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The Influence of Bat Guano on Peat Soil Properties in the Oil Palm Plantations

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ABSTRACT

Highlighting the role of bat guano as an organic fertilizer housing beneficial microbes for soil and plants. The research aimed to assess the effect of bat guano on bacterial diversity and chemical and nutrient properties of peat soil in the vicinity of a bat cave within oil palm plantation in West Sulawesi, Indonesia. Four samples, namely bat guano (BG), peat soil (PS), peat soil mixed with bat guano (PSM), and peat soil inside the cave (PSI) were assessed. Organic carbon, pH, total nitrogen, the C/N ratio, Cation Exchange Capacity (CEC), Base Saturation (BS), macronutrients, and micronutrients were measured across all samples. Bacteria from the samples were also isolated, and their capability in hydrolyzing urea, solubilizing phosphate, solubilizing potassium, and producing the Indole Acetic Acid (IAA) hormone was characterized. The influence of bat guano was found on the enhancement production of IAA hormone, pH, organic carbon, total nitrogen, C/N ratio, CEC, BS, macronutrients, and micronutrients. The results also demonstrated substantial bacterial community resemblance between PSM and BG in contrast to the original PS (3:1). Meanwhile, peat soil inside the cave was indicated unique and has bacterial diversity, which can hydrolyze urea, solubilizing phosphate, and potassium.

Keywords: Bacteria, bat guano, peat soil, soil fertility

INTRODUCTION

A wetland habitat known as a peatland is rich in organic matter that develops from decaying plant matter under low oxygen and waterlogging (Finlayson & Milton, 2018). According to Hergoualc'h et al. (2018), Indonesian peatlands are characterized by deep layers of carbon-rich peat soil, particularly in pristine conditions. Within the region, Indonesia boasts the largest expanse of peatland, comprising 20.6 million ha, equivalent to 10.8% of its total land area. These peatlands are distributed across multiple islands, with 7.2 million ha (35%) located in Sumatera, 6.6 million ha (32%) in Kalimantan, 0.6 million ha (3%) in Sulawesi, and approximately 6.2 million ha (30%) in Papua (Suryatmojo et al., 2019). The area of the peat ecosystem in Sulawesi for the protection function is 28,305 ha, which is divided into West Sulawesi 19,682 ha and Central Sulawesi 8.622; also, the cultivation function 34,985 ha, which is divided into West Sulawesi 22,794 ha and Central Sulawesi 12,192 ha (Anonym, 2017). In West Sulawesi, the peat soil falls into the category of organic peat, characterized by its reddish-brown color, abundant fiber content, some udecomposed wood, and the presence of fine particles and various humic compounds (Nurdin et al., 2021). According to Ritung and Sukarman (2016), the characteristic of peat in North Mamuju Regency, West Sulawesi, was deep peat (200–300 cm). This type of peat depth is suitable for oil palm cultivation.

Oil palm plantations extensively utilize Peatland in Indonesia due to the scarcity of arable land (Harris & Sargent, 2016). In 2021, the contribution of palm oil production to national economic benefit made it one of the major plantations in Indonesia, which covers an area of 14.62 million ha (SRD 2023). In West Sulawesi, regular oil palm plantations cover 25,000 ha, and irregular cover 4,000 ha (Sipayung, 2023).

The contribution of oil palm expansion to peatland deforestation in inland forests led to oil palm planting areas being located near caves. According to Newman et al. (2018), caves are the habitat for bats where a pile of bat guano is occasionally found in the natural caves. Bat guano is the by-product of the bat, with an abundance in carbon, nitrogen, potassium, phosphorus, macronutrients, micronutrients and vital minerals and beneficial microbes which support its role as compost activator as well as plant and soil fertilizer (Shetty et al., 2013; De Leon et al., 2018). Muryanto and Lidar. (2020) reported that guano fertilizer is derived from accumulated bat droppings aged within caves, blending with soil and undergoing decomposition by bacteria over time. This guano fertilizer is rich in N, P, and K, crucial in promoting growth, stimulating root development, and fortifying seedlings.

Typically, peat soil exhibits a low pH, a high capacity for cation exchange, limited base saturation, reduced concentrations of elements like K, Ca, Mg, and P, as well as diminished levels of microelements such as Cu, Zn), M, and B (Sasli, 2011). Guano fertilizer is known to enhance soil fertility due to its N (7-17%), P (8-15%), and K (1.5-2.5%) content, making it beneficial for promoting plant growth (Syofiani & Oktabriana, 2017). Guano supplied substantial nutrients to plants, aligning with findings from other research studies where the application of bat guano as a soil amendment led to enhanced crop productivity (Unal et al., 2018).

This study aims to determine the chemical and bacterial differences between bat guano, peat soil mixed with bat guano, and peat soil inside the cave. Moreover, the influences of bat guano on the bacterial diversity and chemical and nutrient properties of peat soil around bat caves in the oil palm plantations in West Sulawesi, Indonesia were also examined. This research also provides new information on the use of bat guano for the improvement of peat soil properties and its potential contribution to the growth of plants.

RESEARCH METHODS

Samples Collection

This research was a collaboration between BPPT and PT. Astra Agro Lestari from January – December 2013. The sample was taken on October 23, 2013. The sampling location was near the Goa Kareke Conservation, oil palm plantation Blok C14 PT Letawa, Tikke Raya, Pasangkayu, West Sulawesi Province, Indonesia, with coordinates -1.327710, 119.366954. Four samples of bat guano and peat soil were collected randomly from around the bat cave in the oil palm plantation. The samples consist of bat guano (BG), peat soil (PS), peat soil mixed with bat guano (PSM), and peat soil inside the cave (PSI). BG was taken from inside the bat cave. PS was taken from peat soil approximately 200 m from the bat cave. PSM was taken from peat soil flowed with bat guano approximately 20 m from the bat cave. PSI was taken from peat soil inside the bat cave approximately 30 m from a pile of BG. BG has a black color and moist texture. At the same time, PS was identified as hemic (half-decomposed) and brown, and some of the original material was still identified (fiber content). PSM and PSI were a combination of brown and black color.

Bat guano was taken from inside the cave using a sterilized shovel (with alcohol 90%) from a depth of 5 cm and was kept in a clipped plastic bag and labeled. Meanwhile, peat soil was taken using a sterilized PVC pipe (with alcohol 90%) with a diameter of 5 cm and length of 30 cm. The pipe was plugged vertically into the ground with a depth of around 15 cm and then rotated clockwise. The soil was removed from the pipe, kept in a clipped plastic bag, and labeled. Three replications of bat guano and peat soil were taken from three points and were combined into composite samples.

We isolated and characterized the bacterial communities from bat guano and peat soil samples by testing their ability to hydrolyze urea, solubilize phosphate and potassium, and produce Indole Acetic Acid (IAA) hormone. Nutrient and chemical analysis of bat guano and peat soil were also tested as the supporting data. The isolation and characterization of bacteria were conducted in the Laboratory of Development Technology Industry Agro and Biomedic (Laptiab), Puspiptek, Serpong, Indonesia. Chemical and nutrient analyses were conducted at the Indonesian Soil Research Institute (now part of the National Research and Innovation Agency).

Nutrient and chemical analysis

Nutrient and chemical analysis of the samples were collected to demonstrate the fertility of the soil, including soil pH, organic carbon, total nitrogen, the C/N ratio, Cations Exchange Capacity (CEC), Base Saturation (BS), macronutrients and micronutrients. Soil pH was measured by extraction H_2O method, C-organic was tested with the Walkley and Black method, N-total was performed with the Kjeldahl method, cation exchange capacity by extraction of 1 N NH_4OAc pH 7 method, and base saturation was determined by calculation. The availability of macronutrients and micronutrients was analyzed using the Morgan-Wolf method.

Bacterial Isolation

A 10 g of samples were placed into 90 mL of sterile water and homogenized in an orbital shaker for 3 hours to provide mechanical disaggregation of the bacterial cell. Serial dilutions were prepared to 10^{-8}. From each serial dilution, 0.1 mL of suspension was transferred to Nutrient Agar (NA) medium (triplicate) as a selected medium for bacteria. The colonies were monitored after incubation for 24–48 hours at 28°C. Selected bacteria were purified and characterized, including urea hydrolyzing test (Brink, 2010), phosphate solubilizing test, potassium solubilizing test, and Indole Acetic Acid (IAA) test.

Urea hydrolysis test

Urea hydrolysis was tested using a urea broth medium. One loop of the isolate was inoculated into a tube containing a urea broth medium (triplicate). The changing color was observed after 24 hours of fermentation. A bright pink color indicated urease production throughout the broth.

Qualitative measurement of phosphate solubilization

The isolates were checked for phosphate solubilizing ability on solid Pikovskaya medium (Glucose 10.0 g, $Ca_3(PO_4)_2$ 5.0 g, $(NH_4)_2SO_4$ 0.5 g, NaCl 0.2 g, $MgSO_4.7H_2O$ 0.1 g, KCl 0.2 g, yeast extract 0.5 g, $MnSO_4.H_2O$ 0.002 g, $FeSO_4.7H_2O$ 0.002 g, agar 15.0 g, distilled H_2O 1000 mL, and pH 7.0 were used). Each bacterial isolate was aseptically transferred onto the Pikovskaya medium (triplicate). After incubated at 27°C for 7 days, the solubilization of phosphate was observed. The diameter of the clear zone was measured at 3 different points (in millimeters). The solubility index was calculated by comparing clear zone diameter and colony diameter.

Qualitative measurement of potassium solubilization

The isolates were checked for potassium solubilizing ability on Aleksandrov medium (Glucose 5 g, $MgSO_4.7H_2O$ 0.1 g, $FeCl_3$ 0.005 g, $CaCO_3$ 0.1 g, KCl 2 g, $Ca_3(PO_4)_2$ 2 g, agar 15 g, distilled H_2O 1000 mL, and pH 7.2±0.2 were used). Each bacterial isolate was aseptically transferred onto Aleksandrov medium (triplicate). After incubating at 27°C for seven days, the solubilization of potassium was observed. The diameter of the clear zone was measured in 3 different points (in millimeters). The solubility index was calculated by comparing clear zone diameter and colony diameter.

IAA hormone test

Selected bacteria grown in YEM (*Yeast Extract Mannitol*) *broth* were supplemented with 2,5 mg mL L-tryptophan^{-1} (triplicate). After incubated for 48 hours in the shaker with 110 rpm agitation, 0.5 mL supernatant was taken out and added with 1 mL of Salkowski reagent (1 mL of FeCl 0.5 M in 50 mL of perchloric acid ($HClO_4$) 35%) with the comparison 1:2. The mixture was left for 25 minutes. Quantification of IAA was measured by spectrophotometer at wavelength 530 nm. The development of a pink color indicated IAA production.

RESULTS AND DISCUSSION

Chemical and nutrient analysis

Chemical analysis

Based on the pH measurement, the pH condition of bat guano and peat soil ranged from 5.5 – 7.4 with classification: 5.1 – 5.5 strongly acidic; 5.6 – 6.5 moderately acidic; 6.6 – 7.3 neutral; 7.4 – 7.8 slightly alkaline (SSDS, 2017). In general, peat soils are somewhat acidic. According to Suryani et al. (2021), the pH of peat soil varied from acidic to very acidic (pH 2.5–5.4). High levels of organic acids, particularly humic and fulvic acids, are also released during decomposition, causing high levels of peat acidity.

The sample order of pH value from low to high was PS < PSM < PSI < BG. The effect of bat guano was seen on the higher pH of PSM than PS. According to Dariah et al. (2014), tropical peat soil generally has high acidity with a pH of 3 – 5. In contrast, the pH level of fresh guano is between 5.1 and 7.3 (Wurster et al., 2015).

The vital component of soil quality is soil organic carbon (SOC), which also influences soil's biological and physical characteristics (Ge et al., 2013; Esmaeilzadeh et al., 2014). According to the organic carbon measurement, the range of all samples was between 2.05 and 9.01%. Organic carbon value e" 1.7% is considered high fertility (Musinguzi et al., 2016). It means all the samples were fertile. Organic carbon enhancement of PSM was also evidence of bat guano impact. Based on (Suryani et al., 2021), the high C-organic content is caused by the accumulation of plant remains that have not yet decomposed in peat soil.

Total nitrogen content reflects the level of organic material. In the soil, nitrogen is formed by

(1) organic matter, (2) nitrogen fixation by a microorganism, (3) fertilizer, and (4) rainwater (Hardjowigeno, 2003). Total nitrogen of the samples ranged from 0.21 – 0.84. Total nitrogen of PSI was categorized as moderate, while BG and original PS were classified as high, and PSM was rated as very high. The total nitrogen content of PSM seems to be not influenced by bat guano.

The C/N ratio could be estimated using bat guano and soil samples' organic carbon and total nitrogen values. According to Ge et al. (2013), the balance of carbon and nitrogen in the soil is shown by the C/N ratio. Naturally, the C/N ratio follows the organic carbon and total nitrogen, ranging from 9-11. The C/N ratio of PS and PSI were categorized as low, whereas BG and PSM were at moderate levels. The sample order of the C/N ratio from low to high was PS < PSI < BG = PSM. From the data on the C/N ratio, bat guano is contributing to the organic carbon enhancement of PSM.

According to Tomašiæ et al. (2013), CEC measures soil properties in attracting, retaining, and holding the exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+}). Therefore, this parameter of soil indirectly affects soil fertility. Based on CEC measurement, the bat guano and soil samples range was 19.6 – 31.18 %. CEC values of BG and PSI were categorized as moderate, while PSM and PS were categorized as high. The sample order of CEC percentage from low to high was PSI < BG < PS < PSM. This finding suggests that bat guano did not affect the CEC values of PSM.

BS is the indicator of acid and base cations balance adsorbed by soil CEC (Bache, 2008). BS is determined as the base cation sum divided by the total CEC. BS is closely related to pH, and soil pH increases as base saturation increases (Havlin, 2005). From the calculation, the BS of all the samples was over 100 % (very high), except the original PS, only 97 % (high). The impact of bat guano is also seen in the increase of BS values of PSM.

Nutrient analysis

One of the most critical measures of soil 1fertility is the nutrient condition of the soil. Soil nutrient testing measures the macronutrient and micronutrient levels of soil. Misra et al. (2019) reported that the content of bat guano was macronutrients (N, P, K, Ca, Mg, S, C, H, and O) and micronutrients (Al, Cl, Fe, Na, Si, Ti, B, Mn, Cu, Zr, and Zn). Compared to other animal manures like poultry, cow, and sheep, bat guano has higher nitrogen and phosphorus, while bird manure, bat guano is higher in nitrogen and potassium (Sridhar et al., 2006; Jayasvasti & Jayasvasti, 2018; Marwa et al., 2021). Moreover, Nelvia. (2018) stated that the low fertility of peat soil was expressed in the low availability of macronutrients (N, P, K, Ca, and Mg) and micronutrients (Fe and Mo). Table 3 shows that BG's macronutrient and micronutrient availability was the highest among other samples, except for the NO_3 and available Mg. Aside from the average content of macronutrients and micronutrients of PSM, the presence of NH_4, available-K, available-Ca, and available-Mn were low. These experiments confirmed that bat guano enhances the macronutrients (available-P, available-S) and micronutrients (available-Fe, available-Cu, available-Zn, and available-B) of PSM. The macronutrients and micronutrients contained in the PSI were also average but low in available Mg and available Fe.

Furthermore, the evidence from chemical and nutrient analysis has shown that bat guano seems to be contributing to the increase of pH, C/N ratio, and BS values of PSM. The difference in results between PSM and PSI in organic carbon, total nitrogen, and CEC was probably due to peat soil mixed with bat guano in the open space, while the cave is semi-closed. Kosznik-Kwasnicka et al. (2022) reported that a cave is a unique habitat in terms of physical, biological, and chemical properties due to biotic and abiotic factors such as water, sunlight, airflow, and nutrient availability, as interaction with living organisms outside the caves.

Bacterial isolates and morphological characteristics

A total of eighteen bacteria were isolated from BG (isolate: - 1, 2, 3, 4, and 5); PS (isolate: - 6, 7, 8, 9, and 10), PSM (isolate: - 11, 12, 13, 14, and 15) and PSI (isolate: - 16, 17, and 18) using NA medium.

The bacterial isolates morphologies varied between luster, color, and elevation (Table 1). The colonies of two isolates (1 and 8) had glossy luster, milky white color, and flat elevation. The colonies of two isolates (2 and 11) had a slightly glossy luster, tawny color, and flat elevation. The colonies of two isolates (3 and 6) had a slightly glossy luster, milky white color, and flat elevation. The colonies of two isolates (4 and 13) had glossy luster, cloudy white color, and convex elevation. The colonies of two isolates (5 and 15) had glossy luster, milky white color, and convex elevation.

The colonies of one isolate (7) had a glossy luster, cloudy white color, and slightly convex elevation. The colonies of two isolates (9 and 12) had no glossy luster, cloudy white color, and flat

Table 1. Bacterial diversity of samples.

Isolate	Origin of samples	Luster	Color	Elevation
1	BG	Glossy	Milky white	Flat
2	BG	Slightly glossy	Tawny	Flat
3	BG	Slightly glossy	Milky white	Flat
4	BG	Glossy	Cloudy white	Convex
5	BG	Glossy	Milky white	Convex
6	PS	Slightly glossy	Milky white	Flat
7	PS	Glossy	Cloudy white	Slightly convex
8	PS	Glossy	Milky white	Flat
9	PS	Not glossy	Cloudy white	Flat
10	PS	Glossy	Tawny	Slightly convex
11	PSM	Slightly glossy	Tawny	Flat
12	PSM	Not glossy	Cloudy white	Flat
13	PSM	Glossy	Cloudy white	Convex
14	PSM	Glossy	Cloudy white	Slightly convex
15	PSM	Glossy	Milky white	Convex
16	PSI	Mucous	White	Convex
17	PSI	Not glossy	Yellow	Flat
18	PSI	Glossy	White	Convex

BG: bat guano; PS; peat soil; PSM=bat guano-mixed peat soil; PSI= peat soil within the cave (PSI)

elevation. The colonies of one isolate (10) had glossy luster, tawny color, and slightly convex elevation. The colonies of one isolate (14) had glossy luster, milky white, and slightly convex elevation.

The colonies of one isolate (16) had mucous luster, white color, and convex elevation. The colonies of one isolate (17) had no glossy luster, yellow color, and flat elevation. The colonies of one isolate (18) had glossy luster, white color, and convex elevation.

Interestingly, bacteria from PSM showed more similar characteristics to bacteria from BG than the original PS (3:1). As the guano decomposes, the microorganisms within it engaged in a variety of biogeochemical processes (both organic and inorganic nutrient cycles), which resulted in pH and nutritional composition changes as well as changes in the availability of oxygen and other environmental elements. These changes may determine the new bacterial diversity (De Leon et al., 2018; Newman et al., 2018). It might be why bacteria from PSM differ from the original PS.

All the bacteria isolated from PSI have different morphologies from other samples. A unique environment within the cave, such as low to no light, relatively high humidity, relatively stable temperature, and low oxygen conditions, might affect the native microbes that live in it (Kamal et al., 2011; Newman et al., 2018).

Urea hydrolysis testing

The characterization results of these eighteen pure bacterial isolates, which comprise of urea hydrolysis test, phosphate solubilization test, potassium solubilize test, and Indole Acetic Acid (IAA) hormone test, were illustrated in Table 2. Urease is a soil enzyme that determines soil quality (Miśkowiec & Olech, 2020). The crucial process of a nutrient cycle by soil microorganisms will be accelerated with the presence of urease (Koçak, 2020).

The results showed that only one isolate (18) from PSI had a positive urea hydrolysis reaction, indicated by color-changing into purplish-red after incubation. In contrast, other samples did not show any reaction. This indicator showed that the bacteria (18) can break down urea into ammonia and carbon dioxide (CO_2) and increase pH to alkaline (Zoheir et al., 2013). In contrast, the other isolates (16 and 17) cannot hydrolyze urea. The Positive urease activity of bacteria isolated from PSI also correlated to the pH value of the soil (Table 3). PSI has a pH of 6.9 (neutral). According to Mobley. (2001), urease activity increases pH to near-neutral. Unfortunately, bat guano had no impact based on the hostile urease activity of BG, PS, and PSM samples.

Phosphate Solubilization Activity

As shown in Table 2, the colonies of four isolates (14, 15, 16, and 18) had expressed phosphate solubilization on Pikovskaya medium (13.64%; 38.24%; 41.29%; 12.74%). The larger diameter of the halo zone demonstrated a higher ability to dissolve phosphate (Gupta et al., 2022). The bacteria sequence of phosphate solubilizing activity from low to high were 18 < 14 < 15 < 16. Although the colony of isolate 15 has similar characteristics to isolate five from BG, the last one did not form a clear zone on the medium.

In this study, the two bacteria from PSM and PSI were found to have phosphate-solubilizing activity. In contrast, bacteria from the original PS and BG did not show any activity of PSB. These results indicated that bat guano did not influence the phosphate solubilization activity of bacteria from PSM. The growth of phosphate solubilization bacteria (PSB) could also be affected by the C/N ratio. When the medium has the optimal C/N ratio, it can enhance the growth and activity of PSB (Nosrati et al., 2014). Both extremely low and excessively high C/N ratios can hinder the growth of PSB; hence, it is crucial to maintain appropriate levels of carbon and nitrogen sources for optimal PSB growth (Syafitri et al., 2022).

Potassium Solubilization Activity

From this study, only the colonies of two isolates (16 and 18) from PSI demonstrated the ability to solubilize the potassium on the Aleksandrov medium (47.01% and 20.67%). At the same time, other bacteria show an adverse reaction to the medium. The absence of a clear zone around bacterial colonies of BG on the medium showed no effect of bat guano on the activity of potassium-solubilizing bacteria from PSM.

From phosphate and potassium solubilizing activities, two isolates from PSI (16 and 18) could dissolve phosphate and potassium. One of them (16) seems to be the most active in secreting organic acids and reaches the highest efficiency of phosphate and potassium solubilities (41.29% and 47.01%). The C/N ratio also influenced the activity of potassium solubilization. Setiawati et al. (2019) reported that the C/N ratio in the media could affect the activity of Potassium and Phosphate Solubilizing Bacteria.

Table 2. Summary of characterization.

Isolate	Origin of samples	Urea hydrolysis reaction	Efficiency phosphate solubility (%)	Efficiency potassium solubility (%)	IAA concentration (μg mL^{-1} culture)
1	BG	-	-	-	0.93
2	BG	-	-	-	8.43
3	BG	-	-	-	18.11
4	BG	-	-	-	2.71
5	BG	-	-	-	17.14
6	PS	-	-	-	0.25
7	PS	-	-	-	4.86
8	PS	-	-	-	17.57
9	PS	-	-	-	2.71
10	PS	-	-	-	9.96
11	PSM	-	-	-	25.57
12	PSM	-	-	-	0
13	PSM	-	-	-	1.18
14	PSM	-	13.64	-	17.46
15	PSM	-	38.24	-	20.82
16	PSI	-	41.29	47.01	47.14
17	PSI	-	-	-	5.61
18	PSI	+	12.74	20.67	23.00

BG: bat guano; PS; peat soil; PSM=bat guano-mixed peat soil; PSI= peat soil within the cave (PSI)

Table 3. Nutrient and chemical composition of material used.

Parameter	BG	PS	PSM	PSI
pH	7.4	5.5	5.8	6.9
Organic carbon (%)	7.14	6.22	9.01	2.05
Total nitrogen (%)	0.64	0.69	0.84	0.21
C/N ratio	11	9	11	10
CEC (%)	20.65	29.85	31.18	19.6
BS (%)	>100	97	>100	>100
The availability of macro and micronutrients (ppm)				
NH_4	21.3	2.1	1.6	1.9
NO_3	58	70	84	591
P	1846.8	6.3	20.6	365.4
K	495	470	106	289
Ca	63.272	14.626	9.709	28.034
Mg	250	805	794	142
S	81	28	37	68
Fe	37	27	34	14
Mn	36.9	1.2	0.4	1
Cu	11.9	0.5	5.9	9.5
Zn	68.8	2.3	33.3	11
B	8.5	0.8	2	1.9

BG: bat guano; PS; peat soil; PSM=bat guano-mixed peat soil; PSI= peat soil within the cave (PSI)

IAA hormone testing

Almost all of the bacteria from BG, PS, PSM, and PSI samples produced indole-3-acetic acid. The data pointed out that PSI (16) was the best producer, indicating that bacteria had a great capacity to promote plant growth. Interestingly, although some colonies have similar morphologies, the IAA production amount differed. From the results, the IAA production of bacteria from PSM has proven to be influenced by bat guano due to the enhancement of IAA value.

The amount of IAA that different species and strains of bacteria create varies depending on the culture, growth period, and substrate availability (Sridevi & Malllaiah, 2007). According to Datta and Basu (2000), IAA helps plants absorb nutrients by lengthening their roots and increasing the number of root hairs and laterals.

Bat guano only impacted bacterial diversity and IAA synthesis, according to the morphologies and characterizations of all the bacteria isolated from soil and bat guano. On the contrary, the impact of bat guano was not found in the hydrolyzing urea, solubilizing phosphate, and potassium activities. This study also revealed that bat guano is affecting peat soil in open places rather than caves. Peat soil inside the cave seems different and has bacterial diversity, such as hydrolyzing urea solubilizing phosphate and potassium. Kosznik-Kwasnicka et al. (2022) reported that caves have an ecosystem with highly specialized microorganisms.

CONCLUSIONS

The influence of bat guano on peat soil fertility proves that bat guano is a potential biofertilizer due to its rich source of macronutrients and micronutrients. The low nutrient status of peat soil has transformed into fertile soil with the support from bat guano, which is confirmed by the higher pH, carbon, total nitrogen, C/N ratio, CEC, BS, and macronutrients (P, S) and micronutrients (Fe, Cu, Zn, B) than the original peat soil.

From this study, bat guano increased the diversity of bacteria in the peat soil. It was observed from the high similarity morphologies of bacteria colonies from peat soil mixed with bat guano to bat guano than peat soil (3:1). The influence of bat guano was also found on the enhancement production of IAA hormone of bacteria from peat soil mixed with bat guano.

The research also shows that the morphology of bacteria from peat soil inside the cave is unique. This statement is also confirmed by the fact that only one bacteria from peat soil inside the cave can break down urea into ammonia and carbon dioxide (CO_2) and increase pH to an alkaline-positive urea hydrolysis reaction. The colonies of bacterial isolates from peat soil inside the cave also exhibited the ability to solubilize soil phosphate and potassium and produce IAA hormone.

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