Oregon Department of Agriculture
Bat Guano: Definition and Characteristics

> "In the early days of the trade in guano, many unprincipled middlemen found it highly profitable to adulterate it. . . . Owing to the fact that there was at the outset no official inspection of such materials, the way of the transgressor was exceedingly easy."
> – H.J. Wheeler, 1913

Purpose
Oregon's Fertilizer Law [Oregon Revised Statute (ORS) Chapter 633] includes a requirement for accurate labeling of fertilizers, agricultural minerals, agricultural amendments, and lime products. Requirements include a derivation statement "declaring the sources for all primary nutrients, secondary nutrients and micronutrients guaranteed" [ORS 633.321(1)(g)]. Ingredients listed on the label or labeling must be acceptable to the department [ORS 633.321(6)].

Products with inaccurate derivation statements may be in violation of statutes prohibiting mislabeling [ORS 633.366(1)(a)], false or fraudulent applications [ORS 633.366(1)(g)], and product adulteration [ORS 633.366(1)(c)].

Regulatory Definitions
Regulatory programs are based on definitions. Definitions describe the components of the regulatory framework. For consistency and fairness, regulatory definitions of physical materials must be concise, clearly describing characteristics that distinguish a material from similar materials.

Currently, in the absence of a definition for bat guano in Oregon statute or rule, the Oregon Department of Agriculture Fertilizer Program (Department) uses the definition provided by the Association of American Plant Food Control Officials (AAPFCO). In the AAPFCO Official Publication bat guano is defined as:

> N-11 Bat guano – is partially decomposed bat manure (*Official 1951*) [Slater (ed.), 2016].

The "N" designation indicates AAPFCO defines the material as a source of the plant nutrient nitrogen [Slater (ed.), 2016].

Based on recent information and research, the Department is revising this definition to promote greater accuracy in describing products.

A Brief History of the Term "Guano"
Some indigenous people in Peru and Chile used the thick deposits of seabird excrement, which they called "huanu," to fertilize their crops (R.S.F., 1859; Foster and Clark, 2009). The Spanish adopted the term, spelling it "guano." Although the value of guano as fertilizer was known in Europe from the early 1600s, significant commercial exploitation did not begin until the 1840s (R.S.F., 1859).

Bat guano wasn't widely used in commercial agriculture in the United States until the beginning of the 20th century. In 1898 the State of Connecticut reported testing a single sample of bat guano (Connecticut Experiment Station Report, 1899). By 1912, one Texas company was using bat guano as the raw material for all their fertilizer blends (Brown, 1912). A study of bat guano deposits in Puerto Rico (1918) noted agricultural bulletins on bat guano deposits in Cuba, the United States, India, Uruguay, Malaysia, and South Africa, with the earliest report dating from 1903 (Gile and Carrero, 1918).

Some agricultural experiment station bulletins of this period limit "bat guano" to relatively fresh material that may still have visible fecal pellets (Fraps, 1908; Missouri Agricultural Experiment Station, 1921). Others create classes to differentiate material that can be readily identified as excrement from the layer immediately below—a mix of decomposed manure and mineral materials—or a deeper layer of mineral material enriched by nutrients percolating down from the guano above (Gile and Carrero, 1918; Missouri Agricultural Experiment Station, 1921).

It is uncertain when the term "guano" was expanded to include bat excrement, but some maintained is should properly be applied only to the excrement of birds, while accepting its common use was much wider (Wheeler, H.J. 1913; Missouri Agricultural Experiment Station, 1921). Others used "guano" as a general term for dried manure, such as "sheep guano," even while noting the term was misused (Robinson, 1925).

For many, the term became a general term for fertilizing materials, such as "fish and bone guano," "fish flesh & fowl guano," "slaughter house bone guano," "cotton-seed meal guano" (North Carolina Department of Agriculture, 1908; Virginia Department of Agriculture and Immigration, 1919). This trend toward a more generic use of the term was probably increased by companies with names such as the "Peruvian Guano Corporation" or "Royster Guano Company" supplying a wider range of materials, such as sulfate of potash, "bone fertilizer," muriate of potash, and "acid phosphate" (North Carolina Department of Agriculture, 1909; Virginia Department of Agriculture and Immigration, 1919).

Literature Review

Recent journal articles on bat guano note a wide range of differences in the nutrient content and characteristics of various guano and guano-derived materials (Bird et al., 2007; Emerson and Roark, 2007; Mizutani et al., 1992a; Studier et al., 1991; Studier et al. 1994a). A variety of factors influence the nutrient content of guano, including species, feeding strategy (fruit, insects, blood, fish, omnivory), seasonal variations in diet, maternity status, and location (Bird et al., 2007; Emerson and Roark, 2007; Goveas et al., 2006; Mizutani et al., 1992a; Studier et al. 1994a, Studier et al. 1994b; Wurster et al. 2007)

As an example, a study comparing the guano of the fruit-eating Rodrigues flying fox (*Pteropus rodricensis*), the insect-eating Mexican free-tailed bat (*Tadarida brasiliensis*), and the blood-feeding common vampire bat (*Desmodus rotundus*) found those diets higher in nitrogen produced guano higher in nitrogen, with similar correlations between diet and phosphorus and carbon content (Emerson and Roark, 2007).

Similarly, a study examining the nutrient content of guano within a single species found changes in diet affected the nutrient content of the guano. The greater bulldog bat (*Noctilio leporinus*) is a fishing bat with a relatively wide diet. This study found large differences in the nutrient content of guano when the bats fed on fish alone, crab alone, moths alone, or beetles alone. Depending on diet, the nitrogen content of guano ranged from more than 16% (moth) to less than 4% (crab) (Studier et al. 1994a). Similarly, a diet of crab, with large amounts of calcium in the shell, resulted in guano with a calcium content of more than 11%, while guano from a diet of moths or beetles yielded guano with a calcium content of less than 0.5% (Studier et al. 1994a).

At least in part a function of diet, it is not particularly surprising the organic matter content of bat guano also varies widely with location and species (Table 1).

Table 1: Variation in Organic Matter Content

Species	Organic Matter (%)	Diet	Sample Location	Source
Rodrigues flying fox (*Pteropus rodricensis*)	88.8	Fruit	Unspecified Zoo, USA	Emerson and Roark, 2007
common vampire bat (*Desmodus rotundus*)	88.36	Blood	Unspecified Zoo, USA	Emerson and Roark, 2007
Mexican free-tailed bat (*Tadarida brasiliensis*)	84.32	Insects	Florida, USA	Emerson and Roark, 2007
Fruit bat guano (not specified)	60	Fruit	Israel	Shahack-Gross et al., 2004
Insectivorous bat (not specified)	53-65	Insects	Israel	Shahack-Gross et al., 2004
Schneider's leaf-nosed bat (*Hipposideros speoris*)	45.6	Insects	Mangalore, Karnataka, India	Sridhar, et al., 2006

Once bat guano is deposited, insects, bacteria, and fungi begin the decomposition process. This breaks down organic matter, releasing carbon dioxide (CO_2) and ammonia (NH_3) (McFarlane et al. 1995; Mizutani, 1984; Mizutani, et al., 1992a; Mizutani, et al., 1985b). In a guano deposit, the topmost inches will have the highest organic matter content, as it is incompletely decomposed. The organic matter content declines with depth, and is generally completely consumed within the top few feet (Shahack-Gross et al. 2004; Bird et al. 2007; Wurster et al. 2007).

As the organic material decomposes and much of the carbon and nitrogen are consumed or released, the remaining, largely acidic, guano materials interact with material weathered in the cave, to form new, largely phosphatic, authigenic (secondary) minerals with other elements from guano, such as aluminum, potassium and iron (Bridge, 1973; Gile and Carrero, 1918, Giurgiu, et al., 2013, Giurgiu and Tămaş, 2013, Shahack-Gross et al. 2004, Tămaş, Mihet, and Giurgiu, 2014).

In a study of guano deposits in Israel, Shahack-Gross et al. (2004) reported large differences in organic matter content between guanos (53-65%) and authigenic mineral materials derived from guano (6.6 to 16.7% by weight). The organic matter content was the greatest near the top of the deposit, where the decomposition was less complete (Shahack-Gross et al. 2004).

For fertilizers, guarantees for phosphorus are made for a compound, available phosphate (P_2O_5), rather than elemental phosphorus. As defined by AAPFCO, available phosphate is the sum of the water soluble phosphate and citric acid soluble phosphate (Slater (ed.), 2015). There are often significant differences between the amounts of total phosphorus (P) and available phosphate (P_2O_5).

At least one study of bat guano reports elemental phosphorus values of over 12% for Rodrigues flying fox and Mexican free-tailed bat, but this study does not report values for available phosphate (Emerson and Roark, 2007). A sample of straw-colored fruit bat (*Eidolon helvum*) guano, collected at the Oregon Zoo and analyzed by the Department, found a total phosphorus (P) value of 1.14% and available phosphate (P_2O_5) values of 2.1%.

Oregon Department of Agriculture Sampling

Chemical Testing

To better understand the materials currently marketed as guano, the Department tested products labeled as entirely guano purchased from retail locations. The analytical results of our initial sampling, ordered by organic matter (OM) content, are shown in Table 2, below:

Table 2: Analytical Results of Marketplace Bat Guano Samples

Product Name	OM (%)	Total Nitrogen (N) (%)	Available Phosphate (P_2O_5) (%)	Soluble Potash (K_2O) (%)	Calcium (Ca) (%)
10-3-1 Bat Guano	79.20%	11%	3.8%	1%	1.22%
10-1-1 Mexican Bat Guano	73.10%	11%	4.1%	2%	3.1%
10-1-1 Mexican Bat Guano	73.00%	11.2%	3.9%	1.2%	3.6%
9-3-1 Bat Guano	60.50%	10%	3.6%	1.5%	2%
10-4-1 A/P Bat Guano	58.90%	9.89%	4.6%	1.9%	3.8%
10-3-1 Bat Guano	52.80%	6.9%*	3.5%	1.4%	7.95%
10-3-1 Bat Guano	51.10%	6.8%*	3.7%	1.5%	7.4%
1-10-1 Jamaican Bat	13.40%	0.676%	13.0%	0.60%	21%
0.4-6-0.5 Phos Bat Guano	10.90%	1.03%	2.4%*	0.89%	15%
0-10-0 Jamaican Bat	9.31%	0.60%	13%	0.38%	18%
0-13-0 High Phos	8.12%	0.6%	3.0%*	0.6%	12%
0-7-0 Fossilized Bat Guano	7.90%	0.48%	3.3%*	0.5%	22%
0-13-0 Philippine 100% Guano	7.80%	< 0.48%	7.1%*	< 0.1%	4.8%
0.5-13-0.2 Indonesian Bat	6.81%	0.0311%	12.7%	< 0.15%	22%
0-7-0 Phos Bat Guano	5.68%	0.16%	8.7%	<0.06%	19.4%
0-13-0 Philippine 100% Guano	3.73%	0.0618%	6.6%*	<0.083%	4.2%

Note: Samples indicated with an asterisk are deficient (the difference between the claim and analytical results exceeds the investigational allowance) under Oregon statute.

Based on OM contents, the sixteen products sampled sort into two groups (as indicated by broken line), seven products with OM contents greater than 50%, and nine products with OM contents less than 14%. No products had OM contents less than 50% but greater than 14% OM.

Nitrogen content and organic matter content greater than 50% appear to be highly correlated. Those samples within the higher OM group have total nitrogen (N) contents ranging from 6.8% to 11% total nitrogen (N). This is consistent with descriptions of the topmost layers of guano deposit, as discussed above. The highest total nitrogen (N) content of any product in the lower OM group was 1.03%.

There does not appear to be a strong relationship between available phosphate (P_2O_5) and OM content. Products in the lower OM group claim available phosphate (P_2O_5) contents ranging from 6% to 13%, although lab analysis found five of the nine products in this group to be deficient (indicated with asterisk). Analysis showed three of the products in the lower OM content group with available phosphate (P_2O_5) contents less than 3.5%. None of the products in the higher OM group had available phosphate (P_2O_5) contents less than 3.5%.

Physical Appearance
Samples from the higher and lower OM groups also differ in physical appearance and characteristics. Compared to products in the lower OM group, products from the higher OM group are darker in color with an appearance similar to humus, often with visible fecal pellets. Products in the lower OM group are generally tan to orangish in color, with a powdery or granular appearance, similar in appearance to samples of phosphate rock. Products in the lower OM group also have a noticeably higher volumetric mass density than those in the higher OM group.

Due to the similarity in appearance to phosphate rock, the Department ran the same analyses on two samples of phosphate rock (Table 3). The results, including calcium contents, are generally consistent with the range of values for some of the low OM group of bat guano samples.

Table 3: Analytical Results Phosphate Rock Samples

Product Name	OM (%)	Total Nitrogen (%)	Available Phosphate (P_2O_5) (%)	Soluble Potash (K_2O) (%)	Calcium (Ca) (%)
0-3-0 Idaho Phosphate	11.40%	0.37%	2.5%	1.26%	19%
0-3-0 Florida Phosphate	4.05%	0.07%	3%	0.37%	17.3%

DNA Testing.
The Department had four bat guano samples—two from the higher OM group and two from the lower OM group—analyzed for bat DNA by the Northern Arizona University Bat Ecology and Genetics Lab (Table 4). Bat DNA was found in the two samples from the higher OM group. No bat DNA was found in the two samples from the lower OM group.

Table 4: DNA Analysis of Four Bat Guano Samples

Product Name	OM (%)	Total Nitrogen (%)	Available Phosphate (P_2O_5) (%)	Soluble Potash (K_2O) (%)	Bat DNA found?
10-3-1 Bat Guano[1]	79.20%	11%	3.8%	1%	Y
10-3-1 Bat Guano[2]	52.80%	6.9%*	3.5%	1.4%	Y
0-13-0 High Phos	8.12%	0.6%	3.0%	0.6%	N
0-10-0 Jamaican Bat	9.31%	0.60%	13%	0.38%	N

10-3-1 Bat Guano[1] - DNA of *Tadarida brasiliensis*, Mexican free-tailed bat (an insectivorous species found throughout much of the Americas) and *Myotis velifer*, Cave myotis, (an insectivorous bat found from the American SW through Central America) (Walker, F.M. personal communication, Feb. 23, 2016).
10-3-1 Bat Guano[2] - DNA of *Chaerephon plicatus*, Wrinkle-lipped Free-tailed bat (an insectivorous bat broadly distributed throughout SE Asia), *Eonycteris spelaea*, Cave nectar bat (a nectar-feeding bat broadly distributed throughout SE Asia), and *Rousettus leschenaultia*, Leschenault's rousette (a fruit-eating species found broadly distributed in SE Asia and India) (Walker, F.M. personal communication, Feb. 23, 2016).

It should be noted that while the absence of bat DNA is an indicator the material is *not* bat guano, the presence of bat DNA is not proof the material *is* bat guano. For example, while it might be possible to find bat DNA in a mix containing 0.5% bat guano and 99.5% phosphate rock, describing the resulting mix as "bat guano" would not be accurate.

Analysis for Mineral Content
In addition to other testing, the four samples sent for DNA analysis were also sent for quantitative microscopy to determine the mineral content of the samples. The samples were analyzed by using optical crystallography/polarized light microscopy (PLM), capillary fusion and CCD chip digital mapping coupled with PLM instrumentation (Cassell, S. personal communication, March 23, 2016).

Table 5: Analysis of Four Bat Guano Samples for Mineral Content

Product Name	OM (%)	Total Nitrogen (N) (%)	Available Phosphate (P_2O_5) (%)	Soluble Potash (K_2O) (%)	Bat DNA found?	Mineral Content (%)
10-3-1 Bat Guano	79.20%	11%	3.8%	1%	Y	~3.31%
10-3-1 Bat Guano	52.80%	6.9%*	3.5%	1.4%	Y	~3.80%
0-13-0 High Phos	8.12%	0.6%	3.0%	0.6%	N	~100%
0-10-0 Jamaican Bat	9.31%	0.60%	13%	0.38%	N	~100%

The two samples from the higher OM group had relatively little mineralization (less than 4%) and visible chitinous insect remains. Based on organic matter content, mineralization, and physical appearance, it appears these materials may be accurately described as bat guano.

In contrast, the two lower OM samples were nearly completely mineralized (~100%). On physical examination one sample did have “traces of woody chips,” but this was the only organic material identified in the lower OM samples. Based on testing, there is no support for the claim the source of these materials is bats.

Results and Discussion

Research addressing bat guano describes general characteristics of undecomposed guano, and the process by which nutrients dissolved from guano join with existing mineral materials.

The physical and chemical characteristics of the lower OM group of bat guanos sampled are consistent with mineral materials, rather than fresh or partially decomposed guano. The test results for a subset of this group for bat DNA and mineralization found no evidence to support the claim these materials originated with bats. While it is not impossible guano might have contributed to the nutrient content of some of these mineral materials, it is clear these materials are not themselves, guano.

Based on the characteristics of these materials and AAPFCO definitions, it appears the most appropriate descriptor for these materials is phosphate rock:

> P-13 Phosphate rock – is a natural rock containing one or more calcium phosphate minerals of sufficient purity and quantity to permit its use, either directly or after concentration, in the manufacture of commercial products (*Official, 1952*). [Slater (ed.), 2016].

For the purposes of a regulatory program, these lower OM materials are indistinguishable from phosphate rock or similar minerals. There is no test method readily available to regulatory programs that supports the claim the source of these materials is bat guano. Based on the results of testing, to describe these materials as bat guano would be mislabeling.

Based on the literature reviewed and the results of laboratory analyses, the Department is revising the definition of bat guano used for product registration in Oregon, as follows:

> Bat guano – is partially decomposed bat excrement. Bat guano has an organic matter content greater than 40%, is a source of nitrogen, and may contain up to 6% available phosphate (P_2O_5).

Materials that are inconsistent with this definition may not be claimed as bat guano. For product registration of bat guano products claiming available phosphate (P_2O_5), the registrant must provide an analytical report for organic matter content and the percentage of available phosphate (P_2O_5), (determined by analysis, not calculation) for the same sample. If marketplace samples determine the product no longer meets the definition above, it will be considered mislabeled and enforcement action will be taken.

The Department has been asked if materials from the lower OM group may be termed "fossilized bat guano." For two reasons, the answer is "no." First, there is no supporting evidence to support the claim these materials were ever bat guano. Second, to avoid descriptions that are potentially misleading, the Department no longer accepts ingredients claiming to be a fossilized material, such as "fossilized kelp," "fossilized coral," or "fossilized bat guano." The process of fossilization replaces organic material with a mineral cast of the object. Just as petrified wood is stone, not wood, these materials are rocks and minerals, not their original organic matter.

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