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TEXAS AGRICULTURAL EXPERIMENT STATION

A. B. CONNER, DIRECTOR
COLLEGE STATION, BRAZOS COUNTY, TEXAS

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DIVISION OF CHEMISTRY

The Composition and Fertilizing Value of Sewage Sludge

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Sewage sludge is a by-product from the purification of the sewage at several hundred towns and cities of Texas. Two types of sewage sludge are produced: the digested sludge and the activated sludge. Digested sludge is the sludge produced from the sewage of most of the towns and cities in Texas, while activated sludge is produced by only one or two. Digested sludge is low in plant food, containing, on the average, 1.9 per cent nitrogen, 1.6 per cent total phosphoric acid, and 0.2 per cent potash, in the dried condition. The results of a number of pot experiments here reported indicate that the nitrogen of digested sludge has an availability of about half the availability of the nitrogen of cottonseed meal. Dried digested sludge closely resembles farmyard manure in composition. It has sufficient plant food, of sufficient availability, to justify its use in a manner similar to that of ordinary farm manure. Digested sludge may be utilized by farmers who live near enough to sewage disposal plants to be able to haul it away to advantage.

Dried activated sludge contains about 5 per cent nitrogen and 2 per cent available phosphoric acid. The nitrogen of activated sludge has a good availability to crops, about equal to that of cottonseed meal, and it also passes the chemical tests for activity. Dried activated sludge has about 70 per cent of the fertilizing value of cottonseed meal, and it can be used as a fertilizer in the same way as cottonseed meal, either alone or mixed with other materials.

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THE COMPOSITION AND FERTILIZING VALUE OF SEWAGE SLUDGE

G. S. FRAPS.

Sewage sludge is a by-product from the purification of sewage, produced in large quantities by a number of Texas towns. The laws of Texas forbid the contamination of streams or water courses with sewage. This fact necessitates the purification of sewage before it is discharged, by practically every incorporated city or town in Texas with a population of over 3,000. A certain amount of solid matter, or sewage sludge, is formed in the process of purification. As there are several hundred municipalities purifying sewage, large quantities of sewage sludge are produced, which must be utilized or otherwise disposed of. Activated sludge is known to have fertilizing value; most of the sludge produced in Texas is digested sludge. If this digested sludge could be used economically for fertilizing purposes or otherwise, it would aid the municipality in the troublesome problem of disposing of the sludge. If it could be used as a fertilizer to supply plant food, its use should also be of advantage to the farmer or gardener. The chief object of the work here presented was to ascertain if digested sludge might be used for fertilizing purposes.

The value of a fertilizer is considered to be chiefly due to the nitrogen, phosphoric acid, and potash it contains, and upon the extent to which these plant foods can be taken up by plants. While it is known that, under exceptional conditions, other elements have a value to crops, at the present time this need seems to occur in small relatively isolated areas. The fertilizing value of sewage sludges depends upon the percentages of total nitrogen, available phosphoric acid, and water-soluble potash they contain and also on the availability of the nitrogen in them. If the plant food cannot be taken up by plants, it obviously has no value to them.

KINDS OF SEWAGE SLUDGE

The first step in the purification of sewage is the removal of most of the suspended material, or raw sludge, either by settling, or by settling and the action of organisms. Two widely different kinds of sludge are produced and must be disposed of. The disposal of the sludge is sometimes troublesome and expensive.

Digested Sludge. In the Imhoff type of process which produces digested sludge, the raw sludge is retained in closed tanks and undergoes an extensive decomposition. Bacteria and other organisms develop and break down the organic matter, converting the less resistant material into gases and soluble materials. The least resistant material is destroyed, and the more resistant material remains. The digested sludge, therefore, consists largely of material which has resisted the action of the bacteria, and its organic matter could not be expected to decay rapidly in the soil. For this reason also, its content of plant food is low and the availability of the plant food

can be expected to be low. Most of the sludge produced from the purification of sewage in Texas is digested sludge.

Activated Sludge. In the activated-sludge process, the sewage is seeded with activated sludge and air is passed through the mixture. There is an extensive growth of protozoa and other organisms, which take up some of the dissolved material in the sewage. The organisms adhere to the suspended solids, and cause them to settle (3). If the sludge introduced is properly active, the sewage is clarified in 6 to 24 hours. The sludge consists partly of solid organic material from the sewage and partly of bodies of the organisms which produce the clarification and take up some of the dissolved constituents of the sewage. For this reason, it contains more nitrogen than digested sludge, decays more readily in the soil, and its plant food can be expected to be more readily available than the plant food of the digested sludge. There are a number of plants in Texas which use the activated process of purification, but most of them digest the activated sludge in tanks, and thereby produce digested sludge as the final product.

FERTILIZING CONSTITUENTS OF THE SLUDGE

The fertilizing constituents of a number of samples of dried sewage sludge, as collected in Texas, are given in Table 1. The composition of the moist or wet sludge would of course be lower, in proportion to the quantity of water present. The composition of the sludge depends upon the composition of the raw sewage, the particular tanks and apparatus used in the treatment, the time and temperature of the digestion of solids, and other factors. Consequently, a variation in the composition of the sludge is to be expected between different places, and between different times at the same place.

The digested sludge contains 0.88 to 2.99 per cent of nitrogen with an average of 1.87 per cent. The total phosphoric acid varies from 0.47 to 3.74 per cent, with an average of 1.57 per cent. The available phosphoric acid, in the samples analyzed varies from 0.21 to 2.30 per cent in the digested sludge, with an average of 1.07 per cent. The potash varies from 0.02 to 1.44, with an average of 0.24 per cent.

The activated sludge contains 3.59 to 5.54 per cent of nitrogen, usually over 5 per cent. It not only contains more nitrogen than the digested sludge, but it is more nearly uniform in composition. It contains practically no potash. It contains about 2.5 per cent of total phosphoric acid, and usually over 2 per cent of available phosphoric acid. Activated sludge contains about 70 per cent as much nitrogen as cottonseed meal.

Either type of sludge contains sufficient plant food to justify applying it to the soil.

OTHER CONSTITUENTS OF THE SLUDGES

Constituents other than the fertilizing elements are shown in Table 2. It is to be noted that the sludges contain high percentages of ash, ranging

Table 1. Fertilizer constituents of sewage sludge (per cent).

Laboratory Number		Nitrogen	Total phosphoric acid	Insoluble phosphoric acid	Available phosphoric acid	Potash	Water
30487	Digested sludge 1—fresh solids—Waco	4.03	1.20	.42	.78	.09	7.64
14577	Digested sludge—College Station	2.99	2.48	-----	-----	.19	5.48
15924	Digested sludge—Fort Worth	1.85	.75	-----	-----	-----	-----
22537	Digested sludge—Laredo	.88	.80	-----	-----	1.44	2.69
26311	Digested sludge—Brownsville	1.29	1.72	.64	1.08	.02	4.89
28824	Digested sludge—Jacksonville	1.42	.47	.26	.21	.04	5.03
29711	Digested sludge—College Station	2.46	1.44	.30	1.14	.20	5.26
30179	Digested sludge—septic tank—College Station	1.83	1.32	.26	1.06	.17	6.17
30180	Digested sludge—San Benito	1.63	1.28	.24	1.04	.20	4.65
31004	Digested sludge—Greenville	1.61	1.79	.28	1.51	.07	17.11
31011	Digested sludge—Waco	2.62	3.74	1.44	2.30	.07	6.94
31012	Digested sludge—El Paso	2.27	1.38	.31	1.07	.08	4.36
31013	Digested sludge digested under reduced pressure, 15 days—College Station	1.54	1.29	.29	1.00	.23	-----
31014	Digested sludge digested under reduced pressure, 30 days—College Station	1.49	1.30	.28	1.02	.11	-----
31015	Digested sludge digested under reduced pressure, 45 days—College Station	1.55	1.16	.32	.84	.11	-----
31016	Digested sludge digested under reduced pressure, 60 days—College Station	1.66	1.25	.33	.92	.32	-----
31075	So-called ripe Imhoff sludge—Dallas	1.79	1.40	.63	.77	.11	3.65
31333	Digested sludge—Alpine	2.96	1.64	-----	-----	.53	6.21
33244	Digested sludge—El Paso	1.48	2.64	-----	-----	-----	-----
33245	Digested sludge—El Paso	.55	.53	-----	-----	-----	-----
35736	Digested sludge—San Antonio	3.49	2.92	-----	-----	.22	-----
	Average Digested sludge (20)	1.87	1.57	.43	1.07	.24	6.04
14324	Activated sludge—	4.34	2.41	-----	-----	.31	-----
18978	Activated sludge—Houston	3.59	2.69	.72	1.97	.22	5.75
22195	Activated sludge—Houston	5.54	-----	-----	-----	-----	4.58
22210	Activated sludge—Houston	4.87	-----	-----	-----	-----	4.15
27835	Milorganite (activated sludge), Milwaukee Wis.	5.17	2.59	-----	-----	-----	5.18
31334	Dried activated sludge—Houston	5.14	2.85	-----	-----	-----	-----
31335	Dried activated sludge, 20 mesh—Houston	5.29	-----	-----	-----	-----	-----

Table 2. Non-fertilizer constituents of sewage sludge—per cent.

Laboratory Number		Ash	Iron and oxide alumina	Magnesia	Lime	Insoluble ash	Pentosans	Grease	Crude fiber
30487	Digested sludge—fresh solids—Waco	33.43	5.92	.43	6.99	17.55	3.18	8.39	4.71
22537	Digested sludge—Laredo	76.46	4.67	.47	7.12	63.46	.69	4.13	3.23
26311	Digested sludge—Brownsville	.....	7.48	.80	8.30	52.41	.93	3.48	.....
28824	Digested sludge—Jacksonville	.....	13.82	.12	4.59	54.46	.66	14.87	.....
29711	Digested sludge—College Station	42.06	6.59	.49	2.01	30.22	1.96	16.98	11.41
30179	Digested sludge—septic tank—College Station	47.68	5.72	.35	3.12	38.68	2.55	8.08	15.15
30180	Digested sludge—San Benito	61.97	8.86	1.10	6.49	41.74	.98	7.58	4.84
31004	Digested sludge—Greenville	55.38	7.55	.27	2.58	45.66	1.34	5.13	5.06
31011	Digested sludge—Waco	53.30	9.58	.40	9.77	30.42	2.24	5.09	8.23
31012	Digested sludge—El Paso	45.20	5.36	1.18	9.71	25.89	1.30	16.20	4.44
31075	So-called ripe Imhoff sludge—Dallas	47.48	4.62	.11	4.49	34.15	3.06	15.39	13.39
31333	Digested sludge—Alpine	51.48	7.33	.02	4.47	37.49	1.59	8.67	8.41
22195	Activated sludge—Houston	32.48	6.03	.08	.43	24.77	1.81	7.79	11.20
22210	Activated sludge—Houston	35.50	6.52	.66	.92	27.92	1.91	12.13	7.39
27835	Milorganite (activated sludge) Milwaukee, Wis.	31.81	.....	.....	.....	.....	2.58	21.24	5.73

from 33 to 76 per cent. The ash consists chiefly of material insoluble in acids, but also contains some iron and aluminum oxides, and appreciable amounts of lime. Next to protein, the grease makes up the chief constituent of the organic part of the sludge, in most cases, though it is low in some of the samples. The sludge contains some pentosans and some crude fiber. The nitrogenous constituents are not shown in the table, but if the nitrogen shown in Table 1 were calculated to protein, by multiplying the nitrogen by 6.25, the protein would seem to be the ingredient present in next largest quantity to the ash. The organic constituents of sludge do not constitute especially good materials for the formation of humus in the soil.

AVAILABILITY OF NITROGEN OF SEWAGE SLUDGE

Several workers have estimated the availability of the nitrogen of activated sludge, both by means of pot experiments and by chemical methods. Noer, in Wisconsin (12,7) in pot experiments found that 36 per cent of the nitrogen of activated sludge was taken up by oats, compared with 39 to 44 per cent from cottonseed meal, and 46 per cent from dried blood. Extensive field experiments also indicated that the plant food in activated sludge has a good availability and is effective for use on plants. Haskins (5) in Massachusetts found 68 per cent of the nitrogen of activated sludge was taken up by millet, compared with 80 per cent of that of dried blood, and 68 per cent of that of cottonseed meal. Reynolds (13) in Texas found that activated sludge increased the yield of cotton 17 per cent and the yield of corn 13.9 per cent.

Haskins (4) also found activated sludge to pass the chemical tests both by the neutral permanganate method and by the alkaline permanganate method. Tests made in connection with the Texas work here reported on 3 samples of activated sludge showed that over 80 per cent of the nitrogen was soluble in neutral permanganate solution, and the nitrogen of activated sludge therefore passed the chemical test for availability. These tests show that while the nitrogen of activated sludge is not as available as that of dried blood, it has a good availability and is suitable for use as a fertilizer either alone or as an ingredient of a mixed fertilizer.

While tests of the availability of the nitrogen of digested sludge, have been made (1, 2, 8, 11, 14, 15), no exact tests have come to the attention of the author. The high value of activated sludge seems to be definitely established (5, 8, 12); so the work on the availability of nitrogen in sewage sludge here reported has been directed chiefly to that in digested sludge.

POT EXPERIMENTS TO ESTIMATE THE AVAILABILITY OF NITROGEN IN SEWAGE SLUDGES

The efficiency of the nitrogen in a fertilizer can be measured by the quantity of nitrogen taken from a definite amount of it by a crop grown in pot experiments, compared with the quantity of nitrogen taken up from a definite quantity of a standard fertilizer under the same conditions. The weight of the dried crop is sometimes used as a measure of the effect of

the fertilizer, but as the percentage of nitrogen in the crop may vary with the different treatments, the weight of the crop would not necessarily be in proportion to the amount of nitrogen taken up and cannot be considered to be a satisfactory measure of the availability of the nitrogen. The weight of nitrogen taken up by a crop grown on the soil or the sand without any addition of nitrogenous fertilizers, should also be deducted from the weights of nitrogen taken up by the crops grown with the fertilizer being studied in order to get the net effect of the addition. Phosphoric acid, potash, and sometimes other plant foods, should be added to all the pots in sufficient amounts to ensure that nitrogen is the limiting element.

The pot experiments here reported were conducted by the usual methods used in this laboratory. Each pot containing 5,000 grams of soil or sand received additions of dicalcium phosphate and potash salts, and the various nitrogenous materials in amount equivalent to 0.1 gram of nitrogen in most cases, but 0.15 gram of nitrogen was applied in some of the experiments. The sand received, in addition, magnesium sulphate and sodium chloride. The plants were watered three times a week, or oftener, if needed, and were kept in a greenhouse. At the end of about two months, the plants were cut, dried, weighed, and subjected to analysis.

Eight different soils or sands were used. The sand or soils used were selected as being low in nitrogen and are described as follows:

No. 22194. Builders sand, containing .003 per cent nitrogen, and with .40 per cent basicity to acid.

No. 31116. Washed silica sand, quartz.

No. 31185. Hidalgo clay loam, 7 to 19 inches deep, from Frio county, containing 0.89 per cent nitrogen, with a basicity to acid of 10.0 per cent.

No. 31887. Duval fine sandy loam, 7 to 19 inches deep, from Frio county, containing .039 per cent nitrogen, and with a basicity of 0.15 per cent.

No. 31889. Webb fine sandy loam, 7 to 19 inches deep, Frio county, containing .083 per cent nitrogen, with a basicity of 0.95 per cent.

No. 33124. Moscow fine sandy loam, 0 to 3 inches deep, Polk county, containing .047 per cent nitrogen and with a basicity of .20 per cent.

No. 33131. Bowie fine sandy loam, 7 to 15 inches deep, Polk county, containing .020 per cent nitrogen and with a basicity of .01 per cent.

No. 33135 Susquehanna fine sandy loam, 7 to 18 inches deep Polk county, containing .025 per cent nitrogen with a basicity of .07 per cent.

DISCUSSION OF RESULTS OF THE POT TESTS

Detailed results of the tests are given in Tables 3, 4, and 5. A summary of the results is given in Table 6, which shows the net amount of nitrogen taken up by the plants, expressed in percentage of the amounts added. Table 7 contains the comparative availability of the nitrogen in the various materials, compared with that of nitrate of soda equal to 100. That is to say, the quantity of nitrogen taken from the nitrate of soda

Table 3. Nitrogen recovered by corn from sewage sludge—Sand 22194

Pot number	Nitrogenous addition	Wt. crop gm	Nitrogen per cent	Grams nitrogen	Average gms nitrogen	Gain of nitrogen	Per cent N recovered
1 O	None	5.6	.59	.0330	-------	-------	-----
2 O	None	6.2	.50	.0310	-------	-------	-----
3 O	None	5.7	.56	.0319	.0320	-------	-----
4S1	Activated sludge 22210, O.125 gm N	12.5	.55	.0688	-------	-------	-----
5S1	Activated sludge 22210, O.125 gm N	11.6	.56	.0650	-------	-------	-----
6S1	Activated sludge 22210, O.125 gm N	10.5	.59	.0620	.0653	.0333	26.6
7Cs	Cottonseed meal 22146, .088 gm N	10.3	.59	.0677	-------	-------	-----
8Cs	Cottonseed meal 22146, .088 gm N	10.4	.58	.0603	-------	-------	-----
9Cs	Cottonseed meal 22146, .088 gm N	12.1	.57	.0690	.0657	.0337	38.3
	Nitrate of soda, 0.1 gm N	13.5	.64	.0864	-------	-------	-----
	Nitrate of soda, 0.1 gm N	16.5	.54	.0891	-------	-------	-----
	Nitrate of soda, 0.1 gm N	14.5	.57	.0827	.0861	.0541	54.1
19 2S1	Activated sludge, 22210, 0.25 gm N	21.0	.60	.1260	-------	-------	-----
20 2S1	Activated sludge, 22210, 0.25 gm N	18.6	.62	.1153	-------	-------	-----
21 2S1	Activated sludge, 22210, 0.25 gm N	19.3	.67	.1293	.1235	.0915	36.6
25 2Cs	Cottonseed meal, 22146, 0.176 gm N	14.2	.57	.0809	-------	-------	-----
26 2Cs	Cottonseed meal, 22146, 0.176 gm N	15.3	.63	.0964	-------	-------	-----
27 2Cs	Cottonseed meal, 22146, 0.176 gm N	15.2	.59	.0897	.0890	.0570	32.4
	Nitrate of soda, 0.2 gm N	19.4	.73	.1416	-------	-------	-----
	Nitrate of soda, 0.2 gm N	23.1	.63	.1455	-------	-------	-----
	Nitrate of soda, 0.2 gm N	13.7	.98	.1343	.1405	.1085	54.3

Table 4. Nitrogen recovered by corn on sand 31116.

Pot number marks	Nitrogenous addition (equal to 0.1 gm N)	Wt. crop gm	N per cent	Grams N	Average gm of N	Gain by addition	Per cent nitrogen recovered
1 DK	None	3.0	1.02	.0306			
2 DK	None	1.0	1.17	.0117			
3 DK	None	.6	1.10	.0066	.0163		
4 DKNa	Nitrate of soda (0.1 gm N)	7.6	1.04	.0790			
5 DKNa	Nitrate of soda (0.1 gm N)	4.5	1.10	.0495			
6 DKNa	Nitrate of soda (0.1 gm N)	5.1	1.05	.0536	.0607	.0444	44.4
7 DKCSM	Cottonseed meal	2.9	.91	.0264			
8 DKCSM	Cottonseed meal	4.2	1.00	.0420			
9 DKCSM	Cottonseed meal	2.1	1.06	.0223	.0302	.0139	13.9
10 DKS 1	Digested sludge, No. 30179, College Station	1.0	1.08	.0108			
11 DKS 1	Digested sludge, No. 30179, College Station	1.1	1.22	.0134			
12 DKS 1	Digested sludge, No. 30179, College Station	1.6	1.09	.0174	.0139	0	0
13 DKS 2	Digested sludge, No. 30180	1.1	1.32	.0145			
14 DKS 2	Digested sludge, No. 30180	1.5	1.15	.0173			
15 DKS 2	Digested sludge, No. 30180	1.0	1.48	.0148	.0155	0	0
16 DKS 3	Digested sludge No. 30487	1.5	1.24	.0186			
17 DKS 3	Digested sludge No. 30487	3.2	1.09	.0349			
18 DKS 3	Digested sludge No. 30487	1.1	1.54	.0169	.0235	.071	7.1
19 DKS 4	Digested sludge No. 31012	1.0	1.50	.0150			
20 DKS 4	Digested sludge No. 31012	1.2	1.12	.0134			
21 DKS 4	Digested sludge No. 31012	1.0	1.24	.0124	.0136	0	0
22 DKS 5	Activated sludge No. 22210	4.9	.87	.0426			
23 DKS 5	Activated sludge No. 22210	4.5	.94	.0423			
24 DKS 5	Activated sludge No. 22210	4.0	.93	.0372	.0407	.0244	24.4

Table 5. Nitrogen recovered by corn grown on various soils.

Pot number	Nitrogenous addition	Wt. crop gm	N per cent	Grams N in crop	Average gm N in crop	Average gain of N	Per cent recovered
	Soil No. 31885						
1 DK	None	5.0	.56	.0280	.....	.....	.....
2 DK	None	4.0	.60	.0240	.0260	.....	.....
3 DKS 2	Sludge No. 31012, Waco	6.5	.58	.0377	.....	.....	.....
4 DKS 2	Sludge No. 31012, Waco	7.2	.52	.0374	.0376	.0116	11.6
5 DKNa	Nitrate of soda	15.7	.51	.0801	.....	.....	.....
6 DKNa	Nitrate of soda	16.5	.52	.0858	.0830	.0570	57.0
7 DKC	Cottonseed meal	8.7	.51	.0444	.....	.....	.....
8 DKC	Cottonseed meal	10.2	.53	.0541	.0493	.0233	23.3
9 DKS	Sludge No. 31011, El Paso	8.7	.62	.0539	.0539	.0279	27.9
	Soil No. 31887						
1 DK	None	4.2	.52	.0218	.....	.....	.....
2 DK	None	3.7	.58	.0215	.0217	.....	.....
3 DKS 2	Sludge No. 31012, Waco	6.5	.54	.0351	.....	.....	.....
4 DKS 2	Sludge No. 31012, Waco	7.3	.51	.0372	.0362	.0145	14.5
5 DKNa	Nitrate of soda	14.5	.55	.0798	.....	.....	.....
6 DKNa	Nitrate of soda	16.5	.52	.0858	.0828	.0611	61.1
7 DKC	Cottonseed meal	10.7	.50	.0535	.....	.....	.....
8 DKC	Cottonseed meal	10.5	.50	.0525	.0530	.0313	31.3
10 DKS	Sludge No. 31011, El Paso	4.2	.62	.0260	.....	.....	.....
11 DKS	Sludge No. 31011, El Paso	4.2	.58	.0244	.0252	.0035	3.5
	Soil No. 31889						
1 DK	None	4.2	.53	.0223	.....	.....	.....
2 DK	None	3.7	.68	.0252	.0238	.....	.....
3 DKS 2	Sludge, No. 31012, Waco	5.8	.55	.0319	.....	.....	.....
4 DKS 2	Sludge, No. 31012, Waco	6.5	.52	.0338	.0329	.0091	9.1
5 DKNa	Nitrate of soda	13.5	.55	.0743	.....	.....	.....
6 DKNa	Nitrate of soda	15.0	.52	.0780	.0762	.0524	52.4
7 DKC	Cottonseed meal	9.5	.55	.0523	.....	.....	.....
8 DKC	Cottonseed meal	11.5	.48	.0552	.0538	.0300	30.0
9 DKS	Sludge, No. 31011, El Paso	3.5	.63	.0221	.....	.....	.....
10 DKS	Sludge, No. 31011, El Paso	5.2	.55	.0286	.0254	.0016	1.6
	Soil No. 33124						
1 DK	None	7.7	.45	.0347	.....	.....	.....
2 DK	None	6.1	.51	.0311	.0329	.....	.....
3 DKNa	Nitrate of soda	25.1	.41	.0129	.....	.....	.....
4 DKNa	Nitrate of soda	22.0	.43	.0946	.0988	.0659	65.9
5 DKC	Cottonseed meal	11.0	.44	.0484	.....	.....	.....
6 DKC	Cottonseed meal	13.5	.43	.0581	.0533	.0204	20.4
7 DKS 3	Sludge, No. 31004, Greenville	11.5	.43	.0495	.....	.....	.....
8 DKS 3	Sludge, No. 31004, Greenville	11.5	.43	.0495	.0495	.0166	11.1
9 DKS 4	Sludge, No. 31333, Alpine	12.5	.46	.0575	.0575	.0246	16.4

Table 5. Nitrogen recovered by corn grown on various soils—Continued.

Pot number	Nitrogenous addition	Wt. crop gm	N per cent	Grams N in crop	Average gm N in crop	Average gain of N	Per cent recovered
	Soil No. 33131						
1 DK	None	7.0	.49	.0343			
2 DK	None	8.5	.46	.0391	.0367		
3 DKNa	Nitrate of soda	21.6	.46	.0994			
4 DKNa	Nitrate of soda	20.7	.52	.1076	.1035	.0668	66.8
5 DKC	Cottonseed meal	13.0	.45	.0585			
6 DKC	Cottonseed meal	16.7	.46	.0768	.0677	.0310	31.0
7 DKS 1	Sludge, No. 26311, Brownsville (.15 gm N)	15.5	.45	.0698			
8 DKS 1	Sludge, No. 26311, Brownsville (.15 gm N)	13.5	.45	.0608	.0653	.0286	19.6
9 DKS 2	Sludge, No. 30180, San Benito (.15 gm N)	12.5	.44	.0550			
10 DKS 2	Sludge, No. 30180, San Benito (.15 gm N)	14.8	.47	.0696	.0623	.0256	17.1
	Soil No. 33135						
1 DK	None	14.2	.41	.0582			
2 DK	None	14.7	.44	.0647	.0615		
3 DKC	Cottonseed meal	19.7	.47	.0927			
4 DKC	Cottonseed meal	20.3	.44	.0893	.0910	.0295	29.5
5 DKS 4	Sludge, No. 31333, Alpine (.15 gm N)	22.2	.39	.0866			
6 DKS 4	Sludge, No. 31333, Alpine (.15 gm N)	20.7	.43	.0890	.0878	.0263	17.5
7 DKS 5	Sludge, No. 31334, Houston (.15 gm N)	46.8	.71	.3323			
8 DKS 5	Sludge, No. 31334, Houston (.15 gm N)	47.3	.76	.3595	.3459	.2844	18.9
9 DKS 1	Sludge, No. 26311, Brownsville (.15 gm N)	21.7	.46	.0998	.0998	.0383	25.5

Table 6. Percentages of nitrogen added recovered in the crop of corn.

	31885	31887	31889	33124	33131	33135	31116	22194
Nitrate of soda	57	61	52	66	67	----	44	54
Nitrate of soda (double amount)	----	----	----	----	----	----	----	54
Cottonseed meal	23	31	30	20	31	30	14	38
Cottonseed meal (double amount)	----	----	----	----	----	----	----	32
Digested sludge, No. 31012, Waco	28	4	2	----	----	----	----	----
Digested sludge No. 31011, El Paso	12	15	9	----	----	----	0	----
Digested sludge No. 31004, Greenville	----	----	----	11	----	----	----	----
Digested sludge No. 31333, Alpine	----	----	----	16	----	18	----	----
Digested sludge No. 26311, Brownsville	----	----	----	----	19	26	----	----
Digested sludge No. 30180, San Benito	----	----	----	----	17	----	0	----
Digested sludge No. 31014, College Station	----	----	----	----	----	----	0	----
Digested sludge No. 30179, College Station	----	----	----	----	----	----	7	----
Activated sludge No. 22210, Houston	----	----	----	----	----	----	----	27
Activated sludge No. 22210 (double amount used) Houston	----	----	----	----	----	----	----	37
Activated sludge No. 31334, Houston	----	----	----	----	----	19	24	----

was taken to be 100, and the quantities taken up by the crops from the other materials was expressed in percentages of this amount. With soil 33135, the standard was taken to be 45 per cent availability of nitrogen in cottonseed meal.

The availability of the nitrogen of the digested sludge in some cases was very low, in one case it was better than that of cottonseed meal, while in other cases is was nearly as good. The average of all the experiments on digested sewage sludge, gives an availability of 19 for its nitrogen compared with 100 for nitrate of soda, and 47 for cottonseed meal. If the results on sand 31116 are omitted, the comparative availability of the nitrogen of digested sludge is 23. The availability of the nitrogen of digested sewage sludge is about one-half of that of cottonseed meal and one-fourth of that of nitrate of soda. It is also less than that of barnyard manure, given by Lipman, Blair and Prince (9, 10) as about 50 per cent of that of nitrate of soda. However, this includes the residual effect of several years of application of the manure and was not confined to the first crop, as is the work here reported. While digested sewage sludge is not suitable for use in commercial fertilizers, on account of the low availability of the nitrogen and its low content of plant food, the dry sludge can be used locally to advantage, unless the cost of hauling is excessive.

The three pot experiments on the activated sludge gives its nitrogen an availability of about 55 per cent compared with about 50 for cotton seedmeal and 100 for nitrate of soda. The pot experiments on activated sludge confirm the work of other investigators and show that it has a good availability to plants, being approximately equal to cottonseed meal in this respect.

NITRIFICATION OF SEWAGE SLUDGE

Plants are incapable of directly absorbing and utilizing the nitrogen in most organic compounds. For this reason, the nitrogenous compounds of cottonseed meal, sewage sludge, and other organic materials, must be decomposed, and changed into ammonia and nitrates, before the nitrogen can be of any service to plants.

The production of nitrates from three samples of sewage sludge was compared with that produced from cottonseed meal in a number of soils. For the purpose of this work, material equivalent to 0.1 gram of nitrogen (equivalent to 500 parts per million of soil) was mixed with 200 grams of soil and water equal to one-half its saturation capacity, and incubated four weeks at 35°C. The soil was then mixed and nitrates determined by the phenol-disulphonic acid method. The quantity of nitric nitrogen in a sample of soil with no addition, incubated at the same time and under the same conditions, was deducted in order to correct for the nitrates produced by the soil alone (See Table 8).

There was considerable variation in the capacities of the various soils to convert the nitrogen in the added material to nitrates. The nitric nitrogen produced from the cottonseed meal varied from 16 to 321 parts per million of soil as shown in Table 8. The nitric nitrogen produced from

Table 7. Availability of nitrogen of sewage sludge compared with nitrogen of nitrate of soda as 100.

	Builders sand No. 22194	Soil No. 31116	Soil No. 31885	Soil No. 31887	Soil No. 31889	Soil No. 33124	Soil No. 33131	Soil No. 33135	Average
Nitrate of soda	100	100	100	100	100	100	100	----	100
Nitrate of soda (double amount)	100	----	----	----	----	----	----	----	100
Cottonseed meal	71	31	41	51	57	31	46	45	47
Cottonseed meal (double amount)	60	----	----	----	----	----	----	----	60
Digested sludge, No. 31012, Waco	----	----	49	6	3	----	----	----	19
Digested sludge, No. 31011, El Paso	----	0	20	24	17	----	----	----	15
Digested sludge, No. 31004, Greenville	----	----	----	----	----	17	----	----	17
Digested sludge, No. 31333, Alpine	----	----	----	----	----	25	----	27	26
Digested sludge, No. 26311, Brownsville	----	----	----	----	----	----	29	39	34
Digested sludge, No. 30180, San Benito	----	0	----	----	----	----	26	----	13
Digested sludge No. 31014, College Sta.	----	0	----	----	----	----	----	----	0
Digested sludge, No. 30179, College Sta.	----	16	----	----	----	----	----	----	16
Activated sludge No. 22210, Houston	49	----	----	----	----	----	----	----	49
Activated sludge No. 22210 (double amount used) Houston	68	----	----	----	----	----	----	----	68
Activated sludge No. 31334, Houston	----	55	----	----	----	----	----	----	55

Average digested sludge, sand 31116 excluded	23
Average digested sludge, (all 16)	19
Average digested sludge (3)	57

Table 8. Nitric nitrogen produced from sewage sludge in various soils (parts per million of soil).

Laboratory Number		Cottonseed meal	Digested sludge Dallas	Digested sludge Waco	Digested sludge
31332	Amarillo fine sandy loam, 7-19", Potter county	79	54	136	30
31882	Frio clay, 0-7", Frio county	268	58	133	58
31885	Hidalgo clay loam, 7-19", Frio county	224	30	130	65
31889	Webb fine sandy loam, 7-19", Frio county	25	0	83	57
29333	Midland fine sandy loam, 0-7", Midland county	268	50	123	43
29441	Lufkin fine sandy loam, 7-19", Brazos county	16	0	64	17
31326	Amarillo silty clay loam, 7-19", Potter county	39	0	111	26
31329	Potter clay loam, 0-7", Potter county	321	49	115	54
	Average (8)	156	30	112	44
	Per cent of nitrogen changed	31	6	22	9

the Waco digested sludge varied from 64 to 136 parts per million. The nitric nitrogen produced by the other two samples varied from 0 to 58 and from 30 to 65 parts per million. In some cases, more nitrates were produced from the sludge than from the cottonseed meal.

As previously pointed out by the author (4), the production of nitrates alone is not a good measure of the availability of nitrogen in an organic fertilizer, while the production of nitrates and ammonia together is a much better measure. This is due chiefly to differences in the capacity of different soils to convert ammonia into nitrates. It was not practical to determine both ammonia and nitrates produced in the experiments here reported; they were, in fact, performed with the object of ascertaining the effect of the various materials upon nitrification in different soils, and not with the object of measuring the availability of the materials. However, they afford some indications that nitrification of these materials varies in different soils, that different samples of sewage sludge may produce widely different quantities of nitrates, and that the results vary with different soils.

UTILIZATION OF SEWAGE SLUDGE

Dried activated sludge is a nitrogenous fertilizer in fertility content similar to cottonseed meal, and it can be used in the same way. It contains about 5 per cent of nitrogen, compared with 6.88 for 43 per cent protein cottonseed meal. Dried activated sludge contains less plant food than cottonseed meal, about 0.7 as much, and as its nitrogen has about the same availability as that of cottonseed meal, dried activated sludge may be considered, on an average, to have 0.7 the value of cottonseed meal. It can be used as a fertilizer in the same way cottonseed meal is used. It can be applied alone to soils which need nitrogen, at the rate of 300 to 700 pounds to the acre or more. It can be mixed with superphosphate for use in soils which need phosphoric acid as well as nitrogen. It can be mixed with superphosphate and potash salts to make a complete fertilizer but is usually used in combination with other nitrogenous fertilizers, on account of its low content of plant food. Sandy soils east of the Brazos river, in general, need both phosphoric acid and nitrogen, A mixture of 1,000 pounds of activated sludge (5 per cent nitrogen), 1,000 pounds of 20 per cent superphosphate, and 100 pounds of muriate of potash will give (in 2,100 pounds) the equivalent of 1,000 pounds of a 5-10-5 fertilizer or of 1,250 pounds of a 4-8-4 fertilizer, for home use. This has a good ratio of plant food for ordinary farm or garden use.

Dried activated sludge is being sold by the City of Milwaukee, Wisconsin, under the name of Milorganite, and by the City of Houston, Texas, under the name of Hu-Actinite.

Dried digested sewage sludge contains much more plant food than ordinary mixed farm manure (6), and a little more than either dried hen manure or dried sheep manure (see Table 9). It is not as good a material to furnish humus for the soil as farm manure, as it contains much less

Table 9. Composition of dried digested sludge compared with composition of farm manure.

	Nitrogen per cent	Total phosphoric-acid per cent	Potash per cent	Water per cent
Digested sludge (dried)	1.9	1.6	0.2	6
Fresh solid horse manure	0.6	0.3	0.4	75
Fresh solid cow manure	0.4	0.2	0.1	70
Fresh solid sheep manure	0.8	0.5	0.4	67
Dried hen manure	1.5	1.2	0.6	10
Farm manure, average	0.5	0.3	0.5	---

organic matter capable of forming humus. Wet digested sludge contains less plant food than the dry digested sludge, in proportion to the quantity of water present. The availability of the nitrogen in digested sludge is about half that of nitrogen in cottonseed meal; while low, the availability of the nitrogen is sufficiently high to justify its utilization.

Dried digested sludge does not contain enough plant food to justify its commercial use or shipment to any distance. Its manurial value is sufficiently high for those in a vicinity of a sewage disposal plant to take advantage of the opportunity to utilize it.

Partly dried digested sludge should be handled in about the same way as farm manure. It may be applied broadcast at the rate of 10 to 40 tons to the acre, and turned under or harrowed in before the crop is planted. It should not be applied to growing cultivated crops. On some soils, it would be advisable to supplement it with 200 pounds of superphosphate to the acre or even a complete fertilizer may in some cases be used with advantage to supplement it.

Activated sludge as it comes from the tank, when it usually contains 98 to 99 per cent water, may be applied to land near the sewage plant by means of ditches and irrigating furrows. Wet digested sludge, which contains 87 to 90 per cent water, may be applied in a similar way, though additions of water may be necessary to cause it to flow readily.

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SUMMARY

Sewage sludge is a by-product from the purification of sewage and is produced by several hundred cities and towns in Texas.

Digested sludge is produced by most of the sewage purification plants in Texas, and is the residue from the extensive decomposition of the organic matter of the sewage. It is composed chiefly of ash and of insoluble organic matter which has resisted the processes of decomposition.

The activated sludge is produced by only one or two cities in Texas. It is produced by the decomposition of sewage and settling of the sewage solids by means of protozoa and other organisms. It consists of insoluble solids from the sewage and the bodies of organisms.

Sewage sludge is variable in composition. Its composition depends upon the composition of the sewage and on the time and temperature of the treatment, as well as on the details of the treatment and of the particular apparatus used. Activated sludge is less variable than digested sludges. Dried digested sludge contains, on an average, about 1.9 per cent nitrogen,

1.6 per cent total phosphoric acid, of which about 1.1 per cent is available and 0.5 per cent insoluble, and 0.2 per cent potash.

Activated sludge when dried usually contains over 5 per cent of nitrogen and 2 per cent of available phosphoric acid, with about 0.2 per cent of potash. It has about 70 per cent of the fertilizing constituents of cottonseed meal.

The dried sludges contain 33 to 76 per cent of ash, chiefly insoluble in acid. They also contain appreciable amounts of nitrogenous material, and variable, though large, amounts of grease. Some pentosans and crude fiber are also present.

The availability of the nitrogen of sewage sludge was estimated by means of pot experiments on eight different soils or sands.

The availability of the nitrogen of digested sewage sludge was variable, and averaged about one-half of that of cottonseed meal.

The availability of the nitrogen in the activated sludge was about equal to that of cottonseed meal. This agrees with the conclusions of other investigators as to the value of activated sludge as a fertilizer.

The nitrogen of activated sludge also passes the chemical tests for activity.

The nitrification of sewage sludge varied in different soils, being quite low in some soils and much better in others.

Dried activated sludge is a nitrogenous fertilizer similar to cottonseed meal and has about seven-tenths of its value. It can be used alone or in the preparation of mixed fertilizers.

Dried digested sewage sludge contains somewhat more plant food than farmyard manure but is a poorer source of humus. The availability of its nitrogen is about half that of cottonseed meal. It can be utilized in field or garden crops in the same way as farm manure by those sufficiently near to a sewage disposal plant to be able to haul it at a low cost.

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