CHARACTERIZATION OF SUKUMAWERA AND KISARAWE BAT GUANO FROM TANZANIA AS SOIL AMENDMENT AND SOURCE OF PLANT NUTRIENTS

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ABSTRACT

Guanos are excrements of birds and/or bats enriched with varied nutrients. In Tanzania, guanos are found in a number of places but are not fully utilized due to lack of information on their agronomic potential. Therefore, a study was conducted on Sukumawera and Kisarawe bat guano to assess their agronomic potential as soil amendment and source of plant nutrients for maize production. Elemental composition of the studied guanos were analysed at the Geological Survey Laboratories in Dodoma using inductively coupled plasma – optical emission spectrometer (ICP-OES). Their physico-chemical properties were determined at Sokoine University of Agriculture (SUA) Soil Science Laboratories. Pot experiments were carried out at SUA to assess maize response to soil applied with varying amounts of bat guano. Number of leaves, plant height, biomass weight, nutrient concentrations in soils and plants were among the variables assessed. The ICP-OES results indicated that Sukumawera had high level of P ranging from 20 - 41%, while in Kisarawe bat guano its P value was 7 - 15%. Similarly, Sukumawera bat guano had higher level of S (19 - 39%) as compared to that of Kisarawe (6 - 13%). Laboratory analysis found that both guanos are slightly acidic to strongly acidic (pH 4.2 - 6.7). There was significant ($p \leq 0.05$) increase in soil nutrient concentrations and nutrients uptake by maize as guano rate increased. However, the best plant performance was observed at a ratio of 20 : 0.5 for Sukumawera and 20 : 1 for Kisarawe guano. Kisarawe bat guano was superior to Sukumawera in plant performance. The study revealed that high rates of guano application (> 20 : 1) caused poor maize response. It was concluded that both Sukamawera and Kisarawe bat guano are suitable for alkaline soils amendment and source of plant nutrients when applied in small amounts ($\leq$ 20 : 1) for good plant performance. It is recommended that field trials should be carried out to assess the actual maize plant response in the natural environment.

DECLARATION

I, Twisege, Andrew, 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 to any institution.

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LIST OF ABBREVIATIONS AND SYMBOLS

AAS	Atomic Absorption Spectrophotometer
AGRA	Alliance for Green Revolution in Africa
C/N	Carbon Nitrogen ratio
CEC	Cation exchange capacity
cmol	Centimole
Conc.	Concentrated
CRD	Complete Randomized Design
CV	Coefficient of variation
DAS	Days after sowing
dS/cm	deciSiemens/centimetre
DTPA	Diethylenetriaminepenta-acetic acid
ECe	Electrical conductivity
Exch	Exchangeable
Extr.	Extractable
FAO	Food and Agriculture Organization
F-pr	F- probability
GIT	Gastro intestinal track
GM	Grand mean
GST	Geological Survey of Tanzania
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometer
KI	Kisarawe bat guano sampled inside the cave
KO	Kisarawe bat guano sampled near the opening of the cave
MC	Moisture content
mS/cm	milliSiemens/centimeter

OC	Organic carbon
pH	hydrogen ion concentration
PTE	Potentially toxic element
Rep	Replication
SE	Standard error
SI	Sukumawera bat guano sampled inside the cave
SO	Sukumawera bat guano sampled near the opening of the cave
SUA	Sokoine University of Agriculture
TMV1	Tanzanian Maize Variety 1
UVS	Ultra Violet Spectrophotometer

CHAPTER ONE

1.0 INTRODUCTION

Phosphate rocks are naturally occurring geological materials (agro-minerals), which are rich in phosphorous and some other mineral elements. Apart from phosphorus, some agro-minerals may contain potassium, nitrogen, sulphur, limestone, dolomite and silicate minerals that can be utilized either directly as plant nutrients source or serve as raw materials in fertilizer processing (Sanginga and Woomer, 2009). Some are more effective as water soluble fertilizers (Woomer *et al.,* 1997). Naturally occurring geological materials that contain one or more recognized plant nutrients are called 'rock fertilizers' (van Straaten, 2002), or sometimes known as 'petro-fertilizers' (Leonardos *et al.*, 2000).

Guano is among many phosphate deposits found in sub- Saharan Africa. It is the excrement of birds and bats found accumulated in isolated islands and in caves for many years (Sanginga and Woomer. 2009). Bat guano refers to excrement from bats (Mlay and Sagamiko, 2008). In Tanzania, there are many places full of reserves of bat guano, for example Songwe caves in Mbeya, Amboni in Tanga, Kisarawe in Coastal region and Haitajwa and Manapwani caves on Zanzibar Island. Guano found in Songwe caves is known as 'Sukumawera bat guano'. This guano is found at Sukumawera village in Mbeya Region.

Songwe caves are natural caves while Kisarawe caves are artificial caves that were originally used to produce Kaolin minerals; after abandonment bats got their roost. Juma (2001) as cited by Mlay and Sagamiko (2008) points out that Kisarawe caves are said to harbour about three million bats producing one ton of bats' guano per day.

Generally, studies have shown that guano is nutritious and can readily release its nutrients within a short period of time; and these are macro- and micronutrients that are required by plants in natural form (van Straaten, 2002). Hutchinson (1950) as cited by Shahack-Gross (2004) points out that, the primary ingredients of bat guano include nitrogen (8 to 12%) and phosphate [(2 to 7%) as (P_2O_5)] while other elements like Ca, Mg, K, Al, Fe and S are present in quantities lower than 5% of each. Olayiwola (2011) also reported that phosphorus content in guano is high compared to other animal manures. Guano is considered as a highly valuable fertilizer to the organic farming industry due to its tremendous fertilizing capacity, consequently, "many organic farmers hunt for guano today" (Cushman, 2013).

Previous characterization of bat guano from Sukumawera and Kisarawe indicated that these materials had high N, P and other plant nutrients. Results show that Kisarawe bat guano is rich in nitrogen content of about 4%. Other mineral elements were: 4662.5 mg P kg^{-1} , 892.6 mg Ca kg^{-1}, 852.4 mg Mg kg^{-1} , 95.6 mg Zn kg^{-1}, 759.2 mg Na kg^{-1} and 33.44 mg Cu kg^{-1} . On the other hand, Sukumawera bat guano is said to be of good grade material containing 26-37% P_2O_5 (Mlay and Sagamiko, 2008; Chesworth *et al.*, 1988). Thus, these guanos can supply nitrogen, phosphorus and other mineral elements in nutrients deficient soils. Although the fore mentioned studies have been done on guano from these caves there is still need for critical analysis to determine their elemental composition as well as their extractability. Furthermore, previous studies on these materials had not grown plants on soil amended with guano to determine its potentiality on supplying P, N and other mineral elements in the soils. There is also a need to re-analyse guano from Sukamawera and Kisarawe since they do change with time. This is because guanos generate secondary minerals that are beneficial and lose some materials such as urea that are harmful to plants. Formation of secondary minerals such as gypsum and phosphate rocks could help in a long time availability of nutrients to plants as these minerals will be decomposed and release nutrients slowly, hence be of high residual value. On the other hand, harmful materials such as urea, which is due to high concentration of urine, can be volatilized and toxic bases such as sodium and aluminium can be leached with time. This minimises their effects on plants. Immature (fresh) guano has little variations in nutrients concentration due to poor formation of secondary minerals as a result of low decomposition (Shahak-Gross, 2004). This occurs mostly in bat guano from artificial caves. Most of bat guano found in the artificial caves is faecal pellets mixed with urine. However, more work needs to be done on the guano found in Tanzania in terms of their chemical composition as well as assessing their nutrients release characteristics.

Although in Tanzania there are many agro-minerals and rocks, no adequate attempt has been made to use them as soil amendment in order to increase crop production (Harris, 1961; van Straaten, 2002). One reason that is hindering their exploitation is the absence of adequate information on their potential suitability in agriculture. Studies done so far have concentrated on the use of Minjingu rock phosphate as a source of phosphorus (Ikerra, 2004). Other phosphate rocks have been left behind with inadequate information to warrant their exploitation. For instance, near Bahi in Dodoma Region, there is rock phosphate with 20% P_2O_5, similar to that of Minjingu (Harris, 1961), but it is not fully exploited as soil amendment. The same applies to guano found at Kisarawe in Coast Region and at Sukumawera in Mbeya Region.

It is well known that phosphorus (P) is among the most limiting macro-nutrients in most tropical soils, which lead to poor crop yields in many Sub-Saharan Africa (SSA) including Tanzania (Kwabiah *et al.*, 2003). This is partly due to the fact that the rate at which most SSA farmers replenish plant nutrients in soils is extremely low as compared to annual depletion rates (Sanchez, 2002 ; Bekunda *et al*., 2010). Use of industrial fertilizers is a problem. This is because inorganic fertilizers are costly and majority of the farmers cannot afford to buy and apply them on their farms at the recommended rates (Sanchez. 2002 ; van Straaten. 2002 : Bekunda *et al*., 2010).

Use of agro-minerals, in particular guano, in agriculture can be one of the alternative means of assisting the farmers in Tanzania to improve soil productivity. Guano as phosphate material can be used as substitutes for replenishing the soils with deficiency of phosphorus and other essential plant nutrients (Van Straaten, 2002). Since guano is widely distributed in the places where people live, such as in isolated places, caves, our homes in the rural areas where the majority of the farmers live, their exploitation and distribution to the farmers would not be too costly. This could substitute the more costly imported fertilizers and in building soil capital towards increasing crop productivity and, consequently, food security (Sanginga and Woomer. 2009). In addition, mining of guano would provide employment to the rural community as well as being a source of revenue to the government. However, the guanos require characterization to assess their suitability for agricultural applications and to ascertain whether or not they contain potentially toxic elements (PTEs), which could be of health and environmental concern. Characterization could also provide baseline data for further studies and comparisons with other guano found elsewhere in the world. Thus, it will assist in marketing the Tanzanian guano.

A study was therefore conducted to assess the agronomic potential of bat guano from Sukumawera and Kisarawe with the aim of promoting their use as soil amendment and source of plant nutrients.

1.1 Objectives of the study

1.1.1 Overall objective

The overall objective of this study was to assess the agronomic potential of bat guano from Sukumawera and Kisarawe with the aim of promoting their use as soil amendment and source of plant nutrients.

1.1.2 Specific objectives

The specific objectives were:

1. To establish elemental compositions of Sukumawera and Kisarawe bat guano
2. To determine physico-chemical properties of Sukumawera and Kisarawe bat guano with respect to agricultural suitability
3. To determine extractability of essential plant nutrients in bat guano.
4. To establish the optimum amounts of bat guano required as soil amendment for maize production.
5. To compare, through pot experiments, maize growth performance and nutrient uptake from soil amended with bat guano.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of Agro-minerals

The success of phosphate rock applications is revealed by increase in crop yields in different farms in East Africa (van Straaten, 2002). According to Buresh *et al.* (1997), use of phosphate rock to improve soil phosphorus status has been revealed by one-time large application of phosphate rocks which showed positive residual effects on crop yields for several consecutive cropping seasons. This is due to the chemical reaction that phosphorus undergoes in soil, such as: solubility of rocks, complex formation with other mineral elements, fixation and adsorption on the colloidal surfaces; all these result into slow release of plant nutrients with time. This process of slow release is the one known as residue value of phosphate rocks.

2.2 Origin of Bat Guano

Bat guano begins as plant life. Plants fruits are eaten by fruit eating bats, leaves and other parts of plants eaten by insects which in turn are eaten by insect eating bats. This nutritional variation obviously affects the contents of guano (Shahak-Gross, 2004; Sridhar, 2006). Fruit eating bat guano will have most of plant materials such as cellulose, lignin, pollen and seeds; while insect eating bat guano is expected to have insect materials such as chitin (Mlay and Sagamiko, 2008) which are the main component of insects' skeleton as well as a large diversity of other chemical substances excreted by the bat, among which are urea and potassium phosphate (Nieves-Rivera *et al.*, 2009).

2.3 Composition of Bat Guano

Among other things, living organisms, organic substances and mineral elements are the main constituents of bat guano. These components determine the roles and functions of any bat guano.

2.3.1 Living organisms

2.3.1.1 Arthropod fauna

Bat excrement produces an unpleasant pungent smell that attracts arthropod fauna such as beetles, ants and others. These guano fauna eat the droppings as their food, at the same time beneficial decomposing microbes are also eating the droppings. This process composts the bat guano and increases the beneficial microbes in the guano, leading to transformation of bat faecal pellets to humus (humification of bat faecal pellets) (Sridhar *et al.*, 2006).

2.3.1.2. Microbes

Microbes are small organisms which include bacteria, archaea, fungi and nematodes. These are a critical component of cave ecosystems. They perform various functions including decomposition of organic matter..

Recycling of nutrients

Microbes in bat guano help to shape subterranean environments by breaking down organic matter and liberating nutrients for other trophic levels and, in some cases, acting as primary producers of organic matter (Culver, 2005; Shetty *et al.*, 2013). Microbes in guano enhance C and N mineralization rates and enzyme activities (Smith *et al.*, 1993).

Dissolution and precipitation of minerals

Some fungi are capable of growing directly on the mineral surfaces altering them and establishing microenvironments for other microbes (Gorbushina, 2007). This enhances biological weathering of mineral substrates through direct physical separation of particles and the activity of excreted secondary metabolites/ organic acids (Hoppert *et al.*, 2004). Lithic fungi are capable of precipitating carbonate minerals on their hyphal surfaces (Burford *et al.*, 2003) and also can perform complexion by precipitating a variety of minerals through the adhesion of cations such as Fe, Ni, Zn, Ag, Cu, Cd, and Pb to their cell walls (Sterflinger, 2000).

pH modification

Soil microbes are the source of decrease or increase in guano pH. This is because the major waste products of decomposed organic matter and microbial growth are CO_2, CH_4, organic acid such as acetic and formic acids, and alcohol (Gile and Carrero, 1918); also formation of sulphuric acids due to the presence of elemental sulphur that has been oxidized by sulphur oxidizing bacteria lowers the guano pH (Northup *et al.*, 1997). Soil microbes, such as bacteria, are important agents in chemical changes in the guano. Their activities also result in the formation and accumulation of nitrate and sulphate salts (Hill and Forti, 1997; Northup *et al.*, 1997). This increases the pH of the guano.

Biochemical production

Microbes found in guano act as soil cleansers (bioremediation microbes) that help to clear up toxic residues, control root pathogens such as nematodes; and some microbal' species such as *Aspergillus* and *Penicillium* spp are known to produce strong mycotoxins (biochemicals) (Docampo *et al.*, 2009; 2011) that repel other microorganisms such as bacteria, protists, nematodes and dangerous pathogens in the soil (Nieves-Rivera *et al.*, 2009). That is why guano can be used as pesticide in the crop production system.

2.3.2 Organic substances

According to analysis done by Kaya *et al.* (2014), the chitin content of dry bat guano samples was found to be 28% by weight; this is higher than the shell structures of Crustacea. Also bat guano is composed of many other organic substances, among others, insect fragments, hair and pollen; these also add value on guano (Maher, 2006; Mlay and Sagamiko, 2008).

2.3.3 Mineral elements

Bat guano is composed of nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg), potassium (K), aluminium (Al), iron (Fe) and sulphur (S) (Olayiwola, 2011). Other elements such as fluorine (F), chlorine (Cl), copper (Cu), manganese (Mn), molybdenum (Mo), nickel (Ni), zinc (Zn) and cadmium (Cd) occur in low concentrations. Their occurrence is associated with the reaction between bedrock (cave wall) and guano solutions; but all elements exist as compounds (FAO, 2006 ; Giurgiu *et al.*, 2013).

2.4 Factors Determining the Composition of Guano

There are different factors that determine the composition of guano, these are: nutritional habit of the bat, age of guano in the cave (guano maturation), amount of water in the guano, the intrusion of other materials from outside the cave, and the composition of the bedrock forming the floor of the cave.

2.4.1 Nutritional habit factor

Type of feeds

There are some contradictions between scholars on their studies on guano based on the nutritional habit of the bats. According to Shahak-Gross (2004), insect eating bat guano has larger amount of phosphorus than fruit eating bat guano; and protein containing foods are richer in phosphorous than fruits (McCance *et al.*, 1947). On the other hand, Sridhar (2006) and colleagues emphasize that insect eating bat guano has higher nitrogen than fruit eating bat guano which also was stated by Shetty *et al.* (2013) and Mlay and Sagamiko (2008).

Quantity and quality of the feeds

According to McCracken and Gustin (1987), night bats consume about half of their own body weight, and the rate of fecal production and faecal composition reflects the rate of biomass ingested. Minimal or inadequate ingested level for a given element would initiate physiological mechanisms which maximize assimilation of that element and, therefore, minimize fecal concentration of that element (Studiezr *et al.*, 1991).

Sex factor

Variations in faecal element levels were observed within sex (Studiezr *et al.*, 1991). This variability was suggested to reflect differences in physiological status (assimilation efficiencies in males and females), highly variable composition of insects available as opportunistic prey items, or poor selective feeding by the female and male bats. A study done on female and male big brown bats indicates that there is a significant decrease in faecal level concentrations of potassium, calcium, iron and magnesium except sodium, over the summer; but for female there were no variations due to time in season except for calcium, which increased over time. For the nitrogen element guano from both sexes contained similar levels (Studiezr *et al.*, 1991).

2.4.2 Guano maturation factor

The age of the guano in the cave determines the nature of the material in the cave as it affects the completeness of other transforming influences. According to Shahak-Gross

(2004) fresh bat guano contains organic matter and total carbon content higher than in humus guano. Nitrates and sulphates are higher in young guano (faecal pallets) than in mature guano while calcium, potassium, aluminum, iron, magnesium, bacteria, actinomycetes and fungi are higher in humus-like guano than in faecal pellets. On the other hand, phosphates are said to be high in both faecal pellets and humus guano (Shahack-Gross, 2004; Sridhar *et al.*, 2006). This could possibly be because phosphorus is found in the fresh food eaten by bats (fruits, insects and mammals) and also in secondary minerals formed in the caves after guano solution has reacted with cave wall or bedrock.

2.4.3 Water factor

Where there is no water entering the cave and the atmosphere is sufficiently humid to promote bacterial decomposition, guano is likely to contain high nitrates, potash, phosphoric acid, and soluble salts or a product richer than the fresh guano, due to the decomposition of the bulky organic matter. Totally dry conditions, where moisture is deficient for much bacterial decomposition, will most probably produce guano with nearly the same composition as the faecal pellets (Gile and Carrero, 1918) due to low, if any, microbial activities.

The amount of water entering the cave does affect the material more than any other condition. This is because the soluble constituents are leached down to the bedrock. This causes phosphates and sulphates to react with the bedrock, leading to the loss of potash and nitrates in drainage water (Shahak-Gross, 2004). However, if water that enters the cave contains very little soluble material, and if only a small amount of water infiltrates through the rock, that guano may contain considerable soluble phosphates, gypsum, some nitrates, and ammonia from the rock. Leached phosphatic guano may become enriched temporarily by the infiltration of soluble phosphates, nitrogen and gypsum from other parts of the cave. The accumulations of gypsum, which sometimes occur in certain parts of a cave, are obviously due to the evaporation or leaching from other parts of the caves (Gile and Carrero, 1918; Quattropani *et al.*, 1999; Maher, 2006).

Apart from the translocation and removal of soluble materials, water affects the composition of guano by influencing the course of bacterial decomposition. When fresh guano is so saturated with water and becomes covered with a crust of carbonate of lime or a slide of other guano it undergoes anaerobic bacterial decomposition (Gile and Carrero, 1918).

2.4.4 Rock factor

The character of the rock forming the cave determines largely the composition of the leached or phosphatic guanos. Where the cave is formed in pure limestone guano consists mostly of tricalcium phosphate (Gile and Carrero, 1918; Shahak-Gross, 2004). Where the rock, however, contains considerable iron, aluminium, and silica, or these elements are brought in by water, that guano may consist largely of phosphates of iron and aluminium with siliceous impurities (Hill and Forti, 1997; Giurgiu *et al.*, 2013).

2.4.5 Other materials factor

Occasionally earthy materials may be carried into the cave through the mouth of the cave or through holes (openings) in the ceiling. When these materials from outside the cave become admixed with the guano, they decrease its value (Gile and Carrero, 1918). According to Maher (2006), some materials such as pollen found in the guano of insectivorous bat may be brought in the cave through air, seepage, animals or by night-flying bats and insects meet them in the atmosphere.

2.5 Mineral Formation due to Organic Matter Degradation

Different secondary minerals may form under specific chemical conditions. The combination of chemical parameters such as pH, phosphate concentrations, aluminum concentration, potassium concentration, and redox potentials determine the conditions under which the mineral formation and stability is high (Karkanas *et al.*, 2000). Phosphates represent the second largest group among cave minerals after sulphates (Onac, 2012; Giurgiu *et al.*, 2013). The hydrous phosphates such as $K_4H_5Al_3(PO_4)_6 \cdot 11H_20$ and $H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$ and several other minerals such as potassium ammonium hydrogen phosphate $[(NH_4, K)_3HP_2O_7 \cdot H_2O]$, ammonium potassium hydrogen phosphate $[(NH_4, K)_3HP_2O_7]$; aluminium ammonium hydroxide phosphate $[Al_2NH_4OH(PO_4)_2 \cdot 2H_2O]$ are found in bat guano caves (Quattropani *et al.*,1999; Maher, 2006). The phosphate minerals formation is related to the accumulation of significant bat guano or bone, while the clay minerals from detrital sediments in caves are a source for aluminium, silica, potassium, and sodium, which, when combined with the phosphate solutions (phosphoric acid) leaching from beneath the guano will increase the possibility for precipitation of variety of phosphate minerals such as *Hydroxylapatite* $Ca_5(PO_4)(OH)$, *Brushite* $[Ca(PO_3OH) \cdot 2H_2O]$, *Francoanellite* $[K_3Al_5(PO_3OH)(PO_4)_2 \cdot 12H_2O]$, *Taranakite* $[K_3Al_5 (PO_3OH)_6 (PO_4)_2 \cdot 18H_2O]$, *Variscite* $[AlPO_4 \cdot 2H_2O]$, *Leucophosphite* $[K(Fe^{3+})_2(PO_4)_2(OH) \cdot 2H_2O]$, hopeite, or Zn-rich phosphate or Carbonate-hydroxy-apatites $(Ca_{10} (P0_4, C0_3)_6 (OH)_2)$ (Giurgiu *et al.*, 2013 ; Kudeyarova *et al.*, 2014).

One of the most common sulphates in the bat guano deposits from the caves is gypsum (Hill and Forti, 1997). During early stages of organic matter degradation gypsum and nitrate are formed, this is when nitrate and sulphate accumulate due to microbial action. As the pH increases due presumably to the buffering capacity of the carbonate system, and if the local rock is limestone or dolomite will result into formation of other secondary phosphate minerals in case a source of phosphate is still accessible; but gypsum and nitrate are lost with time because these minerals are soluble in water (Shahak-Gross, 2004). Once formed, some secondary minerals will remain insoluble even if the conditions change, this is due to slow kinetics of dissolution process, predominantly when there is no enough water (Nriagu, 1976). Shahack-Gross (2004) reported that the availability of phosphate, Al, K, and Fe increases with increasing organic matter degradation, while the availability of nitrogen and sulphur decreases.

2.6 Plant Nutrients in Guano

According to Sanginga and Woomer (2009), guano is rich in nitrogen, phosphorus and other plant nutrients which are released upon decomposition. There are two broad categories of bat guano based on N-P-K ratios. These are high phosphorus guano (3 : 13 : 4 – 4 : 30 : 4) from fruit- eating bats and high-nitrogen guano (8 : 4 : 1 – 13 : 3 : 3) from insect-eating bats (insectivores) (Sridhar *et al.*, 2006; Shetty *et al.*, 2013).

According to Sridhar *et al.* (2006), the N-P-K ratio is higher in faecal pellets than in humus guano (7.9 : 2.4 : 1.1 vs. 5.7 : 2.2 : 0.9). Humus guano had lower total carbon (26.4 vs. 46%), nitrogen (5.7 vs. 7.9%) and C/N ratio (4.6 vs. 5.9) than the faecal pellets. Nitrogen guano is known to enhance crop growth, while phosphorus guano induces root development, shoot budding, multiple branches and flowering.

According to Gile and Carrero (1918), bat guano can be divided into three classes: fresh bat guano, decomposed guano, and phosphatic guano. Fresh guano mostly composed of faecal pellets and urine. The small faecal pellets represent the non-digestible portion of the animal's diet in the previous few hours (Maher, 2006). Fresh guano is dark brown in colour and it has unusual low volume weight. Its nitrogen exists as soluble organic compounds (such as urea), as insoluble organic compounds (such as proteins and chitin), and sometimes as ammonia and nitrates (Quattropani *et al.*, 1999; Shahak-Gross, 2004; Maher, 2006). Presence of nitrate and ammonia in fresh guano depends on conditions that geared their quick formation (Shahak-Gross, 2004).

Decomposed guano is formed during microbial decomposition of fresh guano. When organic matter is oxidized, it forms carbon dioxide and ammonia that escape into the air (Gile and Carrero, 1918). The solution formed from guano, such as nitric acids, sulphuric acids, and phosphoric acids do leach into the underlying stratum. It often contains lumps of gypsum, organic matter, or fragments of carbonate of lime (Hill and Forti, 1997; Shahak-Gross, 2004; Giurgiu *et al.*, 2013). The decomposed guano is generally brown in colour and pulverulent, with a much higher volume weight than fresh bat guano but lower than ordinary soil (Gile and Carrero, 1918).

The end product of the various reactions and conditions which produce the decomposed guano represents 'phosphatic guano' (mature guano). At this stage almost all organic matter has been oxidized, leaching has carried away all the potash, gypsum, and nitrates and the monocalcium and dicalcium phosphates have been converted into tricalcium, ferric, or aluminium phosphates (Gile and Carrero, 1918; Shahack Gross, 2004; Sridhar *et al.*, 2006). This guano contains almost no nitrogen and consists of the insoluble phosphates of lime, iron, or aluminium, mixed with siliceous impurities (Shahack Gross, 2004) and its total phosphoric acid content is high unless the amount of siliceous impurities is high. It is generally grittier in texture and lighter in colour and has greater volume weight than decomposed guano (Gile and Carrero, 1918).

The N-P-K ratios were given by Sridhar (2006), of high P (3 : 13 : 4 – 4 : 30 : 4) for the fruit eating bat guano and high N (8 : 4 : 1 – 13 : 3 : 3) for insect eating bat guano. The results show great variation in P content within fruit eating bat guanos than in N and K. On the other hand in insect eating bat guano N content varied more than P.

Shetty (2013) and colleagues determined the nutrient concentrations of guano from two semi carnivorous bat colonies. The values in N-P-K ratios were 2 : 3 : 1 and 1 : 3 : 1 for Varanga and Yennehole, respectively. Both were phosphorus-reach guanos with the same phosphorus content but different in nitrogen content. This also has been revealed by some studies done in sub Saharan African caves. For example bat guano from Makindu, Kenya has higher nitrogen than phosphorus that ranges from 7% to 13% nitrogen and 3% to 6% phosphorus (Sanginga and Woomer, 2009). Sikazwe and Waele (2004) characterised guano from two different caves, Kapongo and Chipongwe in Zambia. Both were phosphorus rich guanos with the N-P-K ratios of 2 : 7 : 1 and 4 : 34 : 1 for Kapongo and Chipongwe caves, respectively. These guano samples also showed variation in P content although they were said to come from fruit eating bats, N content also varied except for K. Guano seems to vary with time in the nutrients concentration, compared to the previous analysis done by Brown (1961) on five samples of guano from the same cave of Kapongo the results show that the guano was high in nitrogen (nitrogen-rich guano) it had N-P-K ratio of 7 : 0.03 : 1.

2.7 Roles of Guano in Soils

2.7.1 As pesticide

In agriculture and horticulture, guano has a number of uses. This is due to its chemical properties and different organisms found in the guano that enrich the soil fertility and the texture, together with the microbes that help to clear any toxins in the soil

(Shetty *et al.*, 2013). This process composts the bat guano and increases the beneficial microorganisms in the guano some of which produce biochemicals that rid other organisms.

2.7.2 As nutrients reservoir

Guano as organic inputs can influence nutrient availability by the total nutrients added through guano when it decomposes, and also control the net mineralization-immobilization patterns in the soil (Van Straaten, 2002). Guano also acts as a source of C and energy to drive microbial activities as well as a precursor to soil organic matter fractions. Guano - mineral soil interaction enhances complexing toxic cations and reducing the P sorption capacity of the soil (Haynes and Mokolobate, 2001; Shetty *et al.*, 2013). Furthermore, bat guano can be used in different stages of the plant growth due to the macro nutrients as well as minor and trace elements essential for plant growth. Nitrogen from guano is reported to have enhanced crop growth, while phosphorus induced root development, shoot budding, multiple branches and flowering (Shetty *et al.*, 2013).

2.7.4 As soil amendment

Secondary minerals formed in guano such as gypsum ($CaSO_4.2H_2O$), hydroxylapatite ($Ca_5(PO_4)(OH)$), dolomitic limestone ($CaMg(CO_3)_2$) and Carbonate-hydroxy-apatites ($Ca_{10}(P0_4,C0_3)_6(OH)_2$) can be used to regulate soil pH. For acidic soils, hydroxylapatite ($Ca_5(PO_4)(OH)$), dolomitic limestone ($CaMg(CO_3)_2$) and Carbonate-hydroxy-apatites ($Ca_{10}(P0_4,C0_3)_6(OH)_2$) can be used, because they are composed of calcium and magnesium carbonates that are capable of neutralizing soil acidity and supplying calcium and magnesium to plants. Neutralizing soil acidity and reducing toxicity of aluminium concentration in the soil, results into stimulating soil microbial activity in mineralizing other plant nutrients in the soil (Van Straaten, 2002; FAO, 2006). For alkaline (sodic) soils, gypsum ($CaSO_4.2H_2O$) can remove excess Na^+ from the exchange complex and replace it with Ca^{2+} to make the soil normal and supply S in deficient situations (FAO, 2006). It should be noted that increase in pH in the soil can be due to accumulation of basic cations from organic materials (in guano) (Kretzschmar *et al.*, 1991).

Since bat excreta are organic materials from insects and fruits, all can safely be used to provide the binding sites for toxic substances (Shahak-Gross, 2004). Moreover, organic materials have been shown to reduce the P-sorption capacity of the soil and increase P availability (Palm *et al.*, 1997; Haynes and Mokolobate, 2001). Guano as organic materials can also have several other effects on soils and plants that influence nutrient acquisition and absorption by plants. Plant root growth can increase as a result of reduced exchangeable Al in the soil, caused by complex formation with organic anions that are produced by the decomposition of organic materials (Van Straaten, 2002). Root growth can be stimulated by organic materials either directly or indirectly through their effect on soil bacteria that can suppress root pathogens and produce plant growth hormones (Nieves-Rivera *et al.*, 2009; Shetty *et al.*, 2013). It is important to note that root growth can be inhibited by organics too, particularly if phenolic concentrate in the soil or if bacteria detrimental to root growth increase because of the addition of organic materials (Palm *et al.*, 1997) among which is guano.

2.8 Crop Response to Soil Applied Guano

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 the different rates in weight applied in the red loamy soil. Both crops, in soil amended with guano at the ratio of 20:1 showed the highest shoot length, total dry matter, nitrogen content and nitrogen uptake. The shoot length, total dry matter, nitrogen content and nitrogen uptake in both crops were significantly different between treatment 20:1 and control.

On the other hand, Shetty (2013) studied the effect on the growth of *Vigna radiata* (mung bean) seedlings using guano from semicarnivorous bats; the guano came from two different geographical locations (Varanga and Yennehole) applied in different quantities (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. Noted poor results from pot experiment were due to high amount of guano applied.

In experiments done by Shetty (2013) and Sridhar *et al.* (2006), results clearly indicate that incorporation of low amount of bat guano into the soil enhances crop production. However, we lack information on the response of crops to guano found in Tanzania deposits. This is because there are few studies on these materials and none of the study attempted to assess the efficiency of bat guano in crop production.

Most of studies done on bat guanos reveal their potentiality in agriculture especially as the source of plant nutrients. These materials can be used to benefit local community by reducing hunger due to low crop yields as the product of poor soil fertility. However, their characterizations are of more important to unveil the information on their effectiveness in crop production. This will stimulate their use and hence reveal great impact in crop production in many agricultural soils in Africa and Tanzania in particular; this is because guano are good reservoir of nutrients, water, binding site of toxic substances, easy for application, environmental friend and their transportation cost is low.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sampling of Bat Guano

Bat guanos were sampled from Sukumawera and Kisarawe caves. Kisarawe cave is found in Coastal Region, Eastern zone of Tanzania, while Sukumawera cave is in Mbeya Region, South-Western zone of Tanzania. Both caves are found at different geographical locations, bedrock lithology and different climatic conditions. Furthermore, Sukumawera cave is a natural cave while Kisarawe is an artificial cave. Protective gear such as gloves, respirators and gum boots were used during guano sampling.

The bat guano deposits of Sukumawera in Mbeya area are located in caverns in horizontal travertine formations. The cave has some openings in the ceiling that go directly to the cave. Bats get in and out of the cave through these openings, which also bring in air and light.

The first guano sample at Sukamawera was obtained from a point near the entrance of the cave. This area receives light coming through the entrance and through the opening at the ceiling. It had some bats on the ceiling too. It was 40 - 60 m from the entrance and just 5 m from the ceiling. Guano near the entrance was moist, dark-brown in colour but darker than the guano taken inside the cave. Guano at the entrance was wet because the area had received rains a few days earlier. This guano had plant materials, ash and charcoal and about 15 - 20 m there were other animal dung such as goats dung. Other animal dungs were separated from guano by hand since they were bigger in size than bats dung.

Another sample at Sukamawera was obtained inside the cave, at about 160 - 180 m from the entrance. It was completely dark inside the cave with bats on the ceiling. Guano found here thought to be excavated more than a decade ago. It contained plant materials and some charcoal mixed with guano that might have come through the ceiling openings. Inside the cave, the guano was dry, powdery and dark-brown in colour with sparse faecal pellets. Guano seemed to have accumulated in the cave for some time because some had hardened on rocks and paves. Some guano had semi-decomposed wood, charcoal and white smooth rocks and gravels that some seemed to be weathered by water as the result of dissolution of rocks. All rocks and gravels found in Sukumawera bat guano reacted with dilute HCl to produce effervescence. This shows that the bedrock in Sukumawera cave is a carbonate rock.

The guano samples were collected by using hoe and spade in different points (near the entrance and inside the cave). Samples were collected from the surface to the bedrock. The samples that were close to the bedrock showed visible horizontal stratifications that were dark brown, brown and white, with some clayey sediments within. There were sparse pellets and a dark brown layer in the upper part, representing the organic rich guano.

Three guano samples were taken at the entrance and inside the cave. The samples from each location were mixed together to get a homogenous composite sample. A total of two (2) samples (near the entrance and inside the cave) from Sukumawera cave were collected for laboratory analysis and pot experiment.

As mentioned earlier, the Kisarawe cave is an artificial cave which was previously used for mining kaolinite. There is no rock or opening on the ceiling. The cave walls are not stable and there are disintegrations of materials from the ceiling and the walls too. These fallen materials do admix with guano, so the guano was found mainly mixed with some sand particles and some grey-whitish rock materials (kaolinite) that seem to constitute the cave walls and floor. The cave is accessible hence people enter the cave to excavate guano and sell it to local farmers at a price of 3000 Tanzanian shillings per bag of 50 - 60 kg.

At Kisarawe cave near the entrance, samples were taken from a dark side chamber that branched to the left hand side about 60 - 80 m from the entrance. The area was occupied by fewer bats than inside the cave. Guano found there had no layers resulting from accumulation of guano, only some decomposed guano and faecal pellets were found. Some plant materials (such as dry leaves), different arthropod fauna, furs, skulls and bones of animals (seem to be carnivores), crystals and white-grayish particles/gravels were found admixed with guano.

Another sample was taken inside the cave. This source was a large chamber that is completely dark, found about 120 - 140 m from the entrance. This chamber was occupied by lots of bats. At the upper surface of the place where guano was sampled there were clear faecal pellets but as one sampled down at 2 - 3 cm guano no fecal pellets were identified. This was caused by wetness due to bat urine. This guano was dark-brown in colour which turns into brown when dried. It also had some plant materials such as remnants of leaves, some arthropod fauna, furs and white-greyish gravels but these were fewer than in guano found at the chamber near the entrance. All gravels found in Kisarawe cave did not react with dilute HCl. Therefore, bedrock in Kisarawe cave is not a carbonate.

Total of two (2) samples from Kisarawe cave were collected (near the entrance and inside the cave). The collecting depth of guano was determined by locating the contact between the guano deposits and organic-poor sediments. This deposit had loose sediment samples that were easy to collect from each unit. Near the entrance, sampling was done by hand. Inside the cave sampling was done by spades. Three samples were taken from each point: the samples were then thoroughly mixed together to get homogenous sample for laboratory analysis and for pot experiment

3.2 Preparation and Analysis of Guano Samples

The samples were air-dried in a glasshouse and sieved to pass through a 2 mm sieve.

3.2.1 Determination of elemental compositions of bat guano

Elemental composition of bat guano from Sukumawera and Kisarawe (near the opening and inside the cave) was done at Geological Survey Laboratories located in Dodoma. The elemental composition was determined by Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) technique Prodigy7 model (Halvin and Soltanpour, 1980). The analysis was set to axial plasma orientation and auto samples from Agilent Technologies were used as standard solutions. A summary of the procedure is given below:

5.0 g of each guano was mixed with 30 mls of concentrated nitric acid and then heated at 125°C until all dissolved and volume reduced to 20 mls. Thereafter, the digest was left to cool. The cool digest was then filtered, put into flasks and diluted to 100 ml with distilled water. The filtrate was later taken to ICP-OES machine for analysis of P, K, Cu, Mg, Na, Fe, Zn, Ca, Mn, Ni, Cr, Co, Cd, Pb, Mo, S, U and Sb. For the elements As, Se, and Hg the extracted solution was directed to the hydration unit, and then $NaBH_4$ was added to provide H^- to reduce the mentioned elements to hydrides to be read by machine since the machine cannot read them as elements. Pre-digestion could not be carried out because guano is not so hard a material as to require pre-digestion.

3.2.2 Physico-chemical properties of bat guano

Chemical characterization of guano was carried out at Sokoine University of Agriculture in Soil Science Laboratories. Guano pH was measured in 1 : 2.5 guano: water suspension using pH meter (McLean. 1982). Sulphur was determined by acid solution and turbidimetric method, and then the absorbance was measured by Ultra Violet Spectrophotometer (UVS) (Moberg. 2001). Cation exchange capacity (CEC) was determined by the ammonium-acetate saturation method and quantification of exchangeable bases for Ca and Mg were determined from the ammonium-acetate filtrates by Atomic Absorption Spectrophotometer (AAS) while K and Na by Flame Photometer following the Moberg (2001) and Okalebo *et al.* (2002) methods. Organic carbon was determined by the Walkley and Black method (Nelson and Sommers. 1996) and total nitrogen by micro-Kjedahl digestion followed by distillation then titration (Bremmer, 1996). The extractable P was determined based on the Bray-1-P method (Kuo. 1996), but colour development was done by the ascorbic acid-molybdate blue method (Murphy and Riley. 1962). Extractable micronutrients (Cu, Fe, Zn and Mn) were extracted using DTPA and concentration was determined by AAS (Lindsay and Norvel, 1978). Extractable potentially toxic elements (PTEs) Co, Cr, Cd and Pb were measured by DTPA method (Lindsay and Norvel, 1978) and concentration was determined by AAS based on ICP-OES results. Electrical conductivity was measured in 1 : 2.5 (guano : water) by using dry electrode (Thomas, 1996).

3.3 Soil

3.3.1. Soil sampling and preparation

The soil used for pot experiment came from Mazimbu Farm in Morogoro District. Composite soil samples were obtained from different points sampled randomly at a depth 0 - 30 cm. Soil samples were taken in an area that had not received any fertilizer for the past three years. Soil samples were air dried and ground to pass through a 8 mm sieve. Samples used in the laboratory analysis were air- dried and then ground and sieved to pass through a 2 mm sieve.

3.3.2 Soil analysis

The particle size distribution of the soil was determined by the hydrometer method (Gee and Bauder, 1986). The pH of the soil was measured in 1 : 2.5 (soil : water suspension using a pH meter (Thomas. 1996). Electrical conductivity was measured in 1 : 2.5 soil : water (Thomas, 1996). Organic carbon was determined by the Walkley and Black method (Nelson and Sommers, 1996) and total nitrogen by the micro-Kjedahl digestion procedure followed by distillation (Bremmer, 1996). Extractable P was determined based on the Bray-1-P method (Kuo, 1996), but colour development was done by ascorbic acid-molybdate blue method (Murphy and Riley, 1962). Sulphur was determined by acid seed solution and turbidimetric reagent method, and then the absorbance was measured on a spectrophotometer (Møberg, 2001). Cation exchange capacity (CEC) was determined by the ammonium-acetate saturation method and quantification of exchangeable bases: K, Ca, Na and Mg were determined from the ammonium-acetate filtrates by Atomic Absorption Spectrophotometer following the Lindsay and Norvel (1978) methods. Extractable micronutrients were extracted by using diethylenetriaminepenta-acetic acid (DTPA) and concentration was determined by atomic absorption spectrophotometer (Lindsay and Norvel, 1978).

3.4 Pot Experiment

The objective of pot experiment was to establish the optimum amounts of bat guano that could be used to amend alkaline soil for maize production. In addition, the pot experiment was used to compare growth performance of maize and nutrient uptake from soil amended with bat guano. A bulk of soil was collected for pot experiments, dried, ground and sieved through an 8 mm sieve ready for the pot experiments. The experiment was carried out using the Complete Randomized Design (CRD). Twenty four treatments (T1 - T24) replicated three times each, consisting of soil and guano found near the opening and inside the cave for Kisarawe and Sukumawera in different proportions in 4 L pots.

The treatments were:

T1- soil only (control)

T2-soil + Sukumawera bat guano near the opening at a ratio of (20 : 4) (200 g guano kg^{-1}soil)

T3-soil + Sukumawera bat guano near the opening at ratio of (20 : 3) (150 g guano kg^{-1}soil)

T4-soil + Sukumawera bat guano near the opening at ratio of (20 : 2) (100 g guano kg^{-1}soil)

T5-soil + Sukumawera bat guano near the opening at ratio of (20 : 1) (50 g guano kg^{-1}soil)

T6-soil + Sukumawera bat guano near the opening at ratio of (20 : 0.5) (25 g guano kg^{-1}soil)

T7- soil only (control)

T8-soil + Sukumawera bat guano inside the cave at ratio of (20 : 4) (200 g guano kg^{-1}soil)

T9-soil + Sukumawera bat guano inside the cave at ratio of (20 : 3) (150 g guano kg^{-1}soil)

T10-soil + Sukumawera bat guano inside the cave at ratio of (20 : 2) (100 g guano kg-^{1}soil)

T11-soil + Sukumawera bat guano inside the cave at ratio of (20 : 1) (50 g guano kg^{-1}soil)

T12-soil + Sukumawera bat guano inside the caveat ratio of (20 : 0.5) (25 g guano kg^{-1}soil)

T13- soil only (control)

T14-soil + Kisarawe bat guano near the opening at ratio of (20 : 4) (200 g guano kg^{-1}soil)

T15-soil + Kisarawe bat guano near the opening at ratio of (20 : 3) (150 g guano kg^{-1}soil)

T16-soil + Kisarawe bat guano near the opening at ratio of (20 : 2) (100 g guano kg^{-1}soil)

T17-soil + Kisarawe bat guano near the opening at ratio of (20 : 1) (50 g guano kg^{-1}soil)

T18-soil + Kisarawe bat guano near the opening at ratio of (20 : 0.5) (25 g guano kg^{-1}soil)

T19- soil only (control)

T20-soil + Kisarawe bat guano inside the cave at ratio of (20 : 4) (200 g guano kg^{-1}soil)

T21-soil + Kisarawe bat guano inside the cave at ratio of (20 : 3) (150 g guano kg^{-1}soil)

T22-soil + Kisarawe bat guano inside the cave at ratio of (20 : 2) (100 g guano kg-^{1}soil)

T23-soil + Kisarawe bat guano inside the cave at ratio of (20 : 1) (50 g guano kg^{-1}soil)

T24-soil + Kisarawe bat guano inside the cave at ratio of (20 : 0.5) (25 g guano kg^{-1}soil)

Maize (*Zea mays* L.) Tanzanian Maize Variety 1 (TMV-1) was used as a test crop to assess the efficiency of guano as soil amendment. Seeds were soaked in tap water for six hours. Five maize seeds were sown separately per treatment in 4 L pots and allowed to grow in glasshouse, then thinned to two plants per pot, 12 days after sowing (DAS). The pots were regularly watered by tap water to raise the soil moisture status to about field capacity until harvest (35 days or 5 weeks). Plant height was taken to the nearest centimetre (cm) and averages of two plants in each pot were obtained at 7, 14, 21, 28, and 35 days after sowing (DAS). Number of leaves and any plant colour change were noted. Biomass weight before flowering was determined at 35 days after sowing (DAS). The plant shoots were taken from the pots, oven dried at 80°C to constant weight for determination of dry weight (biomass) and nutrient concentration of the plants.

The dried shoot samples were ground to pass through a 0.5 mm sieve and analyzed for total N, using wet digestion by micro-Kjeldah method (Bremmer, 1996). Other elements were determined by dry ashing. After ashing, for total P colour development was determined by ascorbic acid-molybdate blue method (Murphy and Riley, 1962), total metallic macronutrients and micronutrients by AAS (Motsara and Roy, 2008). Sulphur was determined by acid solution and turbidimetric method, and then the absorbance was measured on an Ultra Violet Spectrophotometer (UVS) (Møberg, 2001).

Soil samples were taken from the pots after harvest and analyzed for exchangeable bases, P, N and micronutrients.

3.5 Data Analysis

The data collected were subjected to Analysis Of Variance (ANOVA) using the GenStat Discovery 15th edition computer software.

3.6 Statistical Model

The statistical model used was as follows:

$Yijk = \mu + Gi + Sj + (GS)ijk + eijk$……………………………………………[Equation 1]

Where:

Yijk = Pot obsertation

μ = general mean effect

Gi = guano rate effect

Sj = site effect

(GS)ijk = interaction between guano rate and site

eijk = error

i = 1, 2,…,6 (guano rates)

j = 1, 2 (sites)

k = 1, 2, 3 (replications)

Treatment means separation was done using Duncan's New Multiple Range Test at the 5 % level of significance.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characterization of Bat Guano from Sukumawera and Kisarawe

A summary of total elemental composition of the studied guano is indicated in Table 1. The results show that total P in both guanos (Sukumawera and Kisarawe) varied with cave and sampling location. The guano found near the openings (SO and KO) had 50% less P than those collected inside the cave (SI and KI). It is suggested that the amount of guano in a specific point might be proportional to the P concentration. This is because near the openings there was little guano and less piled so the sample taken had much cave sediments than inside guano, this affected guano quality (Gile and Carrero, 1918). However, this might be due to leaching and some environmental factors such as light, fresh air, bat colon that inhabit that specific point where guano was sampled and other organisms that visit the caves.

The amount of P in Sukumawera and Kisarawe bat guano is higher compared to the average amount of 2 to 7% mentioned by Hutchison (1951) as cited by Shahack-Gross (2006). Moreover, the P amount in Sukumawera and Kisarawe bat guano was found to be higher than in Makindu bat guano in Kenya that had 3 to 6%, insectivorours bat guano found in Assaigolli village cave (0.8 to 3.7%) and Chipongwe cave guano (4.03%); however, KO had low P (7.38%) than Kapongo cave guano (8.41%) (Sikazwe and Waele, 2004; Sridhar *et al.*, 2006; Sanginga and Woomer, 2009). Also the total P in Sukumawera bat guano differed from that which was given by Chesworth *et al.* (1988). The results showed that level of P in Sukumawera bat guano ranged from 26% to 37%.

Table 1: Total elemental compositions of Sukumawera and Kisarawe bat guano

	Guano type (%)			
	SI	SO	KI	KO
Element				
P	40.67	20.32	14.85	7.38
K	5.53	5.18	5.39	4.31
Ca	5.83	6.04	6.54	3.62
Mg	0.19	0.18	0.19	0.19
Na	0.77	0.77	0.86	0.68
Ni	0.04	0.01	0.01	<0.01
Mn	1.44	0.64	0.90	0.68
Zn	1.57	0.63	0.48	0.59
Cu	0.47	0.14	0.11	0.12
Cr	0.01	0.01	0.02	0.01
Co	0.02	<0.01	<0.01	<0.01
As	0.07	0.08	Trace	Trace
Cd	Trace	Trace	Trace	Trace
Pb	<0.01	<0.01	<0.01	<0.01
Se	0.08	0.05	0.03	0.03
S	39.05	19.11	13.02	6.05
Hg	6.19	24.57	5.99	3.10
U	Trace	Trace	Trace	Trace

SI: Sukumawera bat guano found inside the cave
SO: Sukumawera bat guano found near the opening of the cave
KI: Kisarawe bat guano found inside the cave
KO: Kisarawe bat guano found near the opening of the cave

If the analyzed samples done by Chesworth and colleagues (1988) came from the same point with the samples done in this study (inside the cave), there is an increase of about 3% to 14% of total P content. This variation may be due to many factors including secondary mineral formation, change in nutritional habit of the bats as opportunistic prey (Studiezr *et al.*, 1991; Shahak -Gross 2004; Sridhar *et al.*, 2006) and some chemical reactions that take place in the caves in time (Karkanas *et al.*, 2000). This also happened on the Kapongo cave guano, where the results on samples analysed in 1961 and 2004 were defferent. The guano changed from rich in nitrogen to rich in phosphorus (Brown, 1961; Sikazwe and Waele, 2004). In Kisarawe bat guano, total P level seems to be lower compared to that from Sukumwera, presumably because this guano was relatively younger than that of Sukumawera guano, so it was less decomposed and hence poor formation of phosphate minerals (Shahack Gross, 2004; Sridhar *et al.*, 2006).

Comparing total Ca, Mg, K, and S with the levels proposed by Shahack-Gross (2004), Sukumawera bat guano had higher amounts of K, Ca and S (< 5%), while Mg was within the limit of 0.18 and 0.19% in all locations. In Kisarawe bat guano the amount of S exceeded the limit amount (13.02 and 6.05%); K (4.31%) and Ca (3.64%) were within the limit in KO but beyond the limits in KI (6.54%). Also, Mg was within the limit for KI (0.19%) and KO (0.19%). Comparing bat guano from Sukumawera and Kisarawe with other caves, the amount of K in both guanos was higher than in Assaigoli village cave (0.4 to 1.3%), Chipongwe (0.12%) and Kapongo caves (1.24%). Ca quantity was also higher than that found in insectivours bat guano at Assaigoli village cave (1 to 2.2%) but Mg in both bat guano (Sukumawera and Kisarawe) was lower than in the above comparable bat guanos (Sikazwe and Waele, 2004; Sridhar *et al.*, 2006).

Small K variations in guano from both caves, was probably due to bats inhabiting those caves have the same nutritional habits and the same opportunistic prey species (Studiezr *et al.*, 1991) although they are found in different geographical locations and environment conditions. However, K level in guano is caused by the element K present in the detrital sediments of the caves (Hill and Forti, 1997; Giurgiu *et al.*, 2013).

Based on these results, variation of S was observed among the caves and sampling locations. Amounts of S among the locations showed that SO and KO bat guano had total S < 50% than SI and KI bat guano. As it was previously explained, the interaction of the external factors, such as light, moisture, air, sun, wind and organisms that go in the caves may affect the process that leads to the formation of secondary cave minerals such as gypsum (Hill and Forti, 1997; Onac, 2012). However, guano from Sukumawera had higher S than Kisarawe guano. This may be due to guano decomposition in the cave and the bed rock constituents since Kisarawe guano was relatively younger than Sukumawera guano.

The variation of Ca levels in SI and SO was probably caused by the composition of guano. Guano at SO location was intercalated with cave material hence was not pure and had little guano, resulting in the SO sample having more cave sediments compared to SI sample. However, secondary minerals formation, other materials from outside the cave and dissolution of the bedrock as water enters the cave may increase that amount of Ca (Gile and Carrero, 1918). The sample from SO was taken 5 to 10 metres from the opening on the ceiling and the cave bedrock is a calcic rock. Total Na did not vary much within caves and locations.

The total amounts of micronutrients in guano were very high as compared to those which were suggested by FAO (2006) in phosphate rocks, where guano is inclusive. FAO (2006), indicated that phosphate rocks contain several micronutrients with average content of 42 mg Cu kg^{-1}, 90 mg Mn kg^{-1}, 32 mg Ni kg^{-1} and 300 mg Zn kg^{-1}. These micronutrients exist as compounds which are products of chemical reactions in the cave (Hill and Forti, 1997; Giurgiu *et al.*, 2013). The source of these micronutrients could be the host rocks surrounding the caves. The chemical reactions between cave walls and guano solutions could lead to the formation of different compounds containing these micronutrients.

4.2 Physico-chemical Properties of Bat Guano

Analysis of guano from Sukumawera in Mbeya and Kisarawe in Coastal region indicate differences in extractable fractions of plant nutrients (Table 2). This is because of differences in chemical compounds matrices forming guano in the cave and composition of the bedrock.

4.2.1 Sukumawera bat guano

The pH of bat guano from Sukumawera cave varies within vicinities. The pH of SO was slightly acidic (6.3) like that of humus guano (6.2 to 6.8) in Assaigoli village cave as reported by Sridhar *et al.* (2006) while SI was strongly acidic (4.2). This shows that. guano found at the entrance of Sukumawera cave is humus guano. High pH in SO was presumably due to high level of cations present in guano and low amount of acids released when organic matter decomposes (Shahak-Gross, 2004).

Table 2: The physico-chemical properties of Sukumawera and Kisarawe bat guano

	Guano type			
Guano property	**SI**	**SO**	**KO**	**KI**
pH $_{(water)}$	4.20	6.30	4.30	6.70
ECe (mS/cm)	>20.00	>20.00	10.20	13.06
%OC	12.77	5.99	9.98	9.18
%MC	8.50	13.55	3.37	8.61
CEC(cmol (+) kg^{-1})	19.71	9.04	15.17	11.66
S (mg kg^{-1})	2495.92	650.14	117.99	835.07
Exchangeable cations (mg kg^{-1})				
Mg	1444.14	3067.23	1360.90	1756.27
Ca	36551.33	43861.59	3765.89	2658.28
K	2245.72	7306.89	5245.53	1843.49
Na	903.67	6507.56	12759.34	31230.49
Bray-1 Available P(mg kg^{-1})	2518.72	597.09	2961.63	3730.86
%Total N	3.20	2.87	3.52	4.90

SI: Sukumawera bat guano inside the cave
SO: Sukumawera bat guano near the opening
KI: Kisarawe bat guano inside the cave
KO: Kisarawe bat guano near the opening

Decrease of pH in SI to strongly acidity level is probably due to high organic matter content that released some organic acids upon decomposition as it was suggested by Haynes and Mokolobate (2001) and/or the substantial amount of S present was converted to sulphuric acid by microbes. However, leaching of basic cations present in guano could have also contributed to the decline in pH (Northup *et al.*. 1997).

Sukumawera bat guano had very high ECe (> 20 mS/cm) compared with that of Assaigoli village cave (2.5 to 4.8 mS/cm) (Sridhar *et al.*. 2006). This was probably due to high soluble salts in Sukumawera bat guano whose dissolution released free ions. The ECe is obtained from the dissolution of soluble salts. Na^+ and Cl^- or sometimes soluble ions like sulphates, nitrates and bicarbonate (Thiagalingam. 2000), which are parts of secondary minerals formed in the cave. The ECe values from Sukumawera bat guano could reduce crop yield up to 100% (Msanya *et al.*, 2001). The negative effects could be on the germination and performance of the plant in general.

Moisture content (%) in SO was higher than in SI. This was probably due to amount of moisture at the sampling sites because at the SO site samples had more moisture than at SI. So the amount of moisture in the cave site seems to be proportional to the moisture content found in guano. Additionally, the amount of hydrous phosphates present in the cave may cause guano to have high moisture content (Quattropani *et al.*, 1999; Maher, 2006).

The cation exchange capacity (CEC) of Sukumawera bat guano at pH 7 was higher in SI (19.71 cmol (+) kg^{-1}) than in SO (9.04 cmol (+) kg^{-1}). This is because SI had higher organic matter content than SO (Table 2). The high organic matter content in guano delivers negatively charged surfaces to the clay and organic particles that are sites for positively charged soil nutrients such as Ca, Mg, K and Na. This improves soil fertility.

The variations in nutrients concentrations in SI and SO are possibly due to the cave environments and the bedrocks. The openings on the ceiling in Sukumawera cave might have allowed some amounts of water and other materials to enter in the cave which affect quality of the guano by sweeping away the nutrients, leaching and admixing guano with other materials.

High N was observed in SI (3.20%) than SO (2.87%). Both levels were higher than Chipongwe (0.46%) and Kapongo (1.94%) bat guano but lower than Assaigoli village (3.5 to 8.5%) (Sikazwe and Waele, 2004; Sridhar *at el.*, 2006). From the results obtained by Sridhar (2006) and his colleagues, guano decreases in N as it matures, this also was observed by Sikazwe and Waele (2004). The decrease in N at SO probably was due to volatilization as a result of ammoniac fermentation. Furthermore, due to the opening on the ceiling where SO was sampled, water that entered the cave through the openings might have drained the nitrates and this caused the decrease in N. The same was observed by Shahak-Gross (2004).

Generally, the extractable part of nutrient elements in guano seems to be low compared to the total amount present in guano (Table 1 and 2). This presumably is due to the form that nutrient elements do exist possibly locking some nutrients elements (Hill and Forti, 1997; Giurgiu *et al.*, 2013). If the percentage available part of nutrient present in Sukumawera bat guano were calculated from the total element composition, the amount of P that would be available was only 0.6% in SI, 0.2% in SO while for S it was 0.64% and 0.34% for SI and SO, respectively. This shows that guano from Sukumawera despite having high total

P and S contents in available form is very small. This is because some parts of P and S are locked in compound matrices and in organic form that need some time in the soil to allow their release due to decomposition of organic matter and dissolution of minerals (Thiagalingam. 2000).

In terms of basic cations. SO has shown the superiority in the extractable parts although total amount of some basic cations were lower than in SI. This was probably due to differences in chemical matrices of the compounds found in SO and SI although found in the same cave. The percentage extractable part in SO has unveiled the reason of high pH in SO: increase in readily available basic cations have increased the pH of SO: because basic cations do buffer pH (Thiagalingam. 2000).

4.2.2 Kisarawe bat guano

According to results obtained in this study KI was slightly acidic (6.7) while KO was strongly acidic (4.3). KO pH differs from KI because KO was very dry at its site; the lost solution/moisture was through leaching and evaporation. Leaching solutions are normally rich in basic cations that are responsible for buffering the pH. When leaching took place in KO it transported some cations down the bed rock: this can be justified by comparing the amount of basic cations in KI and KO in Table 2. However. presence of ammonia in the fresh guano does raise the pH temporally: when fermentation took place in guano ammonia volatilized hence pH dropped: the same was observed by Hutchinson (1950). The pH of KI (6.7) slightly differs from that given by Mlay and Sagamiko (2008) (6.8) due to guano decomposition and ammoniac fermentation (Table 2).

The moisture content (MC) of KO was lower (3.37%) than of KI (8.61%) (Table 2). Moisture content in guano seemed to be influenced by the amount of moisture present at sampling location as stated before. The KI was sampled at wet place due to concentrations of bat urine, but KO was found at a dry site. That might be a reason for KI to have higher moisture content than in KO despite long air drying of guano. The cation exchange capacity (CEC) of guano at pH 7 was higher in KO (15.17 cmol(+) kg^{-1}) than in KI (11.66 cmol(+) kg^{-1}). This is because KO bat guano had higher organic matter content than KI (Table 2). The total organic carbon in both guanos varied slightly, in KO it was 9.98% and KI was 9.18% (Table 2): this is because guano seems to be of the same age so the decomposition level was almost the same. However, the %OC of Kisarawe bat guano was lower than the one found by Sridhar *et al.* (2006) in insectivores' bat guano at Assaigoli village (14.5 to 49.9%). The ECe values for both guano (KI and KO) were higher than that of Assaigoli village (2.5 to 4.8 mS/cm) that was observed by Sridhar *et al.* (2006). Despite being high they differ: KO had lower ECe (10.2 mS/cm) than KI (13.06 mS/cm) (Table 2). This was because Na^+ level in KI was higher than in KO, and probably the amount of Cl^- was also high. Also as the moisture increased in KI site dissolution took place leading to the release of Na^+ and Cl^- that caused an increase in ECe. However, dissolution of soluble secondary minerals (nitrates and sulphates) in the cave might be the source of the increase in ECe as it was suggested by Thiagalingam (2000).

The amount of N in KI (4.9%) was nearly the same as that obtained by Mlay and Sagamiko (2008) (4.7%) although N was lower at KO site (3.53%). This is because KI was mostly composed of faecal pellets and urine which is the property of fresh guano. Fresh guano consists of hindgut fermentation by-products, seeds, chitin from insects that pass undigested along the GIT and concentrated urine from bats. The fore mentioned properties together with the immediately formed secondary minerals (nitrates), possibly were the reason for high N in KI than in KO. Decrease of N below the one reported by Mlay and Sagamiko (2008) in KO was presumably due to N volatilization and leaching of nitric acids and/or soluble salts of nitrates. This was also observed by Keleher and Sara (1996).

The amount of sulphur in KO bat guano was lower (117.99 mg S kg^{-1}) than in KI (835.08 mg S kg^{-1}). This was probably due to microclimates of the cave such as moisture content, temperature and air that facilitate the formation of sulphates secondary minerals, which increased S level in the KI. This finding is in agreement with that reported by Hill and Forti (1997) and Onac (2012). There is a difference in the level of P found in this study and that of Mlay and Sagamiko (2008). Mlay and Sagamiko (2008) study showed higher P levels (4662.5 mg P kg^{-1}) than in this study (2961.63 to 3730.86 mg P kg^{-1}) this is because as the time went there were phosphate minerals formed in the cave such as calcium phosphate which are slightly soluble in water, hence tended to disappear due to leaching. However, the insoluble phosphates deposited and accumulated in the cave might have put the P in unavailable forms (Keleher and Sara, 1996).

The results reported by Mlay and Sagamiko (2008) show that guano was less in Ca (892.6 mg kg^{-1}), Mg (852.4 mg kg^{-1}), and Na (759.2 mg kg^{-1}) than the analysis in this study (Table 2.). This is due to dissolutions of different compounds (salts) in guano as a result of chemical reactions in the cave that released cations in the system as the time went; this increased their concentrations. Surprisingly potassium found in KI (5245.53 mg kg^{-1}) was higher than in KO (1843.49 mg kg^{-1}) probably due to leaching of potassium compounds at KO because this guano was dry than KI. Leaching of potassium compounds (salts) was also observed by Keleher and Sara (1996).

If the percentage available part of nutrients present in Kisarawe bat guano were calculated from the total element composition. the amount of P that would be available is only 2.5% (KI) and 4.012% (KO) while S is 0.64% (KI) and 0.195% (KO). These are very small amounts compared to what is within the Kisarawe bat guano. This is caused by nature in which these nutrients elements exist in these organic materials. Nutrients in guano exist in organic form that needs mineralization by microbes when stay some times in the moist place. On the other hand, formation of secondary minerals formed in the caves might be the reason. Release of basic cations from these materials was very low; if calculated from the total element composition, Ca was 4.06% (KI) and 10.4 (KO) while percentage K was 9.73% (KI) and 4.276% (KO).

4.3 Extractable Micronutrients and Potential Toxic Elements

4.3.1 Sukumawera bat guano

The extractable percentage of Mn was 0.84% (SI) and 0.7% (SO) while Zn was 0.97% (SI) and 0.84% (SO); for Cu. the levels were 0.17% (SI) and 0.07% (SO). The extractable percentage of these micronutrients increased with the total amount of element present (Table 3). The pattern of nutrient elements release from Sukumawera bat guano seems to be governed by the chemical compounds matrices forming guano in the cave and the compounds that these micronutrients exit seem to behave the same.

Table 3: Extractable Micronutrients and Potential Toxic Elements from Sukumawera and Kisarawe bat guano

DTPA Extractable Element (mg kg^{-1})	SI	SO	KO	KI
Cu	8.04	1.14	4.42	4.06
Zn	152.50	52.95	182.74	115.10
Fe	148.13	28.63	85.89	110.78
Mn	121.31	44.80	283.75	154.06
Pb	2.89	3.43	0.85	0.99
Co	0.90	2.71	Trace	Trace
Cd	0.79	1.12	0.46	0.46

SI: Sukumawera bat guano inside the cave
SO: Sukumawera bat guano near the opening
KI: Kisarawe bat guano inside the cave
KO: Kisarawe bat guano near the opening

4.3.2 Kisarawe bat guano

In Mlay and Sagamiko (2008). Kisarawe bat guano had less Zn (95.6 mg kg^{-1}) than in this study (115.10 to 182.74 mg kg^{-1}). However. Cu level was higher (33.44 mg kg^{-1}) than in this study (4.06 to 4.42 mg kg^{-1}). This is because Cu is affected by pH and humus (Thiagalingam, 2000). As bat guano stayed in the cave decomposed. resulted to humus increase and because pH was slightly high this shaded the Cu availability. However. Mn and Fe were not determined before. but results from the current study show that manganese was higher in KO (283.76 mg Mn kg^{-1}) than in KI (154.1 mg Mn kg^{-1}) while Fe was higher in KI than in KO (Table 3). This depicts that the extractable amount of the micronutrient elements is proportional to the amount present at particular location. This can be observed in Mn and Cu (Table 1 and 3).

The percentage extractable micronutrients also seem to be low. Mn was 1.7% in KI and 4.176% in KO while Zn was 2.396% in KI and 3.10% in KO. On the other hand Cu was 0.363% (KI) and 0.36% (KO). Trends in cations release from Kisarawe bat guano showed the same pattern as in Sukumawera bat guano. The trends did not follow the same pattern as the amount present but seem to be controlled by the chemical nature of the compounds in which the cations exist. This is because in some cases KI released more than KO although KO was richer than KI and the verse versa.

4.3.3 Comparison between Sukumawera and Kisarawe bat guano on nutrient release

Comparing Sukumawera and Kisarawe bat guano in percentage nutrients release. Kisarawe bat guano was higher than in Sukumawera bat guano despite the fact that total content was higher in Sukumawera than in Kisarawe bat guano: this possibly due to difference in maturation of these materials. Sukumawera was relative older than Kisarawe bat guano, that is why the chemical formation of its compounds thought to be much complicated, so their constituents release. Since the cave is an open system. change in environmental factors such as temperatures and floods for many years might have affected the formed compounds in Sukumawera cave than in Kisarawe. However. there are some elements that their extractable parts seem to be higher than the total amount present. These are Mg in SO and Na in KI and KO. This may be due to shading effects of other elements present in the sample injected in the ICP-OES. since the solutions have the same matrices but differ in their chemistry.

4.4 Pot Experiment

4.4.1 Physico-chemical properties of the experimental soil

The initial properties of soil (before sowing) for trials are shown in Table 4. High pH of the experimental soil was due to high levels of basic cations (Ca. Mg and K) in the soil and low organic matter. Organic matter in the soil would produce organic acids upon decompositions; the acids produced would lower the soil pH. The electrical conductivity of the soil (ECe) was very low. This was due to low levels of S. N and organic matter that are responsible in formation of sulphates. nitrates and bicarbonate salts. whose ions from their dissolution are responsible in ECe determination (Thiagalingam, 2000). However, this level was described by Msanya *et al.* (2001) that at that ECe value of 0.03 dS/cm no yield reduction could occur. The soil organic carbon (%OC) goes together with the organic matter content. Low organic matter is due to poor replenishment of crop residues taken from the land. This is because the soil sample was taken at the land that was used for forage cultivation whereby the forage is cut and given to animals but the excrements are not taken back to the land.

Table 4: Initial physical and chemical properties of the soil used in pot experiments

Soil parameter	Value	Rating	Reference to the rating
Soil pH (water)	6.83±0.33	Neutral	Landon, 1991
ECe (mS/cm)	0.03	Very low	Msanya *et al.*, 2001
Organic carbon (%)	0.93±0.09	Low	Msanya *et al.*, 2001
Organic matter (%)	1.59	Low	Msanya *et al.*, 2001
Total N (%)	0.05	Low	Thiagalingam, 2000
Bray-1 P (mg/kg)	4.76±0.39	Low	Thiagalingam, 2000
Available S (mg/kg)	6.86	Low	Thiagalingam, 2000
CEC (cmol(+)/kg)	9.63	Low	Msanya *et al.*, 2001
Exchangeable Ca (cmol(+)/kg)	10.30±0.03	Very high	Msanya *et al.*, 2001
Exchangeable Mg (cmol(+)/kg)	3.54±0.03	Very high	Msanya *et al.*, 2001
Exchangeable Na (cmol(+)/kg)	0.639	Medium	Msanya *et al.*, 2001
Exchangeable K (cmol(+)/kg)	0.59	High	Msanya *et al.*,2001
DTPA-Extractable Cu (mg/kg)	0.26±0.03	Low	Thiagalingam, 2000
DTPA-Extractable Zn (mg/kg)	0.18±0.03	Very low	Thiagalingam, 2000
DTPA-Extractable Fe (mg/kg)	60.58±0.03	High	Thiagalingam, 2000
DTPA-Extractable Mn (mg/kg)	3.66±0.03	Medium	Thiagalingam, 2000
Sand (%)	86.24		
Silt (%)	1.64		
Clay (%)	12.12		
Textural class		Loamy sand	Motsara and Roy, 2008

Values for the soil parameters are indicated with their standard errors (n=3), where missing it implies the standard error was negligible.

Basically organic matter is the key to sustainable agricultural production and is also a storehouse for carbon, nitrogen, phosphorous and sulphur which are released by mineralization. As it was asserted by Thiagalingam (2000) that "soil organic carbon values of less than 1.0 % will indicate problems of low nutrient holding capacity". The low CEC of the soil was due to low organic matter and possibly low activity clays. It is well known that organic matter adds significantly to the Cation Exchange Capacity of soils and majority of soil nutrients (Ca, Mg, K and Na) are held on negatively charged surfaces of the clay and organic particles. This low CEC portrays low total number of sites available in a soil for the exchange of cations. However, low CEC is associated with low levels of total P and K (Thiagalingam, 2000).

Soil texture of the studied soil was loamy sand whose particle fractions were in the order sand > clay > silt. These results suggest that the soil is relatively course textured, and probably the pore space system is medium to high. The soil has good total porosity, water holding capacity, aeration and has low compaction. This soil is good in crop production, maize is inclusive. The quantities of exchangeable cations was probably due to the nature of the parent material forming the soil. Amount of Ca and Mg was also observed by Thiagalingam (2000) to be the most abundant and dominant cations in the soil whose deficiencies are very rare.

The low available S, P and total N was due to low organic matter in the soil, since these nutrients exist in organic forms. Microorganisms do mineralize soil organic matter and release the available forms of these nutrients. Nevertheless, the main part of phosphorous is present in unavailable form (Organic P and Primary P minerals like rock phosphate). It was described by Singh *et al.* (1980), that Bray 1 available P of up to 15 mg kg^{-1} as being low for maize in some soils of Morogoro.

The low Cu and Zn status of the soil is probably due to the parent material and pH level of the soil. This was described by Thiagalingam (2000) that the deficiency of these two nutrients elements increase as pH increases. Potential toxic elements such as Pb, Co, Cd and Cr were not detected by the machine since their concentrations were very minimal.

Soil analysis before sowing indicated that the major nutrients (N, P and S) and micronutrients (Cu and Zn) were found at low levels. Deficiency of the major nutrients is due to low organic matter content in experimental soil, while the micronutrients was mainly due to the nature of the parent material. These low soil chemical properties indicate that the soil was low in fertility. Therefore, there would be a need for fertilizers application to the soil in order to boost its productivity.

4.4.2 Effects of application of guano on physico-chemical properties of the soil

4.4.2.1 Effects of application of Sukumawera guano

Effects in nutrients concentration of Mazimbu soil as amended by Sukumawera bat guano are shown in Tables 5 and 6. Statistically, all plant parameters differed significantly ($p \leq 0.001$) in all treatments. The results show that there was a decrease in pH values as application rates of SO and SI increased. The pH change was due to the pH of the guano applied and the organic acids released as guano was decomposed by microbes. The decrease in soil pH values between 6.8 and 6.3 in SO is not harmful to crops since most crops prefer pH values between 5.5 and 7.0 (Thiagalingam, 2000). In case of SI, decrease in soil pH below 5.5 in 20 : 4 and 20 : 3 application rate can affect maize crop. As it was narrated by Thiagalingam (2000) when pH decreases from 5.5 to 4.5, excessive Al, Fe and Mn would be toxic to cereals including maize. On the other hand, low pH of between 4 and 6 reduces solubility of phosphorus in the soil solution (Haynes, 1982) and availability of other essential nutrients such as K, Ca, and Mg decreases and might result in their deficiency to plants due to nutrients imbalances.

Table 5: Change of nutrients concentration in Mazimbu soil amended with different rates of Sukumawera bat guano

g Guano kg^{-1}soil			(mS/cm)				mg kg^{-1}				cmol(+) kg^{-1}	
Rate	pH(SO)	pH(SI)	ECe(SO)	ECe(SI)	%N(SO)	%N(SI)	S(SO)	S(SI)	P(SO)	P(SI)	K(SO)	K(SI)
0	6.62ef	6.67efg	0.04a	0.05a	0.02a	0.02a	4.9a	4.4a	3.4a	3.4a	0.60a	0.65a
25	6.82fg	5.54b	2.82c	2.10b	0.21c	0.17b	211.3b	429.0d	279.7b	279.7b	1.95e	0.87b
50	6.87g	5.79c	3.47cd	2.93c	0.24d	0.19c	365.7c	557.6e	346.7c	388.5d	2.29f	1.13c
100	6.68efg	5.60b	6.57f	3.86d	0.28e	0.28c	530.7e	774.9g	454.9e	546.4f	3.22g	1.39d
150	6.55e	5.22a	9.01g	5.27e	0.32f	0.35g	655.0f	874.9h	562.2f	769.0h	4.76h	1.57d
200	6.35d	5.10a	11.29h	6.50f	0.41h	0.40h	755.7g	998.8i	677.1g	916.7i	6.84i	1.97e
GM	6.2		4.41		0.24		513.56		435.65		2.27	
SE±	0.11		0.39		0.01		17.85		17.55		0.11	
Cv (%)	1.9		8.8		3.9		3.5		4		5.1	
F-pr	<0.001		<0.001		<0.001		0.001		<0.001		<0.001	

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

SO: Sukumawera bat guano near the opening of the cave

SI: Sukumawera bat guano inside the cave

GM: Grand mean

SE: Standard error

CV: Coefficient of variation

F-pr: F- probability

Table 6: Change of nutrients concentration in Mazimbu soil amended with bat guano from Sukumawera in different rate

g Guano kg^{-1}soil	cmol (+) kg^{-1}						mg kg^{-1}							
Rate	**Mg(SO)**	**Mg(SI)**	**Na(SO)**	**Na(SI)**	**Ca(SO)**	**Ca(SI)**	**Cu(SO)**	**Cu(SI)**	**Fe(SO)**	**Fe(SI)**	**Mn(SO)**	**Mn(SI)**	**Zn(SO)**	**Zn(SI)**
0	3.45a	3.18a	0.48a	0.44a	10.05a	10.12a	0.21ab	0.20a	55.81i	56.07i	2.60a	2.70a	0.10a	0.11a
25	7.96f	4.35b	0.95c	0.74b	46.22b	47.74b	0.23ab	0.54e	35.86g	39.74h	6.54b	12.71d	2.60b	4.38c
50	10.92h	5.48c	1.14d	0.91c	62.02c	67.46d	0.27abc	0.70f	28.47de	35.18g	9.87c	17.49f	3.89c	5.79d
100	14.88i	6.16d	1.57f	1.19de	88.15e	89.64e	0.30bcd	0.87g	25.75c	32.40f	10.45c	22.96g	6.37d	7.54e
150	20.24j	7.02e	2.25g	1.29e	115.86g	104.86f	0.33cd	1.04h	22.90b	29.18e	12.49d	28.41h	8.78f	15.67h
200	24.15k	8.63g	2.72h	1.56f	146.27h	118.06g	0.36d	1.57i	19.05a	27.26cd	14.96e	35.78i	10.31g	24.95i
GM	9.70		1.27		75.18		0.55		33.97		14.75		7.54	
SE±	0.23		0.07		1.37		0.05		0.94		0.58		0.40	
Cv (%)	2.4		5.4		1.9		8.5		2.8		4		5.3	
F-pr	<0.001		<0.001		<0.001		0.001		<0.001		<0.001		0.001	

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

SO: Sukumawera bat guano near the opening of the cave

SI: Sukumawera bat guano inside the cave

GM: Grand mean

SE: Standard error

CV: Coefficient of variation

F-pr: F-probability.

The ECe values increased as the application rates increased (Table 5). This increase in ECe values was due to the presence of Na^+ and soluble ions like sulphates, nitrates and bicarbonate (Thiagalingam. 2000) from secondary minerals formed in the cave such as. dolomitic limestone ($CaMg(CO_3)_2$). Carbonate-hydroxy-apatites ($Ca_{10}(P0_4.C0_3)_6 (OH)_2$). gypsum ($CaSO_4.2H_2O$) and nitrates. The increase in ECe up to 4 mS/cm shows that the salinity was high in the soil that could cause yield reduction up to 50% (Msanya *et al.*. 2001). Since maize is sensitive to ECe levels as low as (4 mS/cm). the ECe obviously affect its growth and yield. The ECe caused by SO and SI bat guano application would cause substantial yield reduction in crops throughout the application rates (Msanya *at el.*, 2001).

Increase of the macronutrients was observed by some scholars when manure was applied in the soil (e.g. Joann *et al.*, 2000). The same applied to Sukumawera bat guano when applied to the soil. This had improved the P and S of the Mazimbu soil from low to very high level as rated by Msanya *at el.* (2001) and Thiagalingam (2000). The increase in P and S after guano application is because guano is associated with secondary minerals such as apatite and gypsum that contain high amounts of P and S which can be readily available to plants (Sanginga and Woomer. 2009). The concentrations of K. Mg and Ca were increased to very high level and Na to high and very high level (Tables 5 and 6). This increase was caused by the amount present in guano applied. This was also observed when cattle manure was used as soil amendment; P and K increased three to four times at the highest rates of manure application compared to control (Joann *et al.*, 2000). However, the increase in Ca and Mg in the soil may result into antagonistic behaviour to the soil; when Mg is in excess. it can inhibit Ca uptake or verse versa (Thiagalingam, 2000).

The increase in total %N was observed in all the application rates. Higher application rates (20 : 3 and 20 : 4) had shown improvement of soil N up to the medium level while the low rates had pulled it from very low to low level. This implies that at low applications rate of guano from Sukumawera cannot reach the requirement of N supply to N deficient soil.

Furthermore, extractable Mn, Zn and Cu increased significantly ($p \leq 0.001$) in all treatments as the rates increased (Table 6). In all SI and SO applications Zn was improved from very low to medium and high levels; Mn and Cu were improved to within the medium range. The SI bat guano was superior in improving Zn, Mn and Cu because it had higher quantities of those nutrients than SO. However, in SI, Mn was expected to be high because soil pH was low, since low pH increases Mn availability (Thiagalingam, 2000). Moreover, SI had higher %OC than SO bat guano, as it is well known that as the humus content increases and pH decreases Zn availability increases too (Thiagalingam, 2000).

For Fe there was a significant ($p < 0.001$) decrease as the rates of guano applied increased (Table 6). The concentrations of Fe were below the control levels in all treatments. The same was observed by Joann and colleagues (2000) that there was slight decrease in extractable Al and Fe after animal manure application. However, formation of chemical compounds of Fe with P (fixations), as available P was high in the soil due to applied guano (Tables 5 and 6). Probably this was the reason for the decrease in Fe.

4.4.2.2 Effects of application of Kisarawe bat guano

Change in nutrients concentrations of Mazimbu soil as amended by Kisarawe bat guano is indicated in Tables 7 and 8. The pH of the soils in all treatments decreased as the

Table 7: Change of nutrients concentration in Mazimbu soil amended with bat guano from Kisarawe in different rate.

g Guano kg^{-1}soil			mS/cm				mg kg^{-1}				cmol(+) kg^{-1}	
Rate	pH(KO)	pH(KI)	Ec(KO)	Ec(KI)	%N(KO)	%N(KI)	S(KO)	S(KI)	P(KO)	P(KI)	K(KO)	K(KI)
0	6.7g	6.4f	0.03a	0.03a	0.02a	0.02a	4.9a	4.3a	3.7a	3.8a	0.67a	0.67a
25	6.2f	5.4de	0.14a	0.25ab	0.17b	0.21c	23.4b	85.9d	176.5b	337.0d	0.84b	0.89b
50	5.5e	5.2cde	0.40b	0.46b	0.25d	0.26d	38.7c	169.0f	228.0c	426.5e	1.05c	1.59e
100	5.4de	4.9ab	1.50d	0.86c	0.37e	0.35e	76.8d	313.2h	426.5e	548.2f	1.39d	2.16g
150	5.1bcd	4.8ab	2.61e	1.58d	0.45g	0.42f	137.0e	470.5i	672.8g	946.5i	1.96f	3.38h
200	4.9abc	4.8a	3.15f	1.65d	0.59i	0.51h	188.0g	557.6j	718.3h	1108.4j	2.13g	4.14i
GM	5.4		1.05		0.3		172.44		466.35		1.74	
SE±	0.18		0.13		0.01		5.48		17.35		0.05	
Cv (%)	3.2		12.6		4.6		3.2		3.7		3	
F-pr	0.027		<0.001		<0.001		<0.001		<0.001		<0.001	

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

KO: Kisarawe bat guano near the opening of the cave

KI: Kisarawe bat guano inside the cave

GM: Grand mean

SE: Standard error

CV: Coefficient of variation

F-pr: F- probability

Table 8: Change of nutrients concentration in Mazimbu soil amended with bat guano from Kisarawe in different rate

g Guano kg^{-1}soil	cmol(+) kg^{-1}						mg kg^{-1}							
Rate	Ca(KO)	Ca(KI)	Mg(KO)	Mg(KI)	Na(KO)	Na(KI)	Mn(KO)	Mn(KI)	Fe(KO)	Fe(KI)	Cu(KO)	Cu(KI)	Zn(KO)	Zn(KI)
0	10.03a	10.17a	3.41a	3.42a	0.48a	0.45a	3.14a	3.06a	53.93de	57.41ef	0.21a	0.21a	0.08a	0.08a
25	11.03bc	10.78ab	5.04b	5.08b	0.67b	1.11d	20.10b	25.15c	61.54fg	85.69i	0.37b	0.58d	1.35a	2.77b
50	11.31bc	11.42bcd	5.72c	6.07c	0.84c	1.87f	24.22c	42.39e	57.81ef	72.47h	0.46c	0.66e	3.65bc	4.54c
100	11.57bcde	12.22def	6.53d	7.91f	1.17d	2.80g	34.64d	62.27h	42.72bc	66.11g	0.54d	0.77f	9.13d	8.13d
150	12.54fg	12.38ef	6.98e	9.58h	1.69e	4.26h	52.55f	76.31i	38.06b	51.63d	0.66e	0.95g	14.16f	12.67e
200	13.27g	11.90cdef	8.55g	10.07i	2.00f	4.99i	58.47g	92.73j	32.15a	43.40c	0.88g	1.23h	18.51h	15.68g
GM	11.55		6.53		1.86		41.25		55.24		0.63		7.56	
SE±	0.47		0.20		0.08		0.81		2.91		0.03		0.80	
Cv (%)	4.1		3.1		4.4		2		5.3		5.6		10.6	
F-pr	0.029		<0.001		<0.001		<0.001		<0.001		<0.001		0.001	

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

KO: Kisarawe bat guano near the opening of the cave

KI: Kisarawe bat guano inside the cave

GM: Grand mean

SE: Standard error

CV: Coefficient of variation

F-pr: F- probability

application rate increased. The pH changed from slightly acidic to strongly acidic in all application rates. Both KI and experimental soil had high pH (neutral property). The abrupt change in the soil pH following guano application in soils is due to humic and fulvic substances which include carboxyl groups in applied guano (Msaky *et al.*, 2010). These organic groups are known to release protons in high pH soils to lower the pH of the respective soil. The proton exchange process between the soil and the guano added is the one that caused the decrease in pH levels in the current study. The change in pH to strongly acidic levels would not be good for maize production as it was described by Thiagalingam (2000). This is because it reduces phosphorus solubility in the soil solution and causes nutrients imbalances (Haynes, 1982).

Soil treated with KO and KI bat guano showed an increase in ECe as application rates increased. This change in ECe at those levels in KI (0.03 to 1.65) is very low and cannot cause any yield loss; but change of ECe values in KO to 2.6 and 3.15 (at 20 : 3 and 20 : 4) would cause yield reduction of up to 25% (Msanya *at el.*, 2001). This was revealed in this study whereby the plants on 20 : 4 and 20 : 3 in KO did not survive for more than two weeks while plants in KI in the same rates survived, despite the lower pH in KI than in KO (Table 7).

All treatments showed increases in P, N and S as the application rates increased. High concentration of P in the soils due to guano application was probably due to organic groups in guano which may have reacted with Fe, Mn and Al ions thus inhibiting the precipitation of P and/or the organic acids in the manure blocked some of the sites responsible for P fixation in soils (Msaky *at el.*, 2010). However, guano itself supplied P to the soil as it is rich in many essential plant elements, especially P.

According to Thiagalingam (2000) ratings, KO and KI bat guano improved soil N from low to medium levels (Table 7). The increased amount was caused by nitrogenous substances present in guano, including urine, insects' chitins, fruits and seeds (Quattropani *et al.*, 1999; Shahak-Gross, 2004; Maher, 2006). This soil probably may have been improved beyond those levels but due to soil micro-organisms that feed on soil nitrogen during break down of organic materials and volatilization resulted in N decrease. Nevertheless, most of the total nitrogen within the organic matter fraction is not immediately available to plants. The conversion of organic nitrogen into available nitrogen (ammonium and nitrate nitrogen) influenced by the rate of mineralization and is highly associated with soil pH, moisture, temperature and the presence of nitrifying organisms in the soils.

Kisarawe guano applications in Mazimbu soil improved Sulphur to medium, high and very high levels when different rates were applied (Table 7). However, guano might have improved the soil S more than the level observed, because most of the sulphur in guano is present as part of organic matter. As it was explained by Thiagalingam (2000), S in organic form needs bacterial action to be converted to available sulphate ions. Sulphur conversion needs the respective soil to be moist, warm and well aerated.

Potassium and magnesium levels in all treatments differed significantly ($p < 0.001$). As guano application rates increased, the K and Mg levels in the soil increased. In KO and KI treatments, K improvement was from high to very high K, while Mg increased within very high levels. Increase in Ca ranged within very high levels while Na increase was from medium (0.67 cmol (+) kg^{-1}) to high (2.00 cmol (+) kg^{-1}) in KO while in KI was medium (1.11 cmol (+) kg^{-1}) to very high (4.99 cmol (+) kg^{-1}). This was also observed by Joann *et al.* (2000) when animal manure was used as a soil amendment and an increase of macronutrients was noted. In the current study, the observed improvement was due to some nutrients present in the guano from Kisarawe, because KI bat guano had higher Na than in KO but the reverse was for Ca levels.

Cu and Zn concentrations showed a statistical significant ($p \leq 0.001$) increase in all treatments. Copper levels were increased within the medium range (0.37 mg Cu kg^{-1} to 0.88 mg Cu kg^{-1}) and (0.58 mg Cu $kg^{-1}$to 1.23 mg Cu kg^{-1}) for KO and KI respectively. Based on Thiagalingam (2000) rating on Zn and Mn concentrations the increase was between medium to high in both KO and KI bat guano (Table 8). Differences in concentration of these nutrient elements were due to amount present in guano applied. Fe level was high in experimental soil, application of bat guano shows a significant ($p < 0.001$) decrease in Fe levels as application rates increased. However, there is an increase of Fe concentration above the control at 20 : 05, 20 : 1 and 20 : 2 in KI and at 20 : 0.5 and 20 : 1 in KO bat guano, respectively; this is probably due to the pH of the soil, as it was slightly higher than in other rates (20 : 3 and 20 : 4). Despite the decrease in Fe levels in all application rates, still the available levels were high. Therefore, for good supply of nutrients in Mazimbu soil, Kisarawe bat guano shoud be applied on the ratio $\leq$ 20 : 1 (soil : guano)

4.4.2.3 Comparison of effects of application of Sukumawera and Kisarawe bat guano

Sukumawera and Kisarawe bat guano application in Mazimbu soil lowered the soil pH. According to Thiagalingam (2000), the range of decrease in soil pH caused by Sukumawera bat guano would not be detrimental to crops especially maize except the one at rate 20 : 4 and 20 : 3 of guano found inside the cave (SI). However, the one caused by Kisarawe bat guano would cause problems in plants except at 20 : 0.5 and 20 : 1 in guano found near the opening (KO) (Tables 5 and 7). Results from the current study showed that guano found inside the caves were better in lowering the soil pH than the one found near the opening. The effect of low soil pH is nutrient level imbalance. This negatively affects plant growth; also phosphate is poorly available. and aluminium and/or manganese may be present in toxic concentrations (Thiagalingam. 2000; Msaky *at el.*, 2010). This was observed in the current study where all plants in 20 : 4 and 20 : 3 treated with Kisarawe bat guano (KO) did not survive for more than two weeks. Death of the plants was caused by burning due to strong acidity in the soils. It seems that the acidity in the soil increased as the time went, because at the beginning plants performed well but with time plants started developing burning signs and were dying. Presumably, presence of ammonium in guano during planting induced temporary alkalinity that boosted the pH. but with time ammoniac fermentation and volatilization took place hence caused the decrease in pH. Therefore, Sukumawera and Kisarawe bat guano should be applied in alkaline soils with pH ≥ 8.

ECe of the experimental soils when Sukumawera and Kisarawe bat guano was applied showed a significant ($p < 0.001$) increase (Tables 5 and 7). Amendment of Mazimbu soil with Kisarawe bat guano resulted in ECe levels that had no yield reduction except at 20 : 4 and 20 : 3 with up to 10% yield reduction (Msanya *at el.*, 2001). Sukumawera bat guano application in Mazimbu soil has developed ECe levels that would cause substantial yield reduction between 10% and 100% (Msanya *at el.*, 2001). There was an increase in total N and available P when Kisarawe and Sukumawera bat guano were applied. Sukumawera and Kisarawe bat guano improved N between low and medium range (Thiagalingam, 2000) (Tables 5 and 7). In both Sukumawera and Kisarawe bat guano applied soils, P was improved to high levels (Thiagalingam, 2000) (Tables 5 and 7). Despite of Kisarawe and Sukumawera bat guano improving N and P levels to medium and high levels respectively, yet the concentrations in Kisarawe applied soils were higher than in Sukumawera. This is because the available concentrations of P and N were higher in Kisarawe than in Sukumawera bat guano (Table 2.). For S improvement, Sukumawera bat guano improved the soil to very high range in all treatments, while Kisarawe bat guano improved the soil from low to high at 20 : 0.5 and 20 : 1 while in other rates the improvement was to very high levels (Thiagalingam, 2000) (Tables 5 and 7). This is due to low amount of S present in Kisarawe bat guano than in Sukumawera bat guano. In this study the results showed that in N and P improvement, Kisarawe bat guano was superior to Sukumawera bat guano while in S improvement Sukumawera bat guano was superior to Kisarawe bat guano. However, the effect of both guano in P improvement was high.

Exchangeable cations (Ca, Mg, K and Na) in Mazimbu soil were improved by applications of both Sukumawera and Kisarawe bat guano (Tables 5, 6, 7 and 8). This was caused by the amount of basic cations present in guano. From the results obtained from this study Sukumawera bat guano would be better in improving Ca, K, and Mg deficiency soils while in Na deficient soil Kisarawe bat guano would be better.

Micronutrients concentration in the soil has shown an increase when Sukumawera and Kisarawe bat guano were applied. Cu content increased in the soil within medium range (Thiagalingam, 2000). This can be observed from (Tables 6 and 8). Sukumawera bat guano improved Mn concentrations within the same medium range (6.54 mg Mn kg^{-1} and 35.78 mg Mn kg^{-1}) while in Kisarawe bat guano applied soil Mn concentration was within medium to high level range (20.10 mg Mn kg^{-1}and 92.73 mg Mn kg^{-1}). Zn concentration improvement was between medium to high range while Fe concentration in soils applied with Sukumawera and Kisarawe bat guano seems to decrease as the application rates increased. The decrease in Fe concentrations probably is due to the chemical reaction in the soil; probably, most of the Fe ions were used to fix P in the soil. However there was an increase in Fe concentration at 20 : 05 and 20 : 1 in Kisarawe bat guano applied soils. Probably this was due to increase in soil pH, because these soils had slightly high pH.

4.4.3 Maize growth performance and nutrient uptake from soil amended with bat guano

4.4.3.1 Visual performance of screen house experiment

High rates of Sukumawera bat guano applications in Mazimbu soil affected maize germination and growth performance in general. High application of SO induced negative effect on germination at the rate 20 : 4 and 20 : 3 while at 20 : 2 and 20 : 1 (soil : guano) and caused delays in germination, poor leaf formation and development (Plate 1). This presumably was due to high application rates that resulted into accumulation of salts present on bat guano hence high ECe that affected and killed even the embryos of the maize seeds. In 20 : 0.5 seeds germinated on time, but the growth rate was poor, although failure to germinate was not serious as in 20 : 2 and 20:1. Plants applied with SO bat guano had no much increase in height (showed dwarfism). The plants showed wilting and significant burning and were dying at 4th week after planting. This occured probably because, with time there was an increase in salt level in the soil as the results of dissolution of secondary minerals that drained some water from the plants; this caused wilting of the plants. Increase in Na^+, sulphates and nitrates ions in the soil increased the ECe that would not be tolerated by maize plants (1.7 dS/cm) and decrease in pH to acidic level (< 5.5) due to organic acids from guano decomposition possibly affected plants negatively. The maize plants are not comfortable at ECe ≥ 1.7 dS/cm and pH < 5.5. However, Zn concentration might have affected the plants, because Zn level in the soil should not exceed 8 kg Zn ha^{-1} for maize plants (Eteng *et al.*, 2014). Despite high application of SI, seeds germinated on time in all rates. A problem was observed in two pots at 20 : 4 two pots (rep 1 and 2) where low growth rate was observed.

Plate 1: Visual performance of plants grown in the soil applied with Sukumawera bat guano found near the opening 35 days after sowing

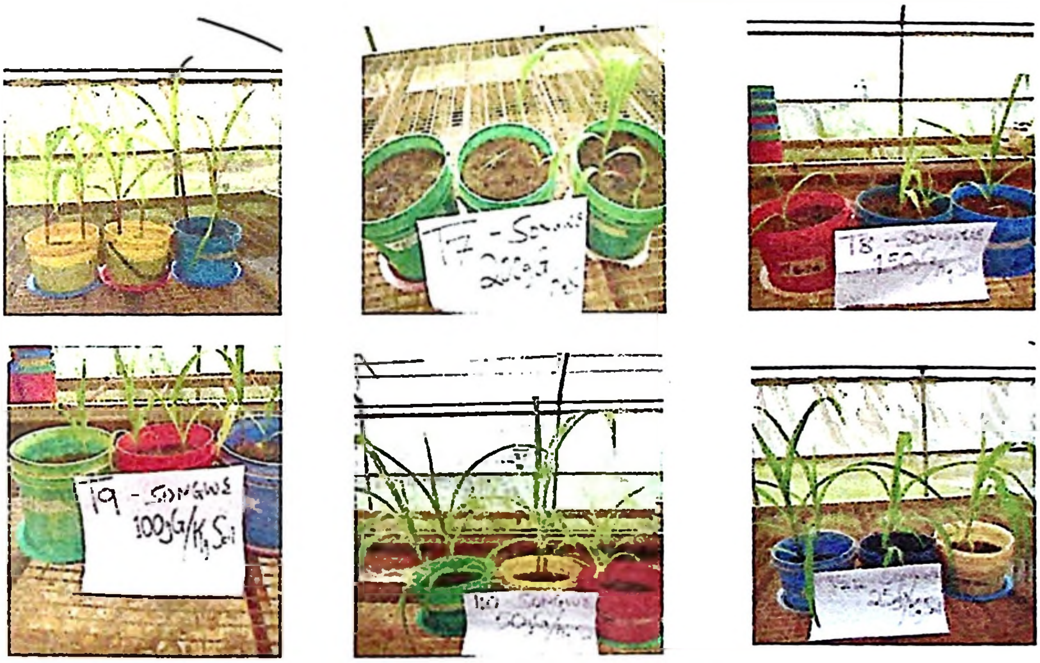


Plate 2: Visual performance of plants grown in the soil applied with Sukumawera bat guano found inside the cave 35 days after sowing

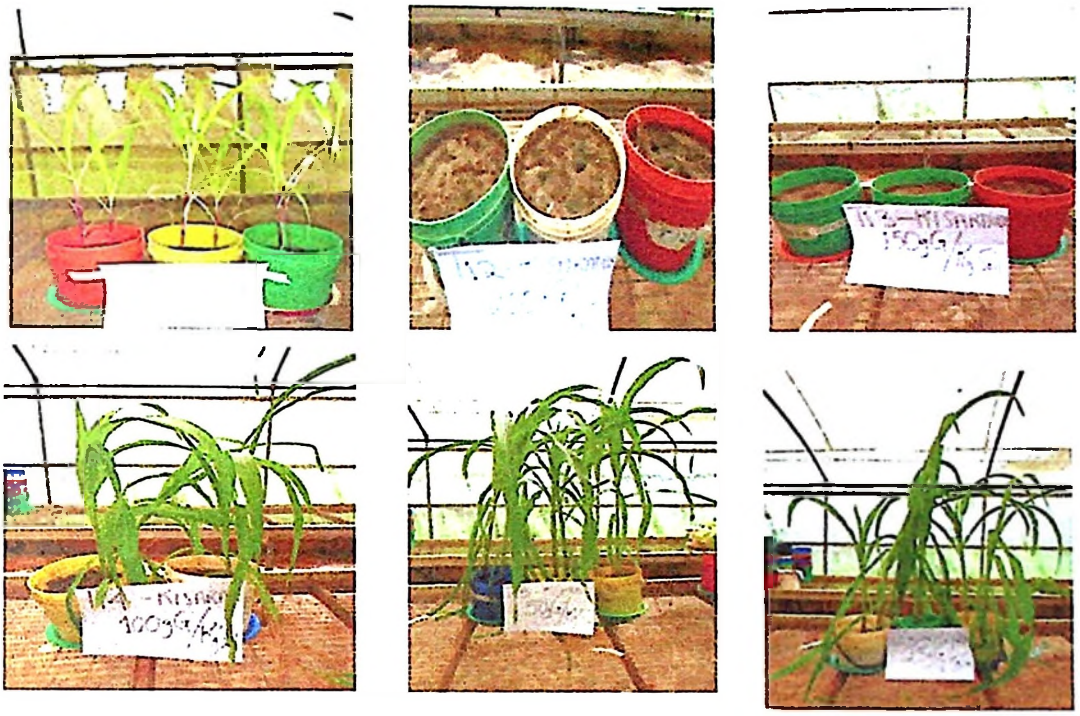


Plate 3: Visual performance of plants grown in the soil applied with Kisarawe bat guano found near the opening 35 days after sowing

Plate 4: Visual performance of plants grown in the soil applied with Kisarawe bat guano found inside the cave 35 days after sowing

Maize plant height increased at the first week, then the growth rate decreased at the 2nd week; then on the 3rd week to 5th week plant growth seemed to be retarded, then showed wilting and some burning although the soils were moist. Similar trend was observed by Sridhar (2006). As mentioned earlier, this could have been caused by the effects of high salts concentration due to dissolution of secondary minerals found in guano and high release of organic acids due to decomposition of guano organic matter. Surprisingly, in one pot (rep 3) at 20 : 4 the plant height increased up to the 5th week (Plate 2).

In pots applied with KO bat guano the germination was good, but at the 2nd week, plants at the application rates of 20 : 4 and 20 : 3 showed burning signs and at the 3rd week they were dying. This is because of the acidity in KO bat guano (pH = 4.34) that lowered the pH of the experimental soil from pH 6.7 to acidity level (< 5.5) that was not conducive for maize growth. On the other hand, harmful materials such as urea which is due to high concentration of bat urine which might have not been volatilized did burn the plants. However, plants in pots with low KO bat guano application rates (20 : 2, 20 : 1 and 20 : 0.5) showed good performance, the growth rate was good and plants were healthy and green (Plate 3).

KI application rates had shown good performance in all the treatments, which is contrary to KO (Plate 4). This was presumably due the pH of the KI bat guano (6.7) and experiment soil (6.8) that was nearly the same (neutral). This pH could not have negatively affected plant performance. All plants in pots applied with KI bat guano had almost similar performance, although in some pots as the plants were growing they started to change colour. The plant leaves at the rates of 20 : 0.5 and 20 : 1 were yellow approached to the plants in control. This shows the deficiency of some nutrients in the soil that the plants could not find particularly N.

4.4.3.2 Effects of Sukumawera bat guano application on the nutrients concentration and uptake by maize

The effects of Sukumawera bat guano application on nutrients concentration and uptake are shown in Tables 9 and 10. The results indicate that application of SI rates of 20 : 2 produced statistically the highest means of nutrients uptake and concentration followed by 20 : 1 while the control had the lowest means almost in all nutrients. The uptake and concentrations of N, P, Mg, K, Ca and Mn showed the same trend: the uptake rate and nutrients concentrations increased as application rate increased up to the maximum at 20 : 2 then started to decrease. This is due to antagonism and synergism of nutrients elements as explained by Ranade-Malvi (2011). Guano as manure enhanced the availability and uptake of nutrients by the maize plants. This was also observed when cattle manure was used as soil amendment in acidic soil (Msaky *et al.*, 2010). The decrease in nutrients uptake at high rates, can either be due to the pH of the soil that hindered the availability of some nutrients in the soil or the effect of the high nutrient supply in the soil caused antagonism to each other (Thiagalingam, 2000; Msaky *et al.*, 2010 and Ranade-Malvi, 2011). The pH at 20 : 2 was in the range that most of crops prefer (>5.5), but as the rates of guano increased the pH decreased to the range that most of the crops could be affected not because of acidity but due to nutrients imbalance. Despite of acidity in soil applied with high rates of guano still some plants survived. Probably these plants developed adaptation mechanism on salts effects. Nevertheless, at that rate (20 : 2) most of the nutrients in the soil were supplied at maximum levels. Nutrients uptake and concentrations of S, Ca, Na, Cu, Fe and Zn in plants showed an increase as application rates increased, and reached the maximum at 20 : 4 which was the highest application rate. This is because as the application rates increased the pH of the soil decreased.

Table 9: Effects of Sukumawera bat guano application on the nutrients concentration and uptake by maize

g Guano kg^{-1}soil Level	P(SO)	P(SI)	N(SO)	N(SI)	Ca(SO)	Ca(SI)	K(SO)	K(SI)	Mg(SO)	Mg(SI)	Na(SO)	Na(SI)	S(SO)	S(SI)
	(%)													
0	0.19a	0.18a	1.090a	1.08a	0.54a	0.55a	4.18d	3.90c	0.30ab	0.28a	0.02a	0.01a	0.13a	0.13a
25	*	0.36d	*	3.67cde	*	0.56a	*	4.35d	*	0.35b	*	0.03ab	*	0.16ab
50	*	0.39d	*	3.81e	*	0.61a	*	4.57e	*	0.36b	*	0.04b	*	0.17abc
100	*	0.40d	*	4.27f	*	0.62a	*	3.96c	*	0.36b	*	0.04b	*	0.18abc
150	*	0.34c	*	3.78de	*	0.57a	*	3.24b	*	0.31ab	*	0.04bc	*	0.22bc
200	*	0.23ab	*	3.23b	*	0.59a	*	2.84a	*	0.28a	*	0.05c	*	0.36c
GM		0.27		3.25		0.58		3.25		0.32		0.03		0.19
SE±		0.04		0.08		0.08		0.31		0.04		0.01		0.03
Cv(%)		13.6		2.3		13.3		9.5		11.2		23.8		17.8
F-pr		<0.001		<0.001		0.532		<0.001		0.02		<0.001		<0.001

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

SO: Sukumawera near the opening of the cave

SI: Sukumawera inside the cave

*: Not determined

GM: Grand mean

SE: Standard error

CV: Coefficient of variation

F-pr: F- probability

Table 10: Effects of Sukumawera bat guano application on the nutrients concentration and uptake by maize

g Guano kg^{-1}soil	(mg kg^{-1})							
Level	**Cu(SO)**	**Cu(SI)**	**Fe(SO)**	**Fe(SI)**	**Mn(SO)**	**Mn(SI)**	**Zn(SO)**	**Zn(SI)**
0	2.395a	2.34a	123.8a	131.1abc	45.94a	45.19a	17.65a	17.53a
25	*	3.03b	*	139.7abcd	*	59.10bc	*	28.78b
50	*	3.54c	*	140.7abcd	*	64.67abc	*	35.85c
100	*	4.03d	*	135.7abc	*	93.16f	*	40.69de
150	*	4.27e	*	156.1bcd	*	83.58ef	*	42.98f
200	*	4.68f	*	164.9d	*	77.80de	*	44.41f
GM	3.64		140.81		65.26		34.74	
SE±	0.094		14.28		6.264		1.128	
Cv (%)	2.6		10.1		9.6		3.2	
F-pr	<0.001		0.016		<0.001		<0.001	

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

SO: Sukumawera near the opening of the cave

SI: Sukumawera inside the cave

*: Not determined

GM: Grand mean

SE: Standard error

CV: Coefficient of variation

F-pr: F- probability

The decrease in soil pH increased Cu, Zn and Fe availability in the soil and this triggered high absorption hence high concentrations (Thiagalingam, 2000). Sulphur (S) exists as part of the soil organic matter. It is not available to plants in the organic form, but needs to be converted into available sulphate ions through bacterial action (Thiagalingam, 2000). Increase in guano application rates has increased the already mineralized S that was available to plants, hence the absorption and concentration increased. High absorption and concentrations of Mg in plants inhibited the absorption of Ca; because both were very high in the experimental soil (Table 4). Ca and Mg in the soil, when present in high concentrations, behave antagonistically in absorption. This also was observed by Thiagalingam (2000). The concentration of Na increased gradually as the application rates increased; this portrays that the absorption rate of Na was low. The increase in Na concentration due to guano application in the soil prompted Na absorption and its concentration in plants too. However, Na uptake and concentration in plants is low compared to other nutrients (Table 9).

In the current study it was observed that, the critical nutrients concentration of maize plants after 35 days was attained at the ratios between 20 : 1 and 20 : 2 of soil : guano (Tisdale *et al.*, 1993). Similar results were obtained by Sridhar (2006) when dealing with guano indicating the highest uptake of N was at 20:1. This is because at this rate most of nutrient elements such as N were supplied at optimum level, thus inducing synergism between nutrient elements and hence acceleration of the uptake as observed by Ranade-Malvi (2011).

The nutrient concentration in SO was not determined because no shoot tissues were obtained from those treatments, except for the controls. The reason is given in visual performance of the screen house experiment.

4.4.3.3 Effects of Kisarawe bat guano application on the nutrients concentration and uptake by maize

The effects of Kisarawe bat guano application on nutrients concentration and uptake are shown in Tables 11 and 12. The nutrient concentration and uptake increased with increasing rates, although in some treatments increase in application rate affected nutrient concentrations and uptake negatively. In the KO bat guano applied soils the uptake and concentration increased as application rates increased in all determined nutrients. However, Fe concentration was at its maximum at 20 : 0.5 and thereafter started to decrease. The results show that there is no significant ($p < 0.05$) difference in increasing rate to K uptake and concentration. For Mg and Ca, uptake and concentration did not differ significantly ($p \leq 0.05$) at application rates of 20 : 0.5 and 20 : 1. According to the ratings provided by Tisdale *et al.* (1993), in KO the uptake and concentrations of Ca, N, P, S and Zn were below critical nutrient concentration in the control. Further, Na and Cu were below critical nutrient concentration in all the treatments. The nutrients concentration in KO at 20 : 4 and 20 : 3 were not determined because no shoot tissues were obtained from those treatments.

In KI bat guano applied soils, increases in application rates increased the nutrient uptake and concentration. However, at 20 : 1 Ca and Mg uptake and concentrations showed a difference, with Ca uptake been higher than Mg uptake. Increase in Mg at 20 : 2 affected the Ca uptake by decreasing it. Considering classification given by Tisdale *et al.* (1993), maize plants in KI bat guano applied soils attained their critical concentration of Ca, P, S and Zn at 20 : 0.5 while N at 20 : 1, this was almost similar to what was observed by Sridhar (2006). However, Na and Cu did not attain critical nutrient concentration throughout the application rates. The uptake seemed to be low for Cu and Na, although Cu was in the medium range in the soil and Na was between the high and very high range.

Table 11: Effects of Kisarawe bat guano application on the nutrients concentration and uptake by maize plants

g Guano kg^{-1}soil	%													
Level	N(KO)	N (KI)	Ca(KO)	Ca(KI)	K(KO)	K(KI)	Mg(KO)	Mg(KI)	Na(KO)	Na(KI)	P(KO)	P(KI)	S(KO)	S(KI)
0	1.04a	1.07a	0.41cd	0.65i	3.30a	4.04c	0.29ab	0.25a	0.02a	0.02a	0.17a	0.17a	0.12b	0.10a
25	3.61g	1.28b	0.63hi	0.32a	3.86b	4.34c	0.37d	0.27ab	0.02a	0.02a	0.41b	0.40b	0.20cd	0.22e
50	4.20h	1.49c	0.64i	0.42cde	3.92b	4.80d	0.35cd	0.32bc	0.02ab	0.02a	0.49c	0.46c	0.20cd	0.23e
100	4.71i	2.49d	0.68j	0.37bc	3.96b	4.87d	0.37d	0.34cd	0.02a	0.03bc	0.53cd	0.58d	0.22e	0.27f
150	*	2.87e	*	0.35ab	*	5.01e	*	0.34cd	*	0.03bc	*	0.57d	*	0.31h
200	*	3.24f	*	0.46e	*	4.89d	*	0.29ab	*	0.04c	*	0.58d	*	0.34i
GM	3.0		0.48		4.17		0.32		0.02		0.46		0.23	
SE±	0.099		0.027		0.13		0.023		0.009		0.033		0.01	
Cv (%)	3.3		5.6		3.1		7.4		36.8		7.3		4.4	
F-pr	<0.001		<0.001		<0.001		<0.001		0.629		0.015		<0.001	

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

KO: Kisarawe near the opening of the cave

KI: Kisarawe inside the cave

*: Not determined

GM: Grand mean

SE: Standard error

CV: Coefficient of variation

F-pr: F- probability

Table 12: Effects of Kisarawe bat guano application on the nutrients concentration and uptake by maize plants

g Guano kg^{-1}soil	mg kg^{-1}							
	Cu(KO)	**Cu(KI)**	**Fe(KO)**	**Fe(KI)**	**Mn(KO)**	**Mn(KI)**	**Zn(KO)**	**Zn(KI)**
0	2.36a	2.45a	76.1a	81.6a	51.6a	50.6a	17.21ab	13.87a
25	3.77b	3.71b	143.1de	129.5c	62.9ab	121.2d	30.84abcd	19.01ab
50	4.04c	4.71e	124.1c	140.1d	90.3c	136.0e	38.81bcde	26.47abc
100	4.38d	5.66f	112.8b	149.0e	112.6d	139.9e	44.73cde	39.58bcde
150	*	6.05g	*	178.6g	*	145.0e	*	49.61cde
200	*	6.22g	*	253.0i	*	147.3e	*	55.53de
GM	4.54		149.72		108.8		38.06	
SE±	0.14		4.96		7.75		13.00	
Cv (%)	3.1		3.3		7.1		34.2	
F-pr	<0.001		<0.001		<0.001		0.904	

NB: Means in the same column followed by the same letter (s) are not significantly different according to Duncans multiple range test at 5% level of significance.

KO: Kisarawe near the opening of the cave
KI: Kisarawe inside the cave
*: Not determined
GM: Grand mean
SE: Standard error
CV: Coefficient of variation
F-pr:F-probability

All the application rates showed significant ($p < 0.05$) difference in nutrient uptake and concentration with the control (Tisdale *et al.*, 1993).

4.4.3.4 Comparison between Sukumawera and Kisarawe bat guano application on nutrient uptake by maize

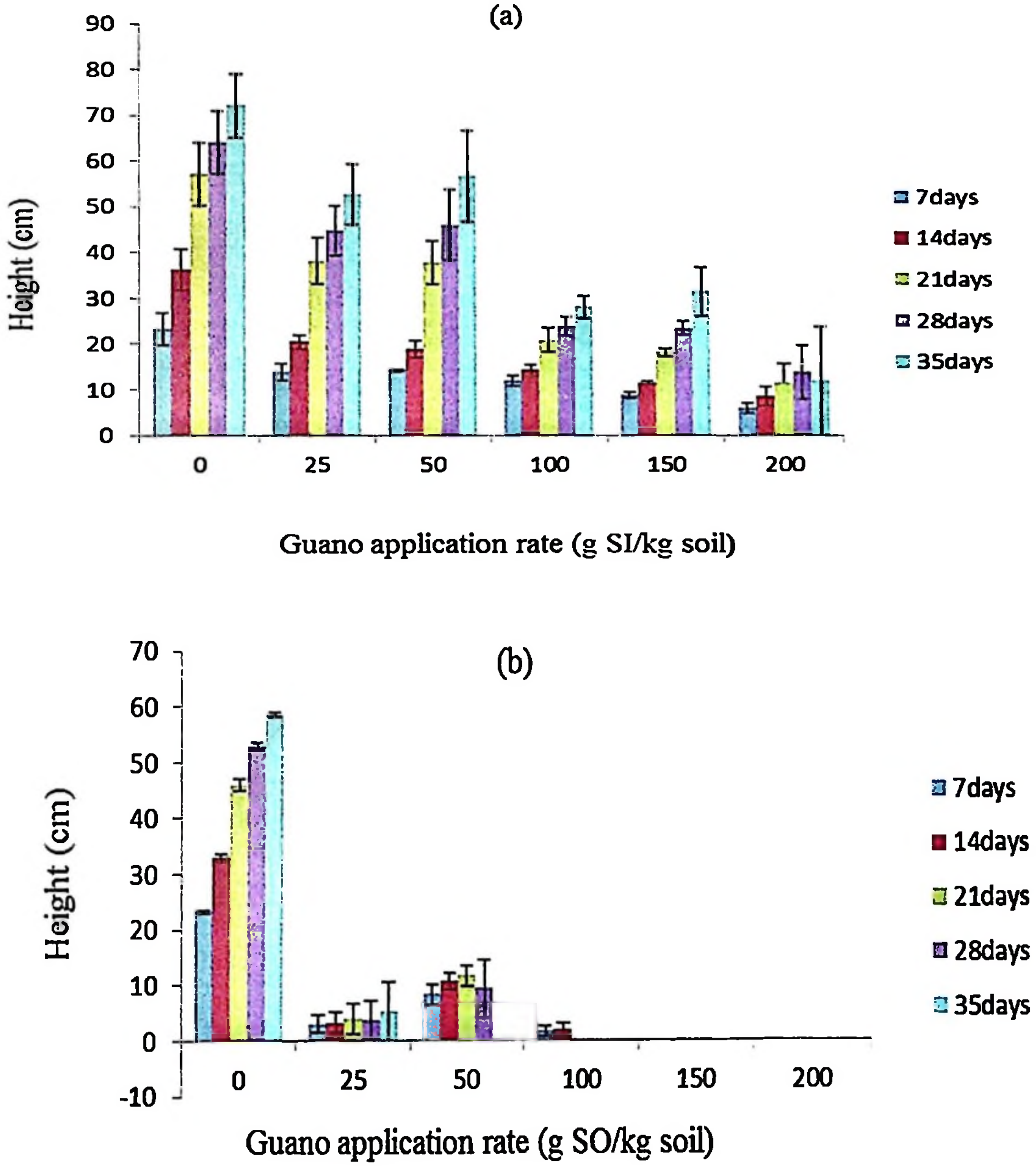
For soil applied Sukumawera bat guano. nutrient uptake increased as the application rate increased and attained its maximum at 20 : 2 then started to decrease. For Na, P, S. Cu and Zn uptake increased as the rates were increased (Tables 9 and 10). Maize uptake of N, Ca, Mg and Na from soil applied Sukumawera bat guano was higher than from soil applied Kisarawe bat guano. while P. S. Cu, Fe and Mn was higher from soil applied Kisarawe guano than from soil applied Sukumawera bat guano (Table 9. 10. 11 and 12). Similarly, K and Zn uptake showed the same trend. In KI applied soils. the nutrients uptake and concentrations increased as application rates increased except for N. Ca and Mg that attained the highest uptake at 20 : 2 then started to decrease. This caused by antagonism and synergism of nutrient elements in the soil as explained by Ranade-Malvi (2011). Therefore, results obtained from plant nutrients uptake and concentration show that Kisarawe bat guano is suitable for Mazimbu soil.

4.4.4 Effect of bat guano application on maize plant height

4.4.4.1 Effect of Sukumawera bat guano application on plant height

Effect of guano on plant height showed that the application of different rates of Sukumawera bat guano had negative significant ($p < 0.05$) effects on the maize plant height throughout the experimentation time (Fig. 1). Plants in the control produced statistically the tallest plants in all the SI and SO treatments. In the Control, plant height increased with time from 7th to 21st day. thereafter did not show much increase.

This is because the readily available nutrients in the experimental soil were depleted in those first days, since soil had low



Key: ⌶ Error bar stands for standard error of the means

SO: Sukumawera bat guano near the opening of the cave

SI: Sukumawera bat guano inside the cave

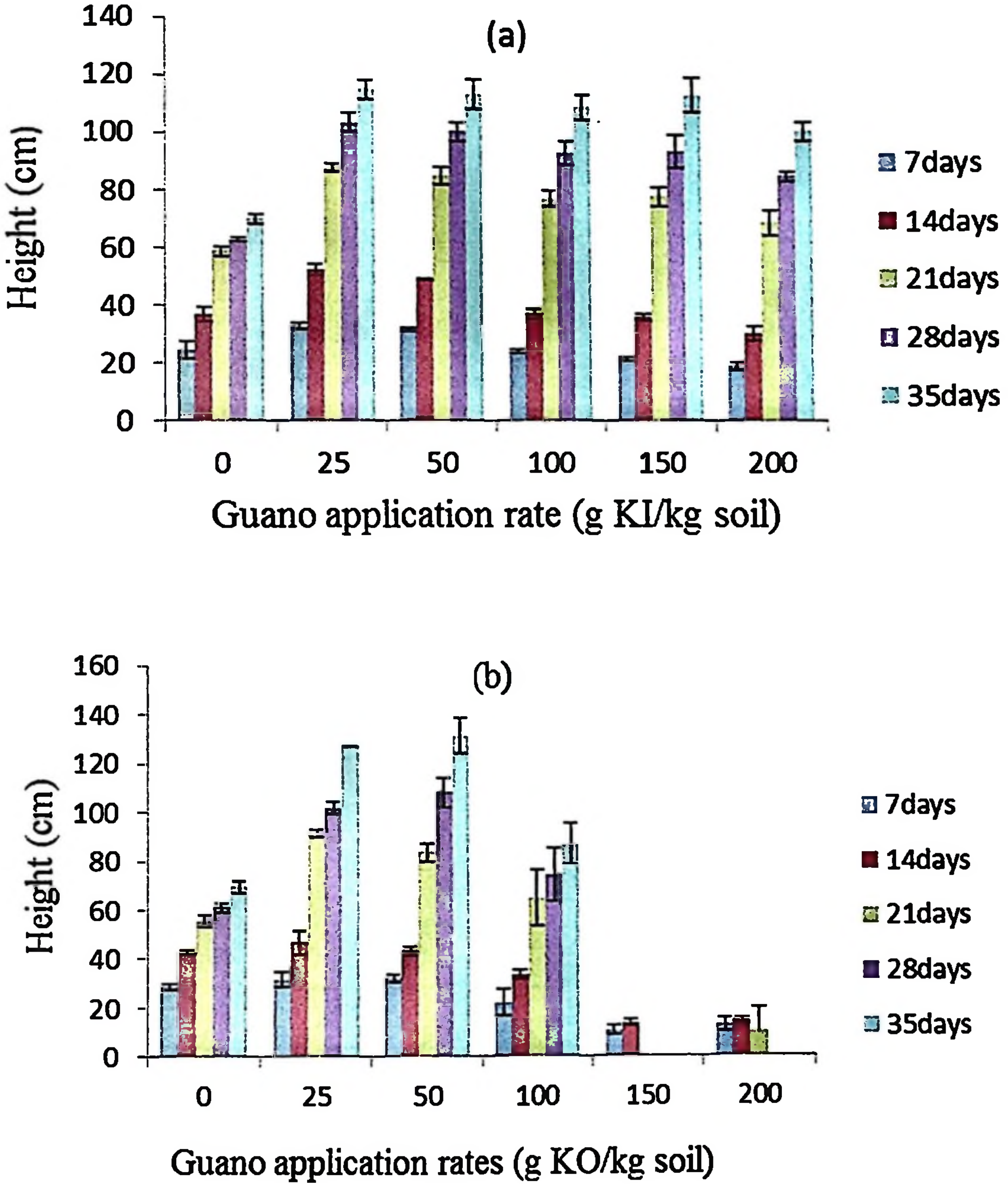
Figure 1: Effect of Sukumawera bat guano on maize plant height

percentage OC with low decomposition and mineralization that could have taken place. In SO bat guano applied soils the tallest plants were in 20 : 1 followed by 20 : 0.5 (soil : guano) the least were the high rate applied soils in all days. The change in plant height seemed to increase as the number of days increased. This was due to the increase in nutrient concentrations as decompositions and mineralization processes took place in the soil. However, the increase in ions due to dissolution of salts (secondary minerals) formed in the cave had intensified ECe to above 1.7 mS/cm. This level could not have been tolerated by maize plant (Smith and Doran, 1996). Also the increase in nutrient concentrations such as zinc might have resulted into toxicity, which killed the plants. The growth rate in 20 : 2 was very low, and the plants did not survive more than two weeks. In the SI bat guano applied soils at the rate of 20 : 0.5 and 20 : 1 (soil : guano) showed the tallest plants in all days data were taken. In all treatment the lowest height was in 20 : 4. This also was observed by Sridhar, (2006) that at low rate application of guano produce tallest plants and highest dry matter yields.

The highest average growth rate was in the 20 : 1 treatment closely followed by 20 : 0.5, while the least was at 20 : 2. The results suggest that the applied guano induced the negative effects for plant growth to the experimental soil as explained in the visual performance of screen house experiment. Therefore, Sukumawera bat guano application rates should not exceed the ratio of 20 : 1 (soil : guano)

4.4.4.2 Effect of Kisarawe bat guano application on plant height

Effect of guano on plant height showed that the application of different rates of Kisarawe bat guano had significant ($p < 0.05$) effects on the plant height of maize throughout the experiment time (Fig. 2).



Key: ⌶ Error bar stands for standard error of the mean

KO: Kisarawe bat guano near the opening of the cave

KI: Kisarawe bat guano inside the cave

Figure 2: Effect of Kisarawe bat guano on maize plant height

For KO and KI bat guano applied soils, plants planted in 20 : 0.5 treatment produced statistically the tallest plants closely followed by those in the 20 : 1 application rate. A similar trend was reported by Sridhar (2006), who applied guano at different rates and the low rates of applied guano produced taller plants than in high rates. In the Control, the growth rate increased from the 14th to 21th day after sowing, thereafter did not show much increase in the remaining days. This is because the readily available nutrients in the experimental soil were depleted in those first days, since soil had low percentage OC no more decomposition and mineralization could take place. The average growth rate in control was between 4.00 and 22.00 cm. In KO bat guano applied soils the tallest plants were in 20 : 0.5 application rate closely followed by 20 : 1. The least plant heights were from soil applied high rates of guano. In pots applied with low rates of KO bat guano, the growth rate seemed to increase as the number of days increased. The rate was at the peak between 14th and 21th day, this is due to the increase in nutrient concentrations as decompositions and mineralization processes took place in the soil. However the high increase in nutrient concentrations that had resulted into toxicity likely killed the plants at higher rates after the 14th day. In KI bat guano applied soils, the plant height increased as the application rates and number of days increased. The increase in plant height was at the peak between 14th and 21th day across all treatments. Basing on the application rates 20 : 3 showed the maximum height followed by 20 : 2. In 7th and 14th day plants on 20 : 4 treatment had low heights than the controls, but on 21th, 28th and 35th days, had taller plants than control.

4.4.4.3 Comparison between Sukumawera and Kisarawe bat guano application on plant height

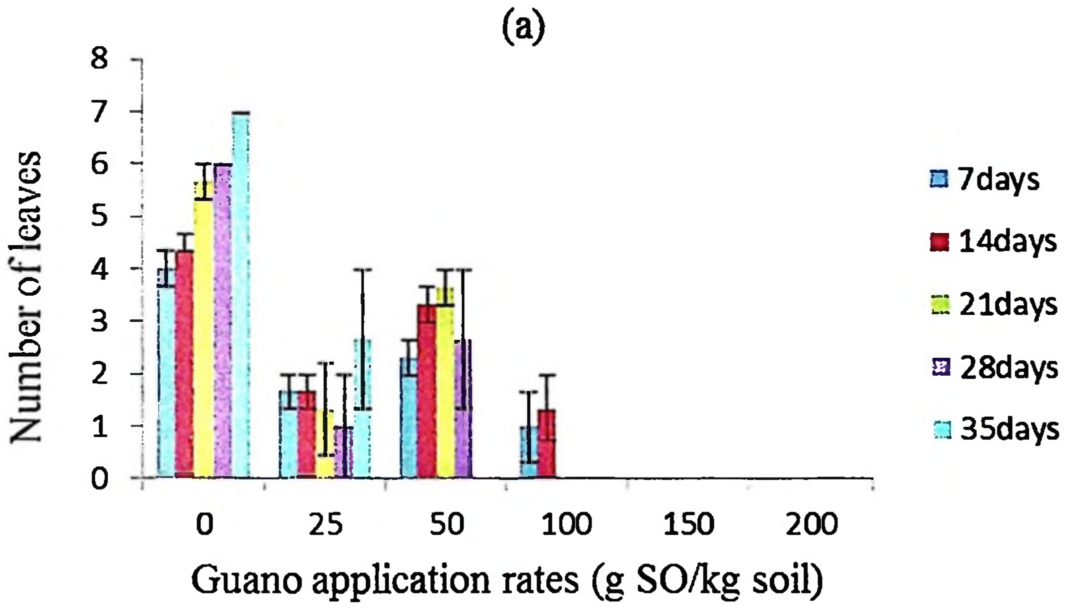
Sukumawera bat guano induced a negative effect on the plant height, while Kisarawe bat guano had a positive effect on plant height. The tallest plants in Sukumawera bat guano applied soils were observed in the treatments with the ratio 20 : 1 followed closely by 20 : 0.5 while in Kisarawe bat guano applied soils tallest plants was observed in 20 : 0.5 closely followed by 20 : 1. Results in the current study show that increase in guano application rates resulted into decrease in plant heights: which was also explained by Shetty (2013). The positive effects of Kisarawe bat guano on plant height was probably due to its higher N content than in Sukumawera bat guano. Furthermore, the percentage extractable nutrients were higher in Kisarawe than in Sukumawera bat guano (Table 2). It is plausible that the effects of high ECe may be the cause of poor performance on maize plant height in Sukumawera bat guano.

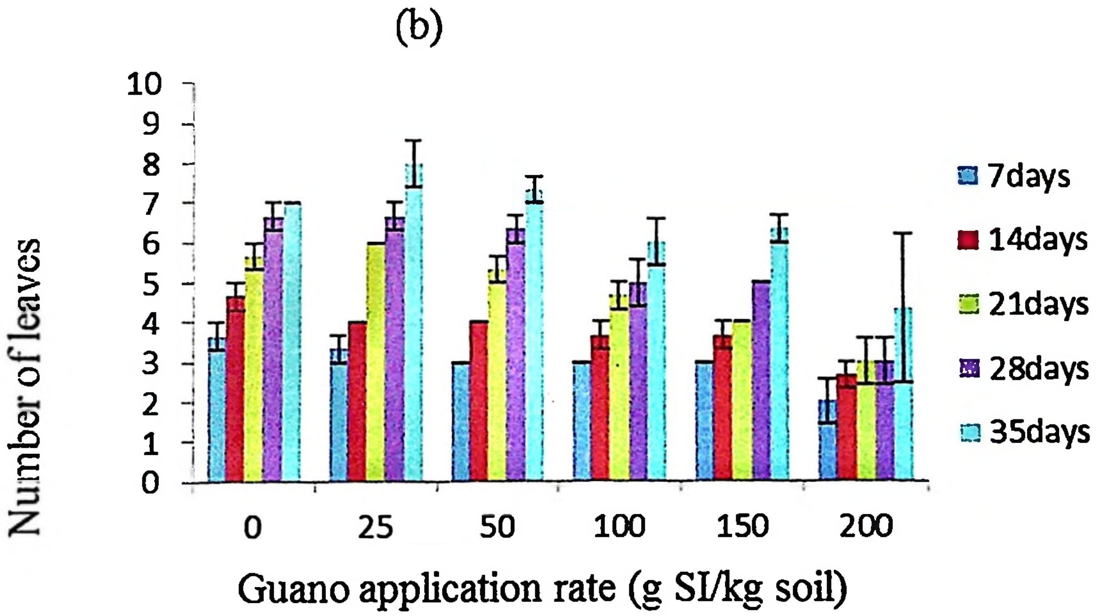
4.4.5 Effects of bat guano application on maize plant number of leaves

4.4.5.1 Effect of Sukumawera bat guano application on maize leaves

Figure 3 shows the trend observed in the number of leaves produced by plants at weekly interval when Sukumawera bat guano was applied. The results show that there was a significant ($p \leq 0.05$) decrease in the number of leaves when the application rate increased. At the 7th and 14th day the Control produced the highest number of leaves followed by the 20 : 05 application rate. At 21st, 28th and 35th days, 20 : 05 had the highest number of leaves followed by 20 : 01 application rate.

Plants from SO bat guano applied soils showed a decrease in leaf numbers as application rates increased. On 7^{th}, 14^{th}, 21^{th} and 28^{th} day there was no significant difference in the number of leaves in the 20 : 0.5 and 20 : 2 application rate. There is a lack of data for the number of leaves on the 35th day of this experiment because all plants were dead after the 28th day after planting. This was due to changes in chemical properties of the soil such as, excessive nutrient supply, pH and ECe that might have affected the availability of some plant nutrients (nutrient imbalance) and toxicity.





Key: ⌶ Error bars stand for standard errors of the mean

SO: Sukumawera bat guano near the opening of the cave

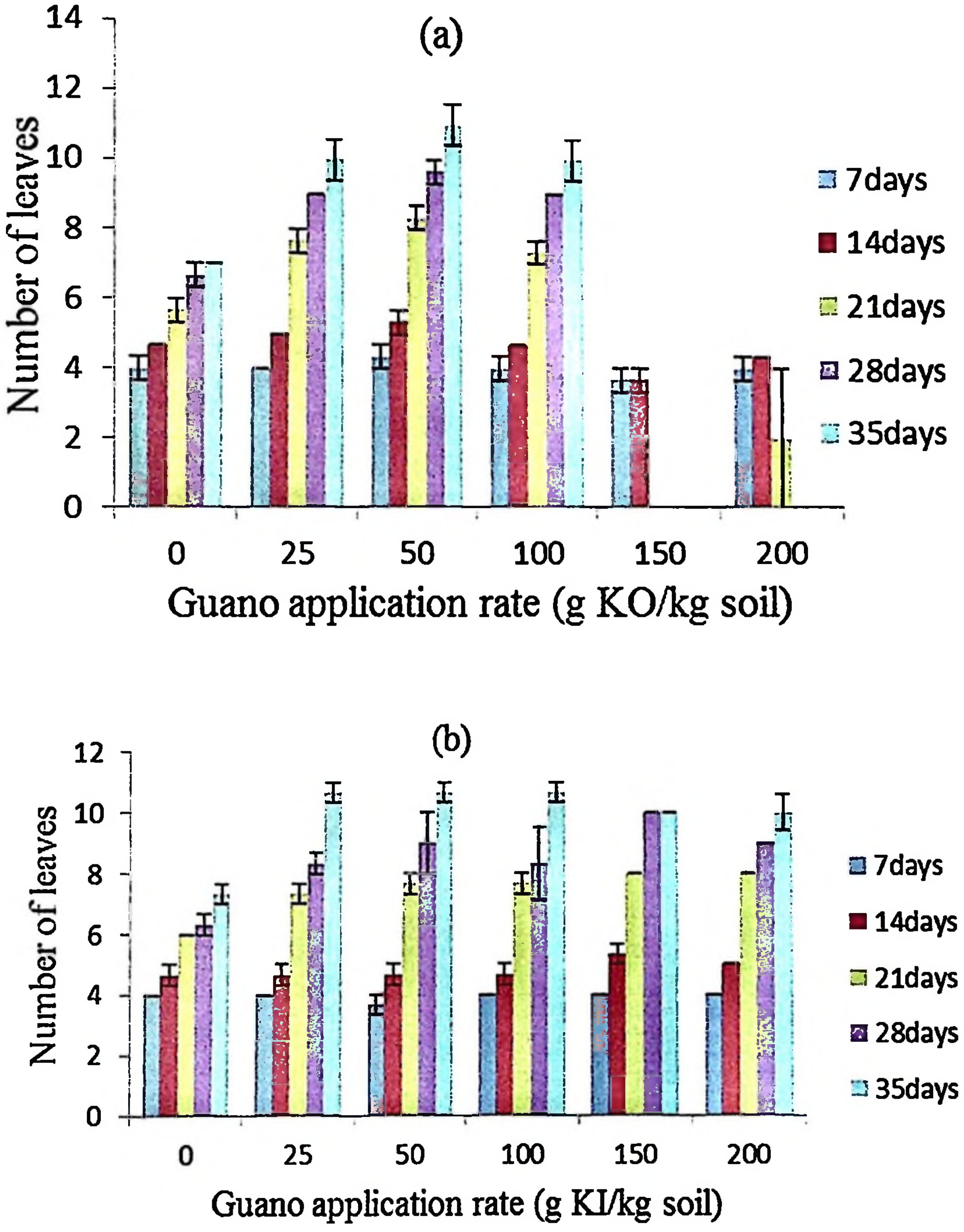
SI: Sukumawera bat guano inside the cave

Figure 3: Effect of Sukumawera bat guano on maize plant leaves

In SI treatments, on the 7th and 14th day after sowing, the Control had a higher mean number of leaves compared to the plants in soils applied with guano. This was probably because nutrients in guano were not released in the soil to boost the growth (Shahak-Gross, 2004). Basically 20 : 2 and 20 : 3 did not vary significantly in leaves production in all the days that data were taken. And 20 : 4, 20 : 3 and 20 : 2 had fewer leaves than the Control in all days. The 20 : 0.5 treatment produced the highest number of leaves per plant followed by 20 : 1 this also was observed by Adamu (2015) and his friends when farm yard manure was used to amend Mazimbu soil. At these times microbes had mineralized the organic matter, roots exudes and microbes might have triggered dissolution of secondary minerals (sulphates, phosphates and nitrates) in guano hence nutrient release in the soil.

4.4.5.2 Effects of Kisarawe bat guano application on maize leaves

Figure 4 shows the trend observed in the number of leaves produced by plants at a weekly interval when Kisarawe bat guano was applied. There was no significant difference in leaf number on the 7th and 14th day in plants found in KO bat guano applied soils and the control (Fig. 4a). On 28th, and 35th day 20 : 0.5, 20 : 1 and 20 : 2 treatments produced the highest number of leaves. However, 20 : 1 treatment had the highest number of leaves followed by 20 : 05. There was no data for the number of leaves on the 35th day of this experiment. This was due to the fact that the plants dried after the 28th day after planting. As explained earlier, this was due to changes in chemical properties of the soil such as, excessive nutrient supply, pH and ECe that might have affected the availability of some plant nutrients (nutrient imbalance) or caused toxicity. For soil applied KI bat guano, there were significant increass in the number of leaves relative to the control (Fig. 4b). However, increase in application rate did not provide much difference among the soil applied KI. Number of leaves increased with time.



Key: ⌶ Error bar stands for standard error of the mean

KO: Kisarawe bat guano near the opening of the cave

KI: Kisarawe bat guano inside the cave

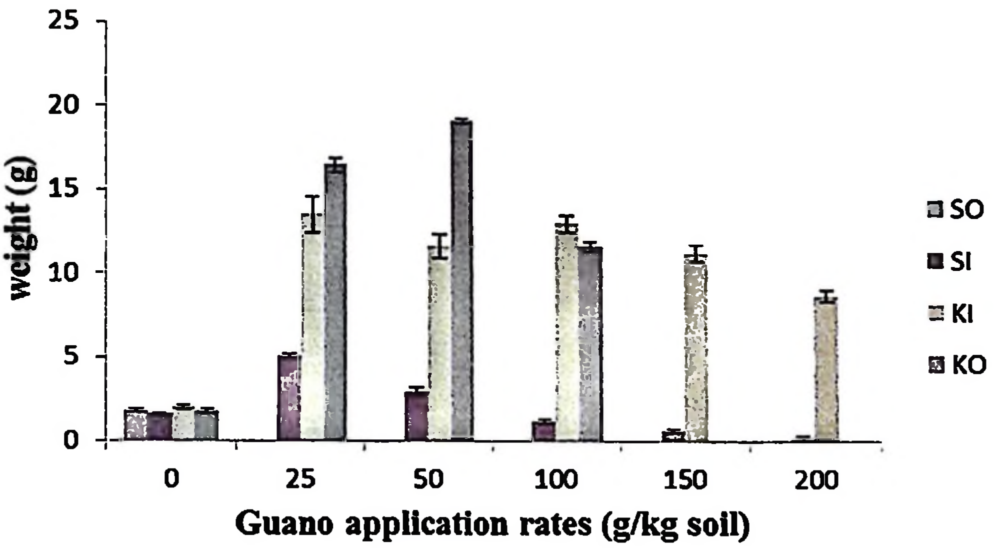
Figure 4: Effect of Kisarawe bat guano on maize plant leaves

4.4.5.3 Comparison of Sukumawera and Kisarawe bat guano on number of leaves

Sukumawera bat guano application in Mazimbu soil produced high number of leaves in 20 : 0.5 (SI) and 20 : 1 (SO) while Kisarawe bat guano applied soil produced highest number of leaves at 20 : 1 (Fig. 3 and 4). However, Kisarawe bat guano in Mazimbu soil has produced higher number of leaves than Sukumawera bat guano; also all the Kisarawe bat guano (KI) applied soils had almost the same number of leaves.

4.4.6 Effects of bat guano on shoot dry matter yield

Figure 5 shows the effects of Sukumawera and Kisarawe bat guano application on shoot dry matter yield. Sukumawera bat guano application (SI) at the rate of 20 : 0.5 showed the highest shoot dry matter yield followed by the 20 : 1 treatment; this is similar to what was observed by Sridhar (2006) that at low rates, guano produced the highest dry matter yield. This was because at those rates (20 : 0.5 and 20 : 1) plant height and average number of leaves were high due to adequate nutrients supply and nutrient uptake by plants (Tables 5, 6, 9, 10 and Fig. 1,3). However other high rates had lower shoot dry matter yields than the control (20 : 0). At higher rates of application (20 : 4 and 20 : 3) plants dried as explained earlier, hence less or no dry matter was obtained.



Key: Ｉ Error bar stands for standard error of the mean

KO: Kisarawe bat guano near the opening of the cave
KI: Kisarawe bat guano inside the cave
SO: Sukumawera bat guano near the opening of the cave
SI: Sukumawera bat guano inside the cave

Figure 5: Effects of Sukumawera and Kisarawe bat guano on shoot dry matter yield

The effects of Kisarawe bat guano application on shoot dry matter yields at the rate of 20 : 1 showed the highest shoot dry matter yield followed by 20 : 0.5 in KO and KI bat guano applied soil plants; as also observed by Sridhar (2006). However, in KI, there was no significant difference between 20 : 2, 20 : 1 and 20 : 0.5 treatments in total shoot dry matter yield. This is because at that rate soil had adequate nutrients concentration, the nutrient uptake was adequate, plant height and average number of leaves were high (Tables 7,8,11,12 and Fig 2, 4). However, other high rates had lower shoot dry matter yields than control (20 : 0). Results showed that KO produced the highest dry matter yield than KI. Presumably, this is because KO had high CEC and organic matter (% OC) than KI bat guano (Table 2).

than KI. Presumably, this is because KO had high CEC and organic matter (% OC) than KI bat guano (Table 2).

In comparison, Sukumawera bat guano application in Mazimbu soil produced lower shoot dry matter yields than in any of the Kisarawe bat guano applied soils. the highest shoot dry matter yield in Sukumawera bat guano was at 20 : 0.5 (SI) while on Kisarawe bat guano the highest shoot dry matter yields was at 20 : 1, which also was observed by Sridhar (2006).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In view of the above results of this study, it is being concluded that:

i. Elemental composition of bat guano found in Sukumawera and Kisarawe caves differs from each other; this is most likely caused by nutrition habits of the bat, maturation of guano and type of the bedrock where the guano is found.

ii. The level of P in Sukumawera bat guano ranged from 20 - 41% while in Kisarawe bat guano it was lower at 7 - 15%. Similarly Sukamawera bat guano had higher level of S (19 - 39%) compared to that in Kisarawe bat guano (6 - 13%). Thus, both guanos could be used as a source of P and S as well as essential micronutrients when used as soil amendment.

iii. Both Sukamawera and Kisarawe bat guano are slightly acidic to strongly acidic (pH 4.2 - 6.7) and, hence, should be used to amend alkaline soils.

iv. Nutrients uptake by maize increased with the amounts of guano applied. However, maize responded well to soil applied with less than 50 g of guano per kg of soil (20 : 1). High rates caused the plants to perform poorly and some dried due to decrease in pH and decomposition of organic matter that resulted in nutrients imbalance.

v. Extractable P, S, Mn, Zn and Cu were higher in Kisarawe bat guano than in Sukumawera, contrary to expectation. Sukumawera bat guano had higher total amount of nutrients than Kisarawe bat guano.

5.2 Recommendations

According to the findings obtained in this study the following recommendations were made:

(i) The results obtained in this study should be confirmed under field conditions from which appropriate fertilizer recommendations based on guano can be drawn.

(ii) Further studies should be done on Sukumawera bat guano to reduce negative effects induced in the soil by this guano by decreasing the application rates.

(iii) Another study is recommended to assess effectiveness of Kisarawe bat guano from inside the cave (KI) in all application rates; this will clarify number of issues raised in this study including influence of high acidity and high application rate on the plant performance.

(iv) Further studies should be done on the Sukumwera bat guano found near the opening to assess more on its poor performance and inefficiency in all application rates; this should clarify on influence of ECe.

(v) From results of this study it is suggested that, there must be an incubation study on Kisarawe bat guano to assess pH change trend especially in guano found inside the cave (KI).

(vi) Sukumawera and Kisarawe bat guano should be used in alkaline soils instead of neutral or acidic soils.

(vii) Pre determination of physico-chemical properties of bat guano before use as soil amendment will help to know the actual amount present and focus on synergism and antagonism that may take place when a particular guano is used.

(viii) All bat guano found in Tanzania should be characterized and assessed for agronomic efficiency before use for agricultural purposes.

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