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REVIEW PAPER

A Brief Review of the Nutritive Value and Chemical Components of Bat Guano and Its Potential Use as a Natural Fertiliser in Agriculture

SITI-SYAMIM NURFATIHAH ABD RAHMAN*[1], ROBERTA CHAYA TAWIE TINGGA[2], MOHAMAD FHAIZAL MOHAMAD BUKHORI[2] & SHARIFAH MONA ABD AZIZ ABDULLAH[2]

[1]Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia; [2]Centre for Pre-University Studies, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia

*Corresponding author: sitisyamim98@gmail.com

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ABSTRACT

New and improved fertilisers are constantly being introduced to the market to help increase crop yields. However, the common usage of chemical fertilisers had brought upon negative impacts to the environment and the study for sustainable fertiliser is still ongoing. This review will highlight the usage of bat guano as a valuable fertiliser which has a potential to diminish the effects of chemical fertiliser usage, increase yield and is cost effective. Its role as a fertiliser can support the agricultural growth and in turn provides additional care for plants. The chemical compositions of guano which was found to be subpar with other fertilisers support its usage of guano as an alternative for crop yield enhancement. Plant growth performance that shows a significant positive impact of guano on crops, further demonstrates its usage as organic fertilisers. In-depth study of the chemical composition of guano should be pursued as the fertiliser has high beneficial value to the ecology and economy.

Keywords: Bat guano, chemical composition, fertiliser, manure, plant growth

INTRODUCTION

Plant growth is highly dependent on the plants' physical, chemical, and biological properties. Enhancement of these properties can be carried out by adding plant regulators or fertilisers (Bender *et al*., 1998). Generally, fertilisers can be classified as organic or chemical. Using fertilisers is important in agricultural production for increment of plant growth efficiency (Karagoz-Sezer & Hanaya, 2020). The significance of agriculture to fulfil the food supply of this ever-growing population has caused farmers to opt out from the environmentally friendly plantation techniques (Fernandez *et al*., 2003). Fertiliser industry had brought over extensive usage of chemical fertilisers worldwide. This is because the chemical fertilisers option was inexpensive and apparently, gave a faster result in yielding production (Kincheloe, 1983).

According to Oo *et al*. (2019), chemical fertilisers (inorganic or synthetic) are defined as artificial chemicals containing primary nutrients for plants such as nitrogen (N), phosphorus (P), and potassium (K) in laboratories. Organic fertilisers on the other hand are fertilisers derived from organic matter that was collected from nature (plant or animal waste) making up to green manure, livestock manure or compost (Demirtas *et al*., 2005).

Application of organic fertilisers such as compost, green manure and bioinoculants are a vital procedure in organic farming management (Thampan, 1993). Organic fertilisers provide constant availability of nutrients and an equal uptake by plants; hence, rainwater does not leach the nutrients away (Linn & Myint, 2018; Oo *et al*., 2019). In addition, organic fertilisers play a role in decreasing greenhouse effect and global warming as it is able to isolate more carbon in the soil (Assefa & Tadesse, 2019). Several animal-derived fertilisers such as chicken manure and cow dung are one of the best organic fertilisers as they provide an eminent source of N, P, K, and other organic matter to the soil (Oo *et al*., 2019). Bat guano can be defined as the excretion matter of bats (Sakoui *et al*., 2020).

Torres-Jimenez *et al*. (2020) stated that guano provides a great alternative for fertilisers, when compared among other organic fertilisers. Based on previous studies, bat guano is known to be the best fertiliser worldwide because it contains high levels of N and K (Hutchinson, 1950; Kasso & Balakhrishnan, 2013; Sakoui *et al*., 2020). It is a better alternative when compared to a synthetic fertiliser as it does not contain nutrient residue (Diba *et al*., 2013). However, surveys done by Kingston *et al*. (2006), noted that only 3.4% of communities in Malaysia were aware of bat guano's usage for crops fertilisers. Therefore, it is important to shed a light on the importance of bat guano as fertiliser through this review.

BAT GUANO

Being the second largest group in Class Mammalia, bats (Order: Chiroptera) accommodates approximately 1,232 species taxonomically identified worldwide (Nowak, 1994; Simmons, 2005; Ghanem & Voigt, 2012; Fenton & Simmons, 2015; Sakoui *et al*., 2020; Torres-Jimenez *et al*., 2020). Bats are distributed throughout each continent except in some remote oceanic islands and polar regions such as Antarctica (Ghanem & Voigt, 2012; Sakoui *et al*. 2020). Diversity of bats particularly in tropical regions (Simmons & Voss, 1998; Bass *et al*., 2010; Ghanem & Voigt, 2012), occurs because of its variety of diets, which is brought by evolution through adaptation and speciation suited for their habitat environment (Voigt & Kingston, 2016; Torres-Jimenez *et al*., 2020). The diet consists of frugivorous, insectivorous, nectarivorous, sanguivorous and carnivorous (Ferreira, 2019; Torres-Jimenez *et al*., 2020). The variety of roost habitats of bats include mines, cave and tree cavities, crevices, and branches. Heterothermic bat species prefers cave areas for roosting to breed and hibernate (Sakoui *et al*., 2020). Cave roosts that accommodate huge bat colonies (thousands of bats individuals), are the main provider of guano, which is an important biomass to the ecosystem (Ghanem & Voigt, 2012; Kasso & Balakhrishnan, 2013; Voigt & Kingston, 2016; Torres-Jimenez *et al*., 2020).

Sridhar *et al*. (2006) and Shetty *et al*. (2013) recorded the morphological characteristics of insectivorous guano as an elongated blackish brown and grey fecal pellet with rough surface. The length or size of the fecal pellets in both studies differs where a size of 9 to 11 mm was measured in Shetty *et al*. (2013) while a 3.5 to 6 mm was measured in Sridhar *et al*. (2006). Ware *et al*. (2020) mentioned that the morphology of guano may be more closely related to the bats' diet than its species, which can be vital in identifying the prey taxa to bring focus on conservation strategies. Composition of guano differs depending on the diet of the bat species (Ferreira, 2019). This is also supported by Karagoz (2014) which also brings to light about the influence of the guano region on the composition of guano.

As a result of the pungent odour produced from the guano that attracts invertebrates, guano also supports the cave ecosystem for diverse organisms of cave inhibitors such as insects, bacteria, and fungi (Harris, 1970; Sridhar *et al*., 2006; Emerson & Roark, 2007; Ghanem & Voigt, 2012; Kasso & Balakhrishnan, 2013). Ferreira and Martin (1998) reported that the invertebrate diversity that inhabits the guano, particularly in dry tropical caves, is dependent on the diet of the bat that produced it (Emerson & Roark, 2007). The physical and chemical properties of guano also vary at different habitats and at different times (Ferreira & Martins, 1999; Newman *et al*., 2018). Further, guano serves as the energy source of the cave ecosystem in temperate regions (Ghanem & Voigt, 2012).

In agricultural aspects, recently, an increase of studies on the beneficial effects of guano on plant growth have been observed (Grantina-Ievina & Ievinsh, 2015). Since long ago, guano had been extracted from caves to be utilised as fertilisers because of its high nutrient levels (Kasso & Balakhrishnan, 2013). This study reported that a high number of guano products have been in demand on the market sales. It was recorded to be one of the world's finest organic fertilisers as it improves the quality and increases the production of plants because of its nutrient levels (Tuttle & Moreno, 2005; Yankova *et al.,* 2016).

BAT GUANO IN BORNEO

Bat guano have been discovered in many caves worldwide and have been exploited commercially as manure because of its high nutrient levels (Sridhar *et al*., 2006; Kasso & Balakhrishnan, 2013). It was reported that since the 19th century, more than 100,000 tonnes of guano have been exploited around the United States to be used as fertilisers (Ghanem & Voigt, 2012). In the past, there were a handful of countries that collected guano for fertiliser such as United States, Cuba, Mexico, Jamaica, Brazil, Cambodia, Thailand, and Indonesia (Ghanem & Voigt, 2012; Sothearen *et al*., 2014; Ferreira, 2019). Harvesting of bat guano can be done in various methods, some research of bat guano was done with samples obtained from a direct collection of guano piles from cave floors (Bird *et al*., 2007; Wurster *et al*., 2015; Wasti *et al*., 2021). Other methods of collections were through a placement of plastic tarps or plates directly underneath bat roosts identified in the cave (McFarlane *et al*., 2017). In Vietnam, bat guano harvesting was done through the construction of bat houses. The guano collected were sourced economically into the fertilisers market and the profits were collected by the owner which calculated to be a monthly average of 50 USD/bat house (Nguyen, 2015).

Due to the stable climate of tropical countries such as Brazil, the availability of guano is constant as there is no migration or hibernation of bats which corresponds to temperate regions (Ferreira, 2019). Considering the matter, it is vital for the tropical country of Malaysia to study in depth on the qualities of bat guano. In Malaysia, bat guano had been discovered in several localities particularly in Borneo. Findings by McFarlane and Lundberg (2018) of bat guano in caves in Sarawak areas: Racer Cave, Mulu National Park and Niah Cave found the presence of multiple minerals associated with the bat guano such as nitrate, phosphate and sulphate. Studies by Wurster *et al*. (2015) on the biogeochemistry on guano from insectivorous bats can be obtained from guano samples in limestone caves located around Malaysia which are Batu Cave in Peninsular Malaysia, Niah Cave and Gomantong Cave in Northern Borneo as well as Makangit and Gangub Cave located in the Phillipines.

Another research on bat guano conducted in Southern Borneo used the bat guano as radiocarbon dating to provide records of environmental changes (Wurster *et al*., 2019). Wurster *et al*. (2019) utilised the radiocarbon dating methods in their effort to prove the presence of a savanna ecosystem in Borneo during Pleistocene epoch. Most recent findings on bat guano in Malaysia is centred on the host properties of the guano for SARS-CoV. In the wake of the Coronavirus pandemic, virology surveillances and studies had been widely conducted throughout Asia. In Borneo specifically, studies conducted by Tan *et al*. (2021) in Wind Cave Nature Reserve, Bau, Sarawak, found a high diversity of alpha and beta coronaviruses which are unique to Borneo Island. Regarding the field of mycology, guano obtained from Madai Cave, Sabah were found to contain 32 species of fungi such as *Penicillium* spp., *Aspergillus* spp. and *Purpureocillium lilnacium* (Wasti *et al*., 2021). Based on previous studies in the matter of bat guano, it is clear that studies referring to bat guano properties specifically as a fertiliser in Malaysia had been low. This may correlate with the inadequate awareness of the chemical component of bat guano and benefits of bat guano in plant growth.

CHEMICAL COMPONENTS OF BAT GUANO

Recent studies on chemical components of guano worldwide provide clear justifications on the usage of guano as organic fertilisers. High levels of organic matter, total N, P (in the form of phosphate), K and carbon (C) were reported in a number of literatures such as Studier *et al*. (1994), Sridhar *et al*. (2006), Emerson and Roark (2007), Buliga (2010), Shetty *et al*. (2013), Richard *et al*. (2014), Jayasvasti and Jayasvasti (2018), Ünal *et al*. (2018), Oo *et al*. (2019), Misra *et al*. (2019), and Ferreira (2019). Most of these studies also mentioned the presence of other micronutrients in guano such as calcium (Ca), magnesium (Mg), aluminium (Al), iron and sulphur (S) that facilitate in controlling the pH of soil. Other than that, guano is composed of microbes from various bacterial taxa majorly from Enterococcaceae and Bacillaceae families (Newman *et al*., 2018). The presence of these microbes might be able to help with nutrient absorption of plants, clearing any soil toxins as well as controlling fungi and nematodes to avoid plant diseases (Shetty *et al*., 2013; Oo *et al*., 2019). This can be proven by a study reported by Shetty *et al*. (2013) where the usage of autoclaved soils with guano still showed the best growth, making guano a suitable candidate for biofertilisers.

However, the composition of guano is dependent on the age of guano, the bats' locality, diet, and species (Studier *et al.,* 1994; Ferreira & Martins, 1999; Emerson & Roark, 2007; Vandzurova *et al*., 2012; Shetty *et al*., 2013; Karagoz, 2014; Jayasvasti & Jayasvasti, 2018; Newman *et al*., 2018; Ferreira, 2019). Study by Sakoui *et al*. (2020) supports the fact that the composition of guano is dependent on the age of guano as higher level of P, Al and iron are found in fresh guano than in guano found at deep layer of cave floors. Wurster *et al.* (2015) also showed that different levels of elements were found on bat guano with increasing depths. Analysis of results from the study shows a high C and N levels at the surface of bat guano collected at every locality. However, both C and N levels in the bat guano decreased with depths, hinting that the age of bat guano will influence on both C and N percentages (Wurster *et al*., 2015).

Other than that, P percentage of the bat guano in each locality was found to differ where the bat guano at Batu Cave and Makangit Cave were analysed to be at low levels, while bat guano obtained from Gomantong and Gangub Cave have moderate levels of P. Meanwhile, P percentage of samples obtained in Niah National Park were the highest among others (Wurster *et al*., 2015). Differences in guano composition amongst various insectivorous bats species can be observed through studies by Misra *et al*. (2019). Composition of the sodium (Na) and potassium (K) levels of the insectivorous bats *Scotophilus kuhlii* is recorded to be higher in its guano, which suggested that it consumes a considerable number of lepidopteran insects. Other than that, P content in the insectivorous bats *Megaderma lyra* measure to be at the highest percentage among all the species tested (Misra *et al*., 2019).

Comparison of guano composition among different diets has been performed in several studies. Emerson and Roark (2007) studies on the comparison between the guano of sanguivorous bat, *Desmodus rotundus* and frugivorous bat, *Pteropus rodricensis*. In this study, it was discovered that the sanguivorous bats have a higher level of C compared to the frugivorous bats, which may be related to the indigestible fruit components consumed by the frugivorous bat that was not included in fecal matter (Emerson & Roark, 2007). Studies by Studier *et al*. (1994), mentioned that the insectivorous or omnivorous bats possessed a higher level of N in comparison to herbivorous (frugivorous) bats. While, P content, on the other hand, shown to be at a higher level in frugivorous bats than in insectivorous bats (Goveas *et al*., 2006; Emerson & Roark, 2007). These statements are supported by Sridhar *et al*. (2006) who reported that the guano of insectivorous bats, *Hipposideros speoris* showed a higher N percentage than P.

Old guano piles observed in Racer Cave by McFarlane and Lundberg (2018), shows a pink coloured layer coverage on the guano pile that was identified by spectral analysis to be phosphate mineral. Spectral analysis of the extensive and stratified bat guano in Niah Cave revealed a fluorine material and nitrogen. Other analysis of the same samples uncovers a composition of oxygen (O), P and Ca as well as a trace component of Na, Al, S, chlorine (Cl) and Fe (Dykes, 2007; McFarlane & Lundberg, 2018). The dry weight of N content from guano collected at Deer Cave in Mulu National Park is said to be 0.076 g (McFarlane *et al*., 2017), where fresh guano from the Free-tailed bat obtained from the same cave was found to contain 7.6% level of N (McFarlane & Lundberg, 2018). The specific nutrient levels recorded by other studies are as shown in Table 1. Only the dietary properties of data from Sridhar *et al*. (2006) were specified while specification of other literatures were absent. Species identification of the data were not recorded in most study in Table 1, except for insectivorous bat guano by Sridhar *et al*. (2006)

PLANT GROWTH STUDY USING BAT GUANO

Discovering the specific levels of N, P, and K in the guano can be used to detect the growth differential in plant parts as well as enhancing crop production (Ferreira, 2019; Misra *et al*., 2019). Supplying N in plants is said to increase leaf growth (Oo *et al*., 2019). When N is paired with P, crop products will have an increase of root growth and dry matter as well as improvement on roots to shoot ratio (Oelhalf, 1978; Poliquit & Calong, 2018). P component in manure will also enhance fruit quality and facilitate in the plants' disease resistance (Walan, 2013; Jayasvasti & Jayasvasti, 2018). Available P in plants is required for maturity of crops and seed formation (Linn & Myint, 2018).

An important factor to note is that the size of grains and seeds is dependent on the levels of K absorbed by the plants. Oo *et al.* (2019) mentioned that K facilitates a stronger stem growth, water movement in plants as well as promotes fruiting and flowering of plants. Its deficiency would cause shrivelled fruits and seeds of plants (Linn & Myint, 2018). Other important components in plant regulators are enzymes as well as Ca and Mg substances. These components will stimulate soil microorganisms in releasing nutrients at a constant which will lead to an easier nutrient absorption for the plants (Yankova *et al.*, 2016).

Table 1. Nutrient levels of bat guano components from previous studies (nr: not recorded)

	Locality	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Other Nutrients
Sridhar *et al.* (2006)					
High phosphorus guano (Frugivorous bats)	India	11 - 15	65 - 79	11 - 20	nr
High nitrogen guano (Insectivorous bats: *H. speoris*)		62 - 68	16 - 31	8 - 16	nr
Altintas *et al.* (2005)	Turkey	0.97 - 5.60	1.20 - 1.50	0.25 - 0.63	OM: 24 - 79
Karagoz- Sezer and Hanaya (2020)	Turkey	8.20	P_2O_5: 2.00	K_2O: 0.5	OM: 67.30 % C/N: 8-15/1 pH: 4.00 Salinity: 1.30 %
Giurgiu and Tamas (2013)	Romania	5 - 10	25	nr	nr
Sothearen *et al.* (2014)	Cambodia	9.97	3.4	0.4	nr
Suwarno and Idris (2007)	Indonesia	7 - 17	8 - 15	1.5 - 2.5	nr
Yankova *et al.* (2016)	Bulgaria	2	nr	nr	OM: 20 % pH: 4.2 - 6.3

Numerous plant growth studies that applied guano as organic fertilisers had recorded a positive output. A study conducted by Poliquit and Calong (2018) was done on the application of guano with garden soil in different ratios as treatment for carrot growth. The study shows several differences when compared to the non-treated soil. A longer and broader circumference of carrots roots was obtained, a more balanced nutrient accumulation of N and P was measured and a better respond in crop growth and development was recorded as well as a more uniformed N unleashed to promote root growth was observed (Poliquit & Calong, 2018).

Other than that, a study by Linn and Myint (2018) recorded an increase in soil nutrients (pH, moisture, N levels, available P and K, exchangeable K, Ca, and Mg) when a mixture of guano, wood ash, and sesame meal was applied on cassava plants when compared to the commercial organic fertiliser (Vedagro^{TM}). Cassava plants treated with the guano mixture also yielded a higher tuber length of cassava compared to the other treatments. Nutrient levels of the cassava plant with guano mixture treatment were also found to have a higher value of protein, fat and fibre (Linn & Myint, 2018).

A study conducted by Sothearen *et al.* (2014), on application of guano on five economically important plant species recorded impressive results. A significant weekly increase of stem circumference and height were measured for all plant species treated with guano in comparison to the control treatment. When compared to chemical fertilisers treatments, three out of five plants with guano as fertilisers showed a better growth performance despite a lower NPK content of guano. This may prove that the presence of micronutrients and beneficial microflora that was not found in chemical fertilisers played a significant role in the effects of plant growth performance by guano (Sothearen *et al.*, 2014). Introduction of guano throughout the study contributes to significant changes on the nutritional content of soil which automatically improves the growth of plants

(Sothearen *et al.,* 2014).

An experiment by Ünal *et al*. (2018) also proved that the usage of guano on plants had increased growth compared to control. Other studies that support the claim are Shetty *et al*. (2013), Almohammedi *et al.* (2014) and Diba *et al*. (2013). Higher growth levels and improvements of plant growth were notably exhibited in all plant species that were treated with guano where a significant difference was statistically measured when compared to chemical fertilisers (Sakoui *et al*., 2020). Furthermore, bat guano is also essential as it supplies nutrition for microfloral growth (Misra *et al*., 2019).

Shetty *et al*. (2013) suggested that incorporation of different proportions of guano with high N as manures could give off a better plant growth performance. Nevertheless, in previous studies conducted, it was reported that only a little amount of guano should be applied to affect the plant growth (Sridhar *et al*., 2006; Shetty *et al*., 2013; Sothearen *et al*., 2014). A review from previous studies on the application of guano on plant growth shows that the guano can be used as a treatment in various state. Poliquit and Calong (2018), Shetty *et al.* (2013) and Sothearen *et al*. (2014) applied guano as fertiliser by a mixture with soil while, Ünal *et al*. (2018) applied the guano as a water mixture through drip irrigation method. Other studies on the other hand, placed the guano treatment with other organic waste such as Diba *et al*. (2013) where the guano was mixed with soybean paste, and Linn and Myint (2018), where guano treatment was mixed with wood ash, and sesame meal before applying as fertiliser. The method and mixture of guano application might give out a variable in plant growth, however a clear study with constant variable were not found to justify the matter.

A study conducted by Ojobor and Egbuchua (2021) informed that the appropriate mixture of bat guano with other manures can control nutrient deficiencies of crops. Furthermore, the suitable percentage of its chemical components, for instance, N, P and K, will undoubtedly enhance the plant structure from its shoot length, leaves, flowers, disease resistance and many more. Additionally, Karagoz-Sezer and Hanaya (2020) mentioned that studies on the influence and effect of guano on plant growth performance showed that positive improvement of soil productivity as well as nutrient availability in soils are expected to be obtained with continuous and sustainable usage of guano.

CONCLUSION

Organic fertilisers had highlighted multiple advantageous effects throughout its years of usage. Although the era of sustainable farming has developed multiple organic fertilisers, the application of cave bat guano in Sarawak particularly, on plant growth performance will become a pendulum of agriculture in the region. This is significant due to the accessibility of bat guano in multiple regions of Sarawak mentioned in previous studies such as in Niah National Park and Mulu National Park. With that, sustainable farming using bat guano carried out by secluded settlement is economically helpful towards low-income household.

Most importantly opting for organic fertiliser such as bat guano, would fulfil the Sustainable Development Goals proposed by the United Nations considering the promotion of several goals such as supply of clean water and sanitation (Goal 6), combating climate change (Goal 13) and conserving the ocean life (Goal 14) (International Fertiliser Association, 2020). This is particularly due to the low amount of toxic run-off to nearby water reservoir provided by bats guano as fertiliser as opposed to chemical fertilisers, which can create a safer water supply to houses and living developments. Other than that, the ecological benefits of bats guano usage as fertiliser in minimising greenhouse effects from its carbon storing characteristics is a valuable outcome to the environment.

The expediency of utilising bats guano on plant growth through the research mentioned throughout this review, it is evident that bat guano is expected to be an effective alternative to chemical fertilisers and would decrease the ecological impacts from chemical fertilisers that have been applied for decades. The chemical composition of bat guano as studied vastly in previous works showed an exemplary nutrient content of bat guano as an organic fertiliser. These reviews with relation to the exploration of bat guano effects on various plant types created a value added for usage of the material in agriculture. Application of bat guano as an organic fertiliser is found to be more beneficial, particularly, for soils with low organic matter content. Lastly, the chemical composition study of bat guano should be continued and expanded to achieve a deeper understanding of its application in agriculture.

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