P-sources and the interaction of P-sources versus P rates on panicle length. Nevertheless, P rates significantly ($P < 0.05$) increased panicle length (Table 4.7). These results are in agreement with Nesgea *et al.* (2012) who showed that panicle length was significantly more in higher application than the control. Similarly, Kanfany *et al.* (2014) reported that panicle length increased significantly with increasing fertilizer levels.

Table 4.7: Effects of P-rates on number of panicle plant $^{-1}$ and panicle length

Treatment	Number of panicle 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.

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 positive effect of P application on panicle length. These results conform to those reported by Siavoshi and Laware (2011). Many studies showed that panicle development is closely associated with preliminary plant growth which produce good vigor of traits such as leaf appearance rate (Dong *et al.*, 2004; Streck *et al.*, 2009; Itoh and Shimizu, 2012; Rebolledo *et al.*, 2012). Lafarge *et al.* (2009) and Borras-Gelonch *et al.* (2012) also reported that tillering influence increase number of panicle in rice while on the other hand Setter *et al.* (1995) and Dutta *et al.* (1997) reported that reducing of tiller number, panicle height and increasing of stem size possibly can increase the potential yield of rice.

4.9 Effect of P Sources, P Rates and P Sources X P Rates Interaction on Dry Matter and Grain Yield

4.9.1 Effect on dry matter yield

There was no significance effect ($P < 0.05$) of P rates and the interactions of P sources and P rates on influence of dry matter yield. P sources showed significant effect ($P < 0.05$) on dry matter yield (Table 4.8). The 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 and BGK-B had statistically lower dry matter yields. Irrespective of the differences in dry matter yields, all P sources had statistically similar grain yields. This implies that bat guano was as effective as TSP when all P sources were applied at same rates based on total P contents.

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

Table 4.8: 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.

These results are in agreement with those obtained by Myint *et al.* (2010) who reported that plant growth characteristics including dry matter yield were higher in rice plants treated with inorganic fertilizers compared to those receiving organic fertilizers. The lowest dry matter yield recorded in BGK-B could also be due to excessively acidic nature of this guano compared to the other two bat guano.

Rorison (1972) reported that acidic condition has a tendency of impairing absorption of Ca, Mg, and P also increase solubility and toxicity of Al, Mn and Fe hence reduces the availability of P in soil. Rorison (1972) also reported that the inhibition of phosphorus uptake and absorption by Al has a drastic effect on the growth of plant include dry matter yield. Similarly, Koo *et al.* (2005) 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 due to antagonistic effects of soluble Al. With increasing soil acidification, smaller amounts of Mg^{2+} remain in exchangeable form due to reduction in negative charge. Since Mg^{2+} is a poor competitor with Al^{3+} and Ca^{2+} for the exchange sites hence it accumulate in the solution and become leached.

4.9.2 Effect on grain yield

The result showed that there was no significant ($P < 0.05$) difference in rice grain yield due to P sources (Table 4.9). The results obtained indicated that the effectiveness of guano is similar to that of inorganic fertilizers. This finding is supported by Karagoz and Hanay (2017) who reported that bat guano to be more effective than farmyard manure. Zapata (2002) reported that TSP have high amount of P than guano from Peru and Zaire (Democratic Republic of Congo) but there was no significant differences in dry matter yield or P uptake in barley among the two P sources used in the study.

4.9.3 Effects of P- rates on dry matter and grain yield

Shoot dry matter yield significantly ($P < 0.05$) increased with increasing application rates of P (Table 4.9).

Table 4.9: 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.

In all three P sources, the application rate of 80 mg P kg^{-1} soil had highest dry matter yield (33.92 g). The results were similar to that shown by Myint *et al.* (2010) who reported that the highest application level for each treatment gave the highest dry matter yield. Similar to grain yield, higher application level of P sources significantly ($P < 0.05$) increases the grain yield (115.06 g pot^{-1}). The results were similar to those shown by Amanullah (2016), reported that increase of grain yield was influenced by application of organic sources rather than inorganic fertilizers. Singh and Agarwal (2001) and Iqbal *et al.* (2002) reported that nutrients which are available in organic sources could be the reason of increasing grain yield after being taken up by plants.

4.10 Correlation between Grain Yield and Yield Components

The grain yield per plant had significant ($P < 0.05$) and positive correlation with number of tillers per plant, plant height, dry matter yield, number of panicles, panicle height and grain weight per panicle (Table 4.10).

Table 4.10: Simple correlation coefficients** for grain yield and yield components

Characters	Grain weight (g)	Dry matter yield (g)	Number of panicle	Panicle height (cm)	Plant height (cm)	Number of tillers
Grain weight	1					
Dry matter yield	0.413	1				
Number of panicle	0.946	0.488	1			
Panicle height	0.844	0.347	0.809	1		
Plant height	0.909	0.469	0.911	0.857	1	
Number of tillers	0.869	0.460	0.918	0.788	0.873	1

** Significant at 0.05 probability level

Number of tillers showed a strong positive correlation with grain yield per plant ($r = 0.87$). Similar result were found by Ranawake and Amarasinghe (2014) Parimala, (2016) and Thippani *et al.* (2017) who reported a strong correlation between productive tillers per plant and grain yield per plant. Plant height showed a very strong positive correlation with grain yield per plant ($r = 0.91$). The results agreed with those reported by Priyanka *et al.*

(2016). Panicle height and number of panicles per plant showed a positive and very strong correlation with grain yield per plant r = 0.84 and r = 0.95 respectively. The result supported by those reported by Naseer *et al.* (2015). Liu *et al.* (2011) reported that panicle number influenced by number of tillers produced which is the most important agronomic character in rice. The higher number of tillers the higher the number of panicles produced as a result of high grain yield. Dry matter yield was significantly correlated with grain yield (r = 0.41). The result is similar to that reported by Wu *et al.* (2008) and Chen *et al.* (2012).

4.11 Pot Experiment

Visual assessment of rice growth

Germination of seeds started seventh day after sowing, and the germination percent 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 21st day by showing yellowing colour of the leaves and in other Pots it was observed during 42nd day where it was controlled by adding 200 mg N per Pot. Pots with bat guano from Kisarawe cave A showed dark green colour in leaves than bat guano from Kisarawe cave B, Sukumawera and TSP fertilizer during vegetative growth stage (Plates 4.1-4.4). Also number of tillers and height of the leaves were higher in the treatments explained above. The first flowering was observed in a treatment of bat guano from Kisarawe cave A at a rate of 80 mg P kg^{-1} on the 81st day. Latest flowering and maturation of rice grain was observed on absolute control treatment.

Plate 4.1: Rice response to applied guano from Kisarawe cave A at booting to early flowering stage. From left to right: absolute control, 0, 10, 20, 40 and 80 mg P kg^{-1} under Screen house condition

Plate 4.2: Rice response to applied guano from Kisarawe cave B at booting to early flowering stage. From left to right: absolute control, 0, 10, 20, 40 and 80 mg P kg^{-1}under Screen house condition

Plate 4.3: Rice response to applied guano from Sukumawera cave at booting to early flowering stage. From left to right: absolute control, 0, 10, 20, 40 and 80 mg P kg^{-1}under Screen house condition

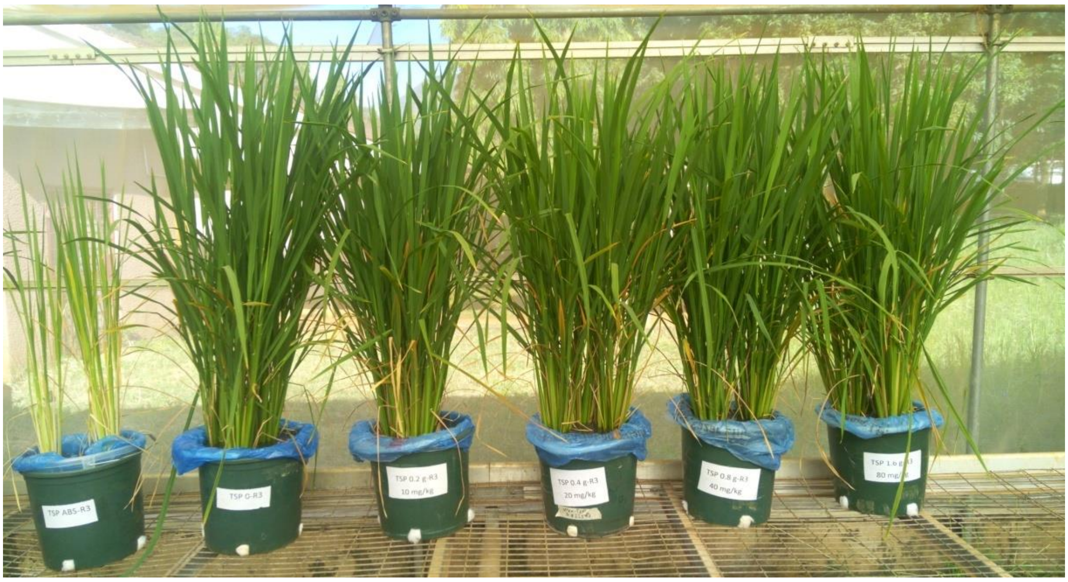

Plate 4.4: Rice response to applied guano from TSP fertilizer at booting to early flowering stage. From left to right: absolute control, 0, 10, 20, 40 and 80 mg P kg^{-1} under Screen house condition

4.12 Conclusions

Rice response as determined in terms of plant height, number of tillers and panicles per plant, dry matter and grain yields to TSP was comparable to that of bat guano from Kisarawe and Sukumawera of Tanzania. There was no difference in rice response treated with three sources of guano BGK-A, BGK-B, BGS and standard fertilizer (TSP). Rice yield increased progressively with increasing P levels to the maximum application level of 80 mg P kg^{-1}. The grain yield significantly ($P < 0.05$) showed strong relationship with other yield components including number of tillers, plant height, panicle height, number of panicle and dry matter yield. The results indicate that the three bat guano are effective as TSP in improving rice yields.

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CHAPTER FIVE

5.0 GENERAL DISCUSSION OF THE FINDINGS

Chemical composition of studied bat guano from Kisarawe and Sukumawera showed relatively higher total P (8.55%) from BGK-A followed by BGK-B (7.03%) and BGS (3.45%). Sikazwe and Waele (2004) studied bat guano and found similar results as obtained from this study. Also, Andrew (2016) reported total P contents of Kisarawe bat guano in the range of 7 - 15% P. Bat guano from Kisarawe caves A and B attained higher total P than that from Sukumawera cave, which is attributed by daily accumulation of fresh bat faeces inside the caves at Kisarawe than at Sukumawera. Similarly as reported by Juma (2001) Kisarawe caves are producing one ton of guano from three million bats per day.

Total P contents determined in Sukumawera bat guano (3.45%) was different from P content of 20 - 41% previously reported by Andrew (2016) using guano from the same deposits. Such differences could be due to decomposition of guano from time to time and leaching of P (Zapata, 1995; Bird *et al.,* 2007; Cleary *et al.,* 2017). In guano from Kisarawe cave A, Potassium (K) was found to be higher (11.4%) as compared to values obtained from Kisarawe cave B (6.3%) and Sukumawera cave (4.0%).

Other nutrient elements contained in guano include Calcium (Ca) (45%) which was higher in guano from Sukumawera deposit than the other two deposits. This could be due to high Ca in parent material of Sukumawera cave which is mainly composed of gneiss and travertine, the rocks that contain amphibole, pyroxene and calcite minerals (Hallimond, 1947). Total Manganese in all guano was low. This finding is in agreement with values of Mn reported by Andrew (2016). Total sulfur in all the three guanos were low, which are lower than that reported by Andrew (2016) in Kisarawe and Sukumawera caves. Apart from Si and Al, other elements include Pb, Pd, Rh, Ti, Sr and Zr were in relatively small amounts in all deposits indicating that application of guano as source of P can’t cause any high risks of potentially toxic elements (PTEs) accumulation in the soil environment.

In the incubation studies P release was gradually increased from day 28 to day 84 followed by slow decrease up to 112 day of incubation. The results supported by Jalali and Zinli (2011) who reported that kinetics of P release from soils can be described as initial rapid rate followed by a slower rate. Similar results were also observed by Horta and Torrent (2007) and Nafiu (2009). Variations of pH from the three guanos affected P release during incubation. Guano with lower pH prevents P availability in soil due to P fixation (Havlin *et al.,* 2005). Research elsewhere reported that organic supplements including guano can increase P availability in P-fixing soils (Iyamuremye and Dick, 1996; Guppy *et al.,* 2005; Agbenin and Igbokwe, 2006; Gichangi, 2009).

Soil pH showed a very strong negative correlation with phosphorus released from P sources (guano), the pH of soil applied bat guano was decreased as the rates of guano increased this could be due to acidic nature of all three guanos. The observations are similar to the findings of Anderegg and Naylor (1988). They reported that the addition of organic sources to soils may result in pH changes due to microbial activity during residue breakdown. Marschner *et al.* (2005) also showed that the soil pH influences microbial community composition more strongly than other soil properties.

In Pot experiment, there was a significant effect ($P < 0.05$) of P rates on number of tillers and plant height. Number of tillers and plant height significantly increased due to P release from bat guano and TSP. Significantly P rate of 80 mg P kg^{-1} gave higher response on number of tillers and plant height. Moreover, there was significant ($P < 0.05$) interaction effect of P sources and rates on plant height.

The significant ($P < 0.05$) effect of P rates on macronutrients tissue concentrations was shown in Pot experiment. N, P and K tissue concentrations significantly were higher on the rates of 80 mg P kg^{-1}. A similar result was reported by Myint *et al.* (2010), they reported that macronutrients concentrations in plant tissues were higher in a maximum rate of application.

There was significant effect ($P < 0.05$) of all P sources on micronutrients tissue concentrations in rice shoots. The significant could be due to micronutrients accumulation in all three bat guanos. The results agreed by Sikazwe and Waele (2004) who reported that bat guano contain high contents of micronutrients. P rates showed significant ($P < 0.05$) effect on the number of panicles per plant and panicle length. At the rate of 80 mg P kg^{-1} number of panicle per plant and panicle length were significantly higher.

On dry matter yield and grain yield, P sources had significant effect ($P < 0.05$) on these parameters. All P sources recorded higher dry matter yields where by BGK-A and BGS statistically gave similar dry matter yields next to TSP. BGK-B gave low dry matter yield, this could be due to its high acidic in nature which hinder P and other nutrients in soil to be taken up by plant (Shen *et al.*, 2011). Similar to grain yield, there was no significant ($P < 0.05$) difference of P sources. The results implied that the effectiveness of guano is similar to that of TSP.

The grain yield per plant had significant ($P < 0.05$) positive correlation with other yield components including number of tillers per plant, plant height, dry matter yield, number of panicles, panicle height and grain weight per panicle. The positive correlation could be due to effectiveness of P sources and rates on rice as a test crop. Results are in agreement with many researchers in their studies of correlation of grain yield and other growth parameters in rice (Wu *et al.*, 2008; Liu *et al.*, 2011; Chen *et al.*, 2012; Naseer *et al.*, 2015; Ranawake and Amarasinghe, 2014; Priyanka *et al.*, 2016; Parimala, 2016; Thippani *et al.*, 2017).

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CHAPTER SIX

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions can be made from the results of the study

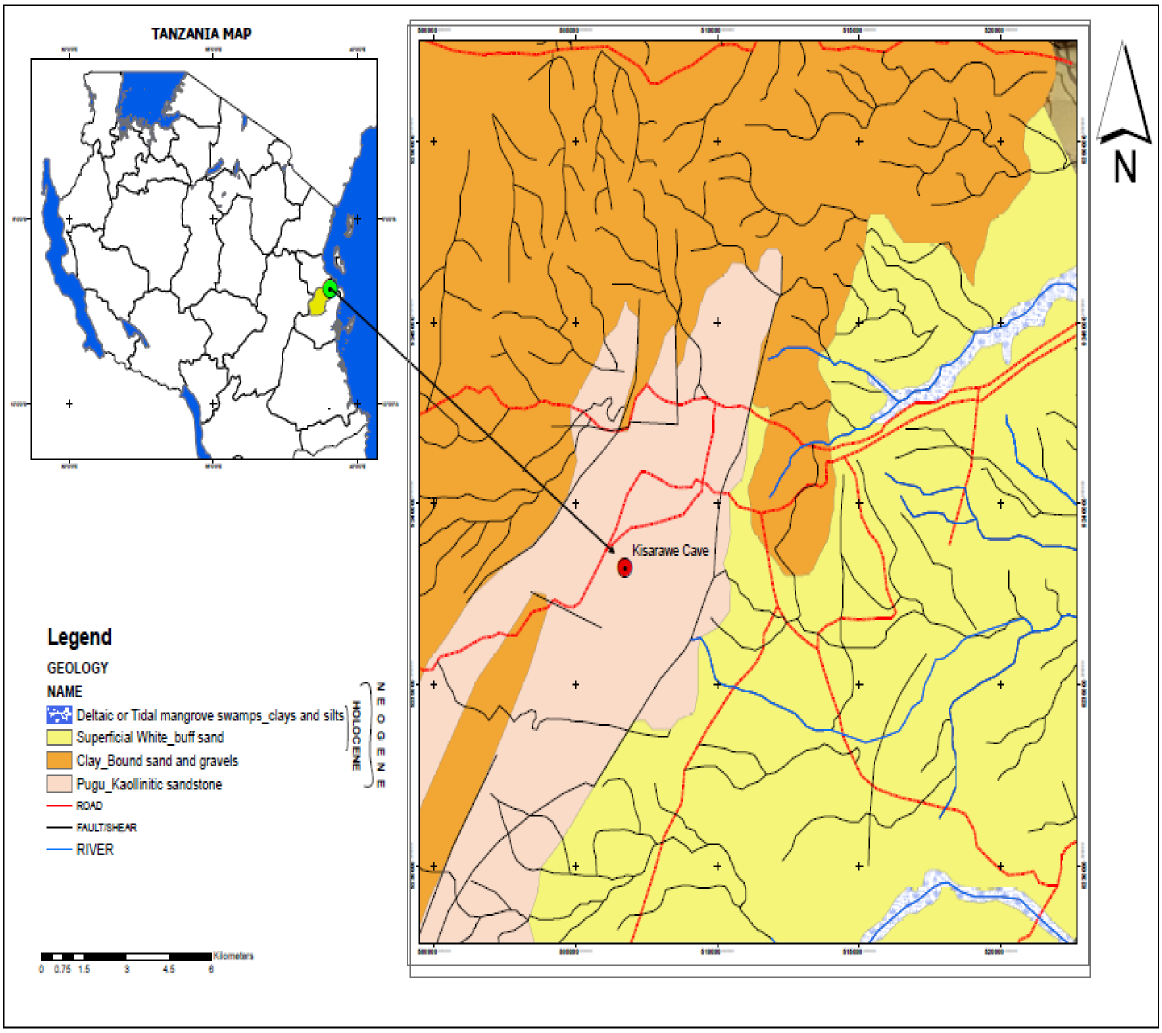
1. All three types of bat guano (BGK-A, BGK-B and BGS) released P in soil during incubation. As the amount of bat guano increased the release of P in soil increased.
2. Guano from BGK-A decomposed more rapidly in the soil and released more available P than BGK-B and BGS. In all three P sources the application rate of 80 mg kg^{-1} gave higher level of P released compared with other treatments including control.
3. The higher quantity of available P released from all guano occurred in day 84 of incubation.
4. There is negative correlation between P release from guano and pH of soil. As guano rate increased P release increased with decreasing of soil pH.
5. There was no difference in response of rice treated with three sources of guano BGK-A, BGK-B, BGS and standard fertilizer (TSP). Indicating that guano can replace TSP as an alternative source of P for rice production.
6. The yield response was increased progressively with an increase of applied P levels mostly at an application rate of 80 mg P kg^{-1}. The grain yield linearly showed strong relationship with other yield components which are number of tillers, plant height, panicle height, number of panicle and dry matter yield. This imply the effectiveness of P sources and rates on rice as a test crop.

6.2 Recommendations

1. Characterization of guano from other deposits in the country is required in order to generate information on their quantity and quality and suitability to be used as fertilizer for the aim of increasing agricultural productivity in Tanzania.
2. There is a need of increasing levels of fertilizer application to show if there is any toxicity effect since it was not seen during the pot experiment.
3. Since most of guano are acidic in nature it is advisable to be used in slightly acidic to alkaline soils for better crop response because its acidic nature lower the pH of the soil.
4. Field trials are recommended to validate results of incubation study and pot experiment.

APPENDICES

Appendix 1: Geological setting of Kisarawe guano deposits



Appendix 2: Geological setting of Sukumawera guano deposits