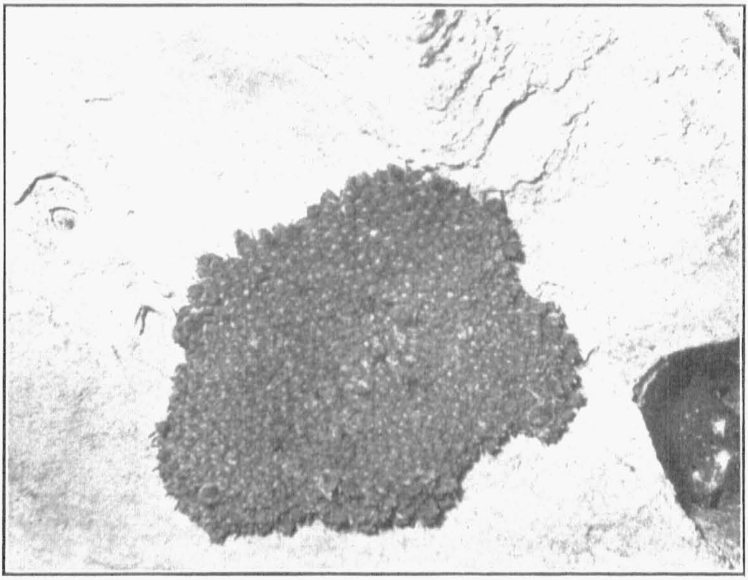
UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
BULLETIN 180

BAT GUANO AND ITS FERTILIZING VALUE



Cluster of more than a thousand bats on a Missouri cave ceiling.

COLUMBIA, MISSOURI
FEBRUARY, 1921

UNIVERSITY OF MISSOURI

COLLEGE OF AGRICULTURE

Agricultural Experiment Station

[1]In service of U. S. Department of Agriculture.

[2]On leave of absence

Bat Guano and Its Fertilizing Value

WM. A. ALBRECHT
Missouri Agricultural Experiment Station

The high cost of manufactured fertilizers and the shortage of nitrogenous materials, together with transportation troubles of the past few years, have put precarious conditions about the farmer dependent on commercial fertilizer. Even the man who has manure finds that his supply is exhausted all too soon and that to meet the demands of increased production he must use commercial plant food either as single element or as mixed products to make up the manure shortage. Such exigencies demand that every possible source of raw material with fertilizing value be searched out and developed. This demand has already brought increased development in utilization of garbage, leather scrap, feathers, wool waste and many other forms of waste products. Garbage alone supplied for commercial fertilizers in 1917 almost 124,000 tons of nitrogenous matter. Bat guano, the bat waste or accumulated excreta of those small winged animals in caves, should have attention for its possibilities in this respect. It contains much nitrogen, and appreciable amounts of phosphorous and potassium—the elements for which fertilizers are desired. In addition, it has such physical properties as to require no special treatment other than drying, and adapts itself readily for fertilizer use. Since caves with bats inhabiting them are common in Missouri, since quantities of bat guano estimated to exceed 16,000 tons have been located in caves of Porto Rico (3)*; and since considerable shipments of such material have already come up from Mexico (5) to go into fertilizers, a brief study of bat guano and tests of its fertilizing value were undertaken.

PROPERTIES OF BAT GUANO

Physical Condition. Bat guano in the strictest sense is not a guano since this term usually refers to accumulated bird excreta; but in the more general sense, referring to nitrogenous fertilizers as a class, its use is appropriate. As a pellet-formed excrement of small mammals this guano requires no grinding or special preparation to reduce it. Rock particles from disintegrating cave walls are usually mixed with it but these are easily sifted out. When completely dry, guano is dusty and too light for mechanical distribution but this difficulty can be overcome by mixing heavier fertilizer salts with it. Such practice would not only improve the physical condition but would permit adjustment of its chemical composition more nearly to fertilizer standards as well. When left to retain a good percentage of moisture guano distributes readily; so, if used alone, incomplete drying makes it scatter nicely. As it comes from the caves this guano may contain varying amounts of water, but the water disappears readily on exposure and there can be no more serious objection to

*Numbers refer to literature cited in Bibliography on page 15.

this feature than to its other physical characteristics, which offer no great handicap to using bat guano as a fertilizer.

Chemical Composition. The chemical composition of bat guano like that of all animal manures is determined by the animal itself and the nature of the food it eats. The cow, for example, with four stomachs, works over the feed stuffs differently from the horse. "The digestive apparatus (1) of the bat is very simple. The stomach is simple with a small fundus. The intestine is short measuring but one and one-half times the length of the body—". The foods cannot be so highly simplified by making this short passage through the animal and the excreta not so greatly changed from the composition of the food itself.

"Bats (1) feed exclusively on crepuscular and nocturnal insects and their diet is made up of mosquitoes, gnats, moths and even the heavily mailed nocturnal Coleoptera, all of which fall victims in large numbers." This means that the diet which is exclusively animal tissue must contain much protein and consequently much nitrogen. In the bat's simple digestive system this highly nitrogenous food cannot be changed greatly and the feces must carry much of this element.

Under the microscope bat guano shows insect remains almost exclusively—save for some wooly body combings and occasional skeletal parts of dead bats, most of these being the hard internal parts and body coverings or skeletons. These are made up of a compound called "chitin", chemically related to cartilage in the skeleton and mucin in the skin of larger vertebrate animals. Chitin (8) is indigestible by chickens and seems to pass through bats also with little or no alterations. The exact proportion of nitrogen in chitin is not known, but regardless of what this figure may be, the excreta made from feeding on it must be comparatively rich in nitrogen.

The composition of fresh guano is in accord with the foregoing deductions. Samples whose form indicated recent deposition were collected near Zebra and Rocheport, Mo., and gave 10.3 per cent and 10.4 per cent of nitrogen respectively on analysis of the dry matter. Such composition is not permanent however. Age brings decomposition with various changes both in physical and chemical make-up. Fresh guano is black when moist and deep brown when dry. Older guano may be reddish, pale brown or even gray when dry. The nitrogen becomes soluble and is readily lost by leaching. It can scarcely escape as ammonia gas, because of the large amounts of water always present to dissolve it and the great absorption by the extensive surface of such finely divided material. Because of decomposition and leaching, the fertilizer value of guano for its nitrogen decreases with age, and a deposit is not well supplied with this element merely because it was rich in this respect when fresh.

There is an irregularity in guano composition with the depth of the deposit, since deeper layers are the older. There is a decrease in per cent of nitrogen and a change in color, but usually an increase in phosphorus percentage with successively deeper layers. The latter element is not so soluble and remains during decomposition while other materials are removed. An old deposit in Marvel Cave of Stone County, to which evidently no recent additions had been made, contained 5.90 per cent of nitrogen in the upper foot, but only 3.46 per cent in the next layer of the same depth below. The analyses for phosphoric acid for these layers were 3.89 per cent and 6.25 per cent respectively, a relation to depth opposite that for nitrogen. This variation in chemical composition of different layers is responsible for great irregularity in bat guano carelessly mined and poorly mixed, and has made many fertilizer concerns hesitate to offer full price for this material.

In fresh guano the nitrogen occurs mainly as a part of some complex organic compound. Decomposition changes this form of nitrogen into the ammonia and nitrate or saltpeter forms. It was for the saltpeter, to be used in making gunpowder, that guano deposits in many caves in Missouri were worked during the Civil War. (4) In the samples gathered and examined in this study little nitrate was found, due no doubt to the fact that most of them were collected from caves having water which carried it away.

Ammonia nitrogen occurs in fresh material in rather unusual quantities Samples were found to contain as much as 1.98 per cent of ammonia nitrogen when the total nitrogen content was 10.4 per cent. Some nitrogen may have been hydrolysed into this form during the process of analysis; but, even so, this large percentage indicates that a good proportion of the nitrogen is in a simple, unstable form and is readily subject to agencies converting it to soluble forms such as ammonia. In samples taken from older deposits or at greater depths below the surface of the accumulation there was less ammonia. Nitrate nitrogen was also lower in older deposits. By far the largest part of the total nitrogen in guano was in the more stable complex organic form. As a general rule it was found that the ammonia decreased with age except in very fresh guano, while the nitrate form was almost negligible in the majority of the deposits studied.

Not only the nitrogen, but phosphorus and potash in guano have some fertilizing value although generally in the newer deposits these are of less importance than the nitrogen. In older deposits they take on considerable significance.

ANALYSES OF BAT GUANO

Nitrogen. In Table I are given analyses of guano from various caves in Missouri, tabulated for their total nitrogen content. Determinations were made on samples in air-dry condition, containing approximately 8 per cent hygroscopic water.

TABLE I. NITROGEN IN BAT GUANO FROM VARIOUS MISSOURI CAVES

Location of Cave		Sample	Per cent	
Town	County	Number:	Nitrogen:	
Notch*	Stone	1	8.69†	Known as Marvel Cave.
		2	5.90	Sampled at 2 ft. depth.
		3	..31	Sampled at 3 ft. depth.
		4	5.24	Sampled at 2 ft. depth.
		5	3.46	Composite samples; 6, 7, 8, 9, 10
		6	2.91	and 11, taken in different parts
		7	3.66	of cave after guano had been
		8	3.91	dug and mixed.
		9	3.98	
		10	3.03	
		11	2.71	
Colleda	Camden	1	7.52	Nearly fresh guano.
		2	2.32	Sampled at two feet depth.
		3	1.77	Saturated with water.
Ink	Shannon	1	7.36	Depth 0-6 inches.
		2	6.42	Depth 7-12 inches.
		3	1.96	Depth 13-16 inches.
Richland (7)	Pulaski	1	1.86	
		2	6.34	
		3	8.78	
Salem	Dent	1	7.98	
		2	1.13	
Phillipsburg (7)	Laclede	..	2.87	
Hoecker	Miller	..	7.30	63 lbs. water per 100 of fresh gua-
Laquey (7)	Pulaski	..	4.71	no.
Leasburg	Crawford	..	2.06	
Montgomery City, (7)	Montg'ry	..	1.45	
Rocheport	Boone	..	10.44	1.97 per cent as ammonia, no ni-
Zebra	Camden	..	10.35	trate nitrogen.
	Oregon (6)	..	8.10	

*Exact geographical locations were seldom available, hence the locations are given by postoffice nearby.

†Data above are based on air-dry weights.

Table II gives the content in phosphorus and potash for the samples analysed, and indicates that the phosphorus must not be neglected when considering the fertilizer value of bat guano.

Tables I and II show that there is a wide variation in composition of guano. In buying it for fertilizer one must be cautious and purchase solely on the basis of guaranteed analyses with respect to nitrogen, phosphorus and potassium, as well as its moisture content. With percentage ranges from 0.3 to 10.4 for nitrogen, from 2.5 to 7.9 for phosphoric acid, from 0.36 to 1.9 for potash and from 8 to 50 for moisture, it is evident that no small financial hazard is involved in purchasing such material in the hope of putting it on a market closely guarded by State Fertilizer Control laws.

TABLE II. PHOSPHORUS AND POTASH IN BAT GUANO FROM SOME MISSOURI CAVES

Location of Cave		Sample	Per cent:	Remarks.
Town	County			
PHOSPHORUS			P_2O_5	
Notch	Stone........	7	6.63*	Known as Marvel Cave
....	....	9	6.27	
....	....	11	5.56	
Hoecker	Miller.......		2.50	
Leasburg	Crawford....		7.91	
....	Oregon......		2.06	By U. S. Dept. Agr.
POTASH			K_2O	
Notch	Stone........	8	.36	Known as Marvel Cave
....	Oregon......		.58	By U. S. Dept. Agr.
Hoecker	Miller.......		1.90	

*Data are based on air-dry weights.

EXPERIMENTS WITH BAT GUANO AS A FERTILIZER

Ammonification. Since nitrogen is the prominent constituent of most bat guano, studies were conducted on its changes within the soil as compared with the nitrogen changes of other fertilizer materials such as tankage and dried blood.

To test the ammonification of guano 100-gram portions of Marshall silt loam were treated with 1.5 gm. guano and compared with the same soil weights given 1.118 gm. dried blood and 1.859 gm. tankage separately. The guano had 10.6 per cent, the dried blood 13.40 per cent and the tankage 8.06 per cent nitrogen. The weights of these materials taken were such as to add exactly 150 mgm. of nitrogen. Determinations of the ammonia* in the soil were made at the outset and at intervals of seven and eleven days with the average results for duplicate determinations given in Table III.

TABLE III. AMMONIA NITROGEN IN SOILS TREATED WITH BAT GUANO, DRIED BLOOD AND TANKAGE.

Treatment	Added in Fertilizer	At Outset	7 days later	11 days later.
	mgm.	*mgm.*	*mgm.*	*mgm.*
Soil Alone	None	2.660	2.359	2.484
Soil and Tankage	150	10.893	25.752	36.842
Soil and Dried Blood	150	3.814	25.200	40.862
Soil and Guano	150	34.110	22.389	36.997

*The guano used in all subsequent experiments contained 10.4 per cent total nitrogen, of which 1.97 per cent occured as ammonia and scarcely a trace as nitrate. This was a high grade guano and a nitrogen content above the average shown in Table I.

Table III shows that soil treated with guano contained much ammonia at the start but less a week later, because, no doubt, of its being converted into the nitrate form. Four days later the ammonia content increased again, equalling that of the tankage and almost that of the blood. This indicates that the nitrogen in guano is readily converted into ammonia and is subject to the changes undergone by other nitrogenous fertilizer constituents.

Nitrification. To test further transformation of guano nitrogen through nitrification in the soil, studies were made comparing nitrate pro-

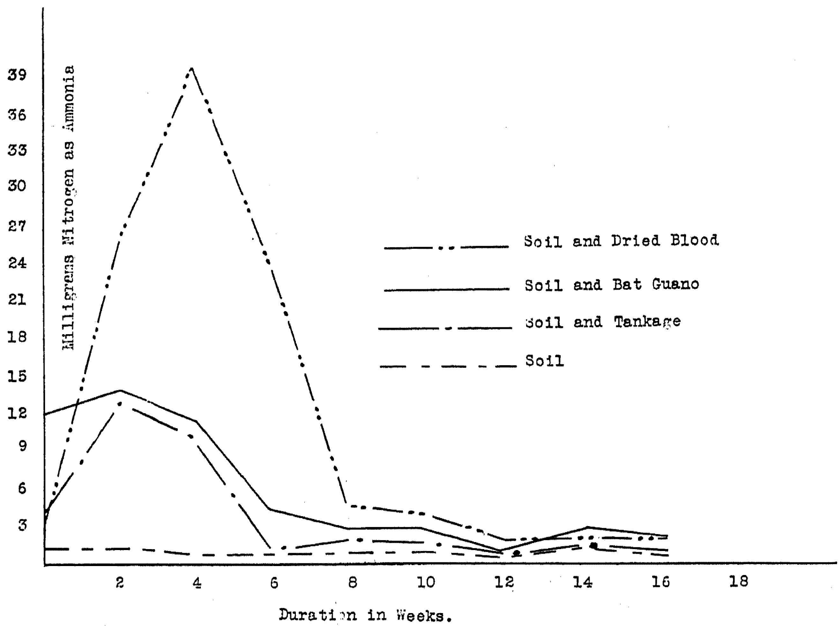


Fig. 1.—Ammonia Accumulation in Soil Treated with Bat Guano Compared with that of Tankage and Dried Blood.

duction by guano with that from dried blood and tankage. One hundred gram lots of Marshall silt loam soil treated with one gram of calcium carbonate were made up in jelly tumblers. Series of nine tumblers each were treated separately with one gram of guano, one of dried blood and one of tankage and kept at optimum moisture. Duplicate determinations were made on ammonia nitrogen and nitrate nitrogen at the start and at intervals of two weeks over a period of sixteen weeks. Table IV gives the data of the above determinations. Table V shows the percentage of nitrogen in each substance that was changed to nitrates. Figure 1 is a graphical representation of data for ammonia production given in Table IV. Figure 2 shows in a similar way the nitrification data from the same table, while in figure 3 the curves reproduce Table V.

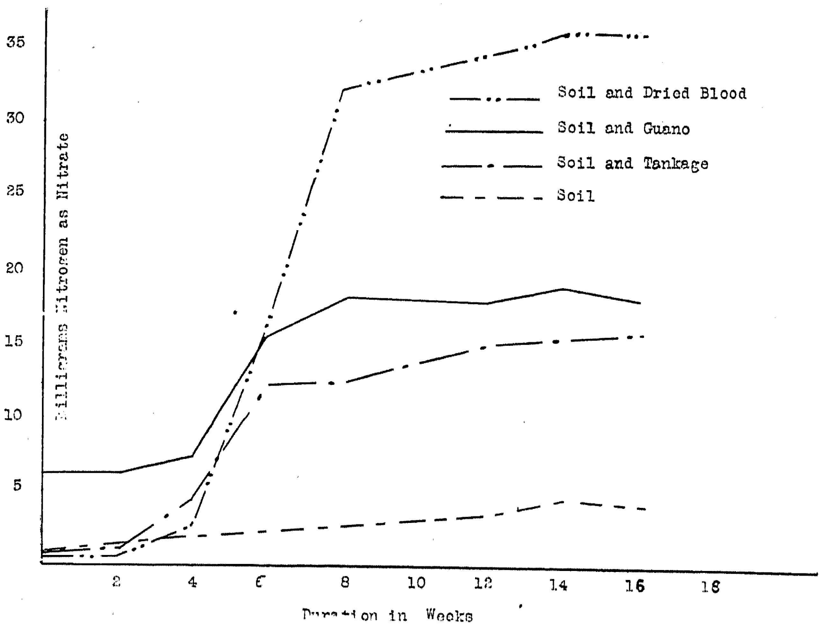


Fig. 2.—Nitrification of Guano in Soil Compared with Dried Blood and Tankage.

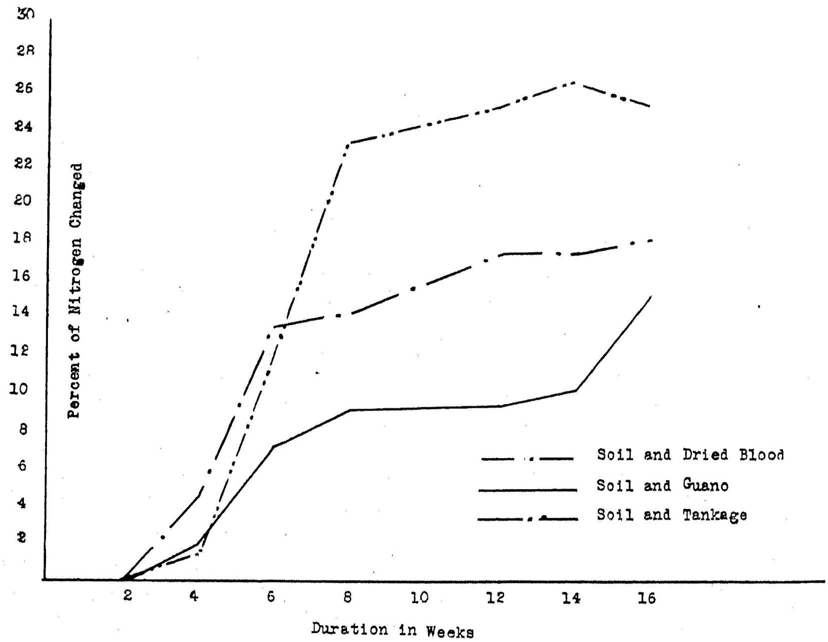


Fig. 3.—Percent of Total Nitrogen in Guano Changed to Nitrates as compared with that of Dried Blood and Tankage.

TABLE IV. NITROGEN IN SOILS TREATED WITH BAT GUANO AS COMPARED WITH SOILS TREATED WITH DRIED BLOOD AND WITH TANKAGE.

Treatment	Fertilizer added	At outset	After 2 wks	After 4 wks	After 6 wks	After 8 wks	After 10 wks	After 12 wks	After 14 wks	After 16 wks
Ammonia Nitrogen.										
	gm.	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
Soil	1	1.28	1.35	.80	1.40	1.14	1.30	.57	1.30	.87
Soil and tankage	1	3.66	12.84	9.96	1.35	2.13	2.58	1.68	1.53	1.95
Soil and dried blood	1	2.43	26.30	39.13	22.93	4.81	3.31	1.30	1.73	2.05
Soil and Guano	1	12.29	13.70	11.34	4.41	2.28	2.73	1.45	1.82	1.83
Nitrate Nitrogen.										
Soil	1	1.11	1.43	2.22	2.35	2.68	(*)	3.55	4.33	4.57
Soil and tankage	1	.79	1.24	4.41	12.19	12.49	(*)	15.03	15.21	15.68
Soil and dried blood	1	.81	1.29	2.94	17.08	31.89	(*)	34.33	36.42	35.49
Soil and Guano	1	7.50	7.76	9.62	15.08	17.23	(*)	17.52	18.32	23.66

TABLE V. PER CENT OF TOTAL NITROGEN IN TESTED MATERIAL CHANGED TO NITRATES.

Treatment	After 2 wks.	After 4 wks.	After 6 wks.	After 8 wks.	After 10 wks.	After 12 wks.	After 14 wks.	Afer 16 wks.
Soil and tankage	.55	4.49	13.88	14.50	(*)	17.66	17.85	18.45
Soil and dried blood	.36	1.29	12.14	23.19	(*)	25.01	26.57	25.88
Soil and guano	.24	1.74	7.15	9.17	(*)	9.45	10.20	15.24

*Tenth week determinations in this experiment were lost.

†One gram sample of each fertilizer was used analysing as follows for nitrogen; tankage 8.06 per cent, dried blood, 13.40 per cent, guano 10.60 per cent.

Brief study of the data and graphs given shows that in the production of ammonia and its change to nitrates, fresh guano is a very efficient fertilizer. It does not produce as high a concentration of ammonia as dried blood, but higher than tankage. Its rate of nitrification is similar to that of tankage, as is shown in figure 2 by the curve for this process in guano which parallels that for tankage very closely but is slightly higher on the scale. Guano does not equal dried blood in nitrate production, neither in rate nor in total amount, which might well be expected from the much higher initial nitrogen content of the blood. It does, however, equal tankage when its change of nitrogen into soluble form is considered.

Pot Experiments With Bat Guano. To test further the fertilizing effects of bat guano, pot cultures were run comparing it with ammonium sulfate, tankage and dried blood. Applications were made at the following rates of nitrogen per 2,000,000 pounds of soil; ammonium sulfate 100 pounds, dried blood 200 pounds, tankage 200 pounds and guano 100 pounds in one series and 200 pounds in another. The soil used was a Lindley silt loam with a low nitrogen content. It was treated with fertilizers at the rate of 2 tons limestone, 300 pounds acid phosphate and 50 pounds muriate of potash per 2,000,000 pounds of soil in an attempt to make nitrogen the limiting element. Duplicate pots were used with oats as the crop. The results of the test are shown by the total crop weights of duplicate tests given in Table VI.

TABLE VI. WEIGHTS OF OATS ON POTS TREATED WITH BAT GUANO IN COMPARISON WITH OTHER NITROGENOUS FERTILIZERS.

Treatment	Equivalent of nitrogen added. (Lbs. per two million),	Grain	Straw	Total Crop	Increase by treatment.
		gm.	*gm.*	*gm.*	*gm.*
None		7.45	17.85	25.30	
Ammonium sulfate	100	8.60	19.70	28.30	3.00
Dried blood	200	11.35	21.70	33.05	7.75
Tankage	200	12.39	21.66	34.05	8.75
Bat Guano	100	12.96	20.04	33.00	7.70
Bat Guano	200	12.06	25.99	38.05	12.75

The results of pot cultures show that, when measured by a crop of oats, the application of bat guano at a rate of 100 pounds of nitrogen per acre was about equal to dried blood and tankage at twice that rate. This was true for both seed and straw production shown by the data in Table VI. That the addition of even the smaller application of bat guano improved the crop over the check is shown in Plate I, and that such treat-

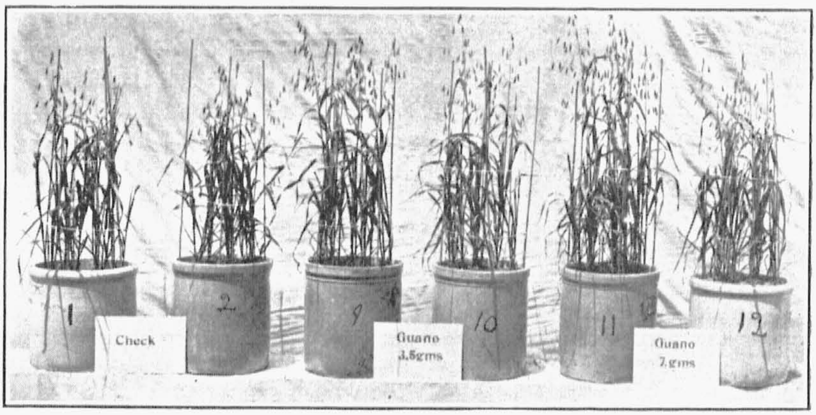


Plate I.—Pot cultures with oats showing the effect of bat guano as a fertilizer. Duplicate treatments from left to right are check, bat guano 100 pounds, and bat guano 200 pounds nitrogen per two million pounds soil.

ment gives results greater than the same nitrogen content in ammonium sulfate is shown in Plate II. This emphasizes very clearly the possibility of using guano as a fertilizer constituent just for the sake of its nitrogen, especially when its effects are so superior to those of the common fertilizer constituents used for this element.

Field Experiments With Bat Guano. Field tests comparing ammonium sulfate with guano under various application rates also show interesting results. Five small field plots of Putnam silt loam were used. One was left untreated to serve as a check, one was treated with ammonium sulfate at the rate of 100 pounds per acre and the remaining three plots were

Plate II.—Pot cultures with oats showing the fertilizer effect of bat guano compared with that of ammonium sulfate. Duplicate treatments from left to right are ammonium sulfate 100 pounds, bat guano 100 pounds and bat guano 200 pounds nitrogen per two million pounds of soil.

given guano at the rates of 200, 400, and 800 pounds of guano per acre. Oats were grown as the crop, carefully harvested and threshed to test the effects of the above treatments. Table VII gives the crop weights produced by the different treatments, and Plate III shows the appearance of the plot treated with ammonium sulfate as compared to the one treated with the highest application of bat guano.

TABLE VII. WEIGHTS OF OATS PRODUCED BY BAT GUANO IN COMPARISON WITH AMMONIUM SULFATE.

Plot	Fertilizer added per acre.	Bushels grain per acre.	Increase over check.	Pounds straw per acre.	Increase over check.
1	Guano 400 lbs.	31.17	4.45	1328	163
2	Guano 200 lbs.	30.81	4.09	1318	156
3	Check	26.72	...	1162	...
4	Ammonium sulfate 100 lbs.	27.04	.32	1180	18
5	Guano 800 lbs.	33.29	6.57	1444	282

The data in Table VII show that the guano produced greater increases in all three applications than did the 100 pounds of ammonium sulfate. The minimum increase by the former was something over 4 bushels of oats per acre. This is a fair increase from 200 pounds applied, showing such application superior to the 100 pounds of ammonium sulfate. These results indicate that it is not only the nitrogen of the guano, but also the other fertilizer elements, phosphorus and potassium, which it contains, that produce increased yields. For had nitrogen been the limiting element in this soil the treatment with ammonium sulfate should have done equally as well.

Plate III. Field results on oats fertilized with bat guano at the rate of 800 pounds per acre (on the right) compared with ammonium sulfate, 100 pounds per acre (on the left). Plot on the right yielded 6.5 bushels over that on the left though not indicated clearly in the picture.

RECOMMENDATIONS FOR USING BAT GUANO

According to its composition bat guano, as found in most deposits, is an unbalanced plant ration with high nitrogen content and will serve best when this excess is balanced by other plant foods. The fresher guano should be reinforced by adding phosphorus although that taken from older deposits is fairly rich in this element. Guano may, of course, be used alone, but when dry it is so light in weight as to scatter through fertilizing machinery with difficulty. It would be far more serviceable as a constituent of mixed fertilizer. The addition of the heavier fertilizer ingredients would overcome the mechanical difficulty of spreading as well as balance the plant ration. For the farmer who owns a deposit of guano or can get such cheaply, it may be advisable to use the guano without modification, but for most efficient results it should be reinforced with those plant foods that balance the deficiencies.

SUMMARY

Bat guano, usually found in caves, has a chemical composition which makes it favorable for use as fertilizer.

Age affects the fertilizing value of guano seriously. While it loses much of its nitrogen and potash by leaching, it becomes relatively richer in phosphorus.

Guano in Missouri caves shows variations in nitrogen from 0.31 to 10.44 per cent, in phosphoric acid from 2.5 to 7.9 per cent, and in potash from 0.36 to 1.9 per cent. Its content in moisture is usually high, often approaching 50 per cent. These irregularities have made guano buying a hazard to commercial fertilizer manufacturers.

Experimental ammonification tests showed that the fresher bat guano produced ammonia in amounts equal to and nitrates in amounts even greater than that of tankage. It did not equal that of dried blood in these respects.

In pot cultures bat guano gave results superior to those of dried blood, tankage, and ammonium sulfate and in field tests with oats, comparing it with ammonium sulfate, it proved itself superior.

Average bat guano makes a good fertilizer on poor soils when applied directly at the rate of two hundred pounds of dry material per acre. As a general fertilizing material it can be used more satisfactorily as a constituent of mixed fertilizer, especially when mixed with phosphorus carriers.

BIBLIOGRAPHY

1. Allen, H. Monograph on Bats of North America. Bul. U. S. Nat. Mus. **43** (1893) 198 pp.
2. Fraps, G. S., Commercial Fertilizers in 1912-1913. Texas Agr. Exp. Sta. Bul. 160 (1913).
3. Gile, P. L. and Carrero, J. O. Bat Guanos of Porto Rico and Their Fertilizing Value, Porto Rico Agr. Exp. Sta. Bul. 25 (1918) 65 pp.
4. Mcfarland, A. W., Blairstown, Mo. In correspondence with author.
5. Newhouse, E. E. Secretary for Arkansas Fertilizer Company in correspondence with author.
6. Miller, C. F. On the Composition and Value of Bat Guano. Separate U. S. Dept. Agr. Bureau of Soils.
7. Trowbridge, P. F. Inspection of Commercial Fertilizers. Missouri Agr. Exp. Sta. Bul. 145 (1917) 27. Missouri Agr. Exp. Sta. Bul. 154 (1918) 30.
8. Zaitschek, A. The Digestibility of Chitin and the Nutritive Value of Insects. Arch. Physiol. (Pfluger) **104** (1904) 612-623. Exp. Sta. Rec. **16** (1904-05) 585.