Digested Sewage Sludge for Soil Improvement

Herbert A. Lunt

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CONTENTS

WORK HERE REPORTED

Digested sewage sludges, typical of those produced in Connecticut municipalities, were applied to soil in which plants were grown. Such treatment usually improved the soil and frequently increased plant growth. Some sludges contained materials toxic to plants, probably metals. The addition of lime prevented this toxicity.

A variety of plants were grown during the course of these experiments, and data are given on the changes in growth or composition of these plants.

The Author

Herbert A. Lunt retired from the active staff of the Station in 1955 as soil scientist, Department of Soils.

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All spectrographic analyses reported in this bulletin were made in the Department of Analytical Chemistry (Mathis, W. D. Anal. Chem. 25:943-47, 1953).

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Connecticut sewage treatment plants produce more than 30,000 tons of digested sludge annually, and the amount is increasing with the growth of our cities and larger towns. Most of this vast quantity of sludge is either dumped or incinerated.

Analysis of digested sludges shows about 50 per cent organic matter, plus considerable available plant food. Except for potash, digested sludge compares rather favorably with farm manure, both in analysis and in demonstrated usefulness.

Maintenance of soil organic matter is a serious problem on our intensively cropped farms, especially since stable manure has become very limited in supply. Digested sewage sludge is a good substitute, but offers some minor problems that the experiments here reported attempted to solve.

During the Second World War, when commercial fertilizers were in short supply, interest in sludge was quite active (15). At that time some preliminary tests were made in the Station greenhouses. Certain problems were noted in the use of several Connecticut sludges on some vegetable crops (9). After the War much more detailed studies were made in greenhouse, laboratory, and field.

Kinds of Sewage Sludges

Sewage sludges vary widely in composition and properties, depending on the type of treatment and the sources of the sewage, but they can be grouped as follows:

Raw, also known as plain settled or primary sludge, is a lumpy material with an offensive odor. A potential carrier of pathogenic bacteria, it is not recommended for use on the soil.

Digested, of which there are several kinds, depending on the treatment process. Following the primary sedimentation, the sludge is subjected to anerobic decomposition which changes much of the organic matter to gases and soluble compounds and destroys most of the pathogenic bacteria. Ferric chloride and lime may be added to facilitate filtration. The sludge is either partially dried on filter beds in the open or under glass, or is dewatered on rotary vacuum filters. All of the work reported in this publication was done on digested sludges, primarily because most of the Connecticut treatment plants produce this type of sludge.

Activated, in which the sewage from the primary tanks is inoculated with previously processed sludge and treated with large volumes of air, resulting in aerobic decomposition. When dried and ground the sludge is relatively high in nitrogen, free of pathogenic organisms, and can be bagged and sold as fertilizer. Several brands of activated sludge are on the market. The Milwaukee product, Milorganite, was the first to appear and is the best known in this area.

Literature

Studies on sewage sludge utilization prior to 1946 were reported by the Committee on Sewage Works Practices of the Federation of Sewage Works Associations (5). Sludge was sometimes found to be about as effective as manure, but in other instances the benefits were uncertain. The chief conclusion of the Committee concerning digested sludge was that more and better experimentation was needed in order to properly evaluate sludges for soil improvement.

Bear and Prince (3) compared a digested sludge with (a) two undigested moist sludges, (b) an activated sludge, and (c) cow manure. A study of the properties of these materials and of their use in greenhouse and field led to the conclusion that when sludge is reinforced with potash fertilizer it is as effective as cow manure in increasing corn yields. Objectionable odors from undigested sludges could be controlled by plowing under or otherwise mixing it with the soil. The rate of application was 20 tons of moist material per acre.

A British paper (2) states that sludge from drying beds did not have the crop-producing power of equal quantities of manure. Digesting and shredding or mechanically drying the sludge improved its physical condition and increased the rate of availability of its nitrogen. When straw was composted with sludge, the resulting product had a beneficial effect on the physical properties of the soil.

Rost (11) compared 10 and 20 tons per acre of sludge with the same amounts of barnyard manure. He found that where phosphorus and potassium were adequate in the soil or were supplied by fertilizers, sludge was equal to manure in yield-increasing ability and in residual effects on succeeding crops.

Among the papers on sludge appearing since our work at The Connecticut Station was concluded, the following are of particular interest. Anderson (1) described the several kinds of sludges and compared chemical composition with manure and with several other organic fertilizers. He found that phosphorus varies considerably in digested sludges, and potassium is always low. Sludges are typically high in trace element content.

Toth and Kelly (14), in a study of organic wastes on the farm, presented a table giving the percentage of moisture, ash, nitrogen, P_2O_5, and potash in a large number of different materials, including sewage sludge. However, the 1.7 per cent potash given in the table is not typical of digested sludges which are generally lower in potash.

Sciaroni and O. R. Lunt (12), on the basis of their own data and some supplied by Anderson (1), found that under laboratory conditions

Table 1. Principal characteristics of sewage sludges from six Connecticut sources

Source of sludge	New Haven	Stamford	Torrington	Wallingford	Waterbury	West Haven
	Type of sludge					
Physical and chemical characteristics	Digested; $FeCl_3$ and lime; vacuum filtered	Digested; $FeCl_3$ lime; vacuum filtered; flash dried	Digested; air dried on sand beds	Digested (Imhoff tanks) dried on sand beds	Raw, primary; $FeCl_3$ and lime; flash dried	Elutriated; digested $FeCl_3$; vacuum filtered
Moisture content (moist basis, per cent	72	6	69	66	8	71
as sampled (oven dry basis, per cent ..	257	6	223	191	9	245
pH as used	7.5	4.9	5.6	6.7	7.9	6.0[1]
Loss-on-ignition, per cent oven dry	42	54	43[2]	41	71	56
Total nitrogen, per cent air dry	1.5	1.8	2.3	1.3	1.6	2.5
Organic carbon, per cent air dry	29	......	28	25	50	36
Total phosphorus, per cent air dry	0.67	0.27	0.58	0.31	0.50	0.60
Total potassium	VL[3]	VL[3]	VL[3]	VL[3]	VL[3]	VL[3]
Total calcium, per cent air dry	4.3	1.1	1.1	1.5	3.6	1.9
Total magnesium, per cent air dry	0.26	0.32	0.18	0.22	0.17	0.14
Cation exchange capacity air dry me./100 g. ..	25	......	27	18	23	32
Weight per cu.yd. as delivered, lbs.	1085	500[4]	1450	1378	428	1210[4]
Weight per cu.yd. water free, lbs.	300	477[4]	627	472	404	350[4]
Industrial waste	Some textile dyes	No appreciable amount	Wool scouring and metal-plating wastes	No appreciable amount	Large amounts of metal-plating wastes	No appreciable amount

[1]Subsequent samples tested 5.2 and 4.5.

[2]Average of six samples which ranged from 29 to 51%.

[3]VL—very low.

[4]Estimated.

digested sludge nitrified much more slowly than did activated sludge, hoof and horn meal, bloodmeal, and urea-formaldehyde nitrogen fertilizers. From field experience they learned that digested sludge releases available nitrogren slowly over prolonged periods.

CHARACTER AND COMPOSITION OF TYPICAL CONNECTICUT SLUDGES

The principal characteristics of the six Connecticut sludges used in one or more of the experiments are given in Table 1.

The New Haven sludge was produced in the Boulevard plant. As taken from the conveyor belt, the sludge has a pH of about 11, but upon exposure to the air it loses ammonia and the pH gradually drops to 7.5 or 8.0. Aside from a small quantity used by local home gardeners, the New Haven sludge is incinerated at the plant. Torrington sludge is shredded and sold to local city people. Little of the other sludges are used for soil improvement. Four of the six sludges contain industrial wastes.

Table 2. Trace-element content and pH of Connecticut sewage sludges and of other organic materials

Source	B p.p.m.	Cu p.p.m.	Mn p.p.m.	Zn p.p.m.	pH
Bristol	210	540	210	3570	6.1
Hartford	360	830	280	3200	5.4
New Haven	190	830	190	3280	7.5
Torrington	160	1025	135	3170	5.7
West Haven	225	465	105	2200	6.2
Waterbury	265	760	170	2540	7.9
Ave. of municipal plants[1]	211	758	172	3205	6.1
Ave. of state institutions[2]	148	535	110	2433	5.8
Milorganite	38	500	170	2000	5.0
Peat Moss	31	24	30	Trace	4.0
Cow manure	38	61	150	210	.....
Peat soil	50	5	40	Trace	5.5
Forest litter (hardwoods)	40	54	2800	150	4.5

[1]Based on 25 to 31 samples from 12 plants: Danbury, North Manchester, Stamford, Tariffville, Wallingford, Watertown, and those listed above.

[2]Based on six samples from five plants: Farm and Prison for Women, Niantic; Connecticut State Hospital, Middletown; Fairfield State Hospital, Newtown; Mansfield State Training School and Hospital, Mansfield; Southbury Training School, Southbury.

Some earlier analyses of one or two Connecticut sludges had shown appreciable amounts of copper and zinc. To obtain additional information on trace element content, a spectrographic analysis was made of a number of sludges produced in municipal treatment plants and, for comparison, of sludges from five State institutions, free from industrial wastes. Also included was a sample of commercial, dried activated sludge (Milorganite), peat moss, manure, and several other organic materials. The results of the analyses are given in Table 2.

It is readily seen from the table that boron, copper, zinc, and, to a lesser extent, manganese are higher in sludges than in peat moss and the other forms of organic materials. One exception is forest litter which contained at least 10 times as much manganese as did sludge. Other analyses of forest litter have likewise shown very high concentrations of manganese.

Comparing sludges from municipal plants with those from State institutions, the data show a somewhat lower trace element content in the institutional sludges, but the differences are much smaller than had been anticipated.

EXPERIMENTAL

Outline of Experiments

Eleven experiments were conducted during the period 1949-1955 as follows:

A. Greenhouse pot cultures.

Experiment I. Comparison of New Haven and Torrington sewage sludges: (a) on seed germination and root injury in Cheshire loam in the 1949 growing season. This work was supplemented by further germination tests in the laboratory, and (b) on plant growth, plant composition, and soil properties from data obtained during the cropping with six successive crops (beets and spinach). This was followed by a slight revision of treatments and the growing of two more crops, 1951-52.

Experiment II. A comparison of three rates of application of Torrington and West Haven sludges in Hartford loamy sand, at two pH levels, on plant growth, plant composition, and soil properties, 1951-53. The crops were oats, beans, and turnips on the acid soils, and beets and spinach on the neutral soils.

Experiment III. Comparison of four sludges (New Haven, Torrington, Waterbury, West Haven) and two rates of application on plant growth and soil properties, in Hartford loamy sand, 1953-54.

Experiment IV. Comparison of three sludges (New Haven, Stamford, Torrington), manure, and peat moss in potting mixtures, 1954-55.

Experiment V. Pot culture studies on copper and zinc toxicity.

B. Outdoor soil frames containing Cheshire loam.

Experiment VI. The effect of two rates of New Haven and Torrington sludges on plant growth, plant composition, and soil properties (three beet crops and one of snapdragons), 1950-53. This was followed by a slight revision of treatments on which one crop of beets was grown.

C. Field plot work.

Experiment VII. Covering three corn crops on Cheshire loam at Mt. Carmel Farm, 1950, 1951, and 1953, using New Haven sludge.

Experiment VIIa. Torrington sludge used at Peoples State Forest on Merrimac sandy loam in which coniferous tree seedlings were grown two years from seed, 1951-53.

Experiment VIIb. Budded apple trees in a commercial nursery on Hartford sandy loam, 1952-54, using Wallingford sludge.

D. Further studies on seed germination.

E. Comparative leaching qualities of manure and sludge.

The general procedure was to incorporate sludge into the soil, then grow successive crops without further additions of sludge. Yields of the crop were recorded and the soils quick-tested from time to time. Quantitative physical and chemical analyses were made on the soil at various times to determine what improvement, if any, had been brought about by the treatments. Unless specified otherwise, all pot culture and seed germination work was carried out with topsoil (plow layer) of the soil in question.

The principal findings from these experiments are presented under three general headings: (a) effect of sludge on soil properties; (b) effect on the growing plant, and (c) a comparison of sludge and manure with respect to their ability to retain nutrients against leaching.

Methods of Analysis

Quick tests were made by the Morgan method[1]. *Soil reaction* was determined in a thin paste soil-water suspension by means of a glass electrode pH meter; *total nitrogen* by the Gunning method; *organic carbon* by the wet combustion method of Schollenberger[2], and *cation exchange capacity* according to Chandler's[3] barium acetate-electrometric titration method.

The physical tests included *moisture equivalent* determined by the centrifuge method of Veihmeyer[4]; *field moisture capacity* by sampling the soil within 48 hours after a very heavy rain; *bulk density* by obtaining the dry weights of 250 ml. core samples; *water-holding capacity* by soaking the core soil samples overnight, then determining the moisture remaining after the soils had drained 24 hours on a thick mat of newspapers; total *pore space, capillary* and *non-capillary* by standard methods[5,6]; and *aggregate analysis* by a modification of the Yoder method as used by Swanson, Hanna, and de Roo[7].

1Conn. Agric. Expt. Sta. Bul. 541, 1950.
2Soil Science 40:311-320, 1935.
3Jour. Agr. Res. 59:491-506, 1939.
4Proc. First Internatl. Cong. Soil Sci. Washington 1:512-534, 1927.
5Jour. Am. Soc. Agron. 33:1003-1008, 1941.
6Baver, L.D. Soil Physics. John Wiley and Sons, New York, 1948.
7Soil Science 79:15-24, 1955.

Effect of Sludge on Soil Properties

Although there were variations in the net effect of sludge on the soil, depending on the materials used, rate of application, character of the soil, and other factors, there was no question as to the beneficial effects from sludge treatments. This is illustrated by the data in Table 3 for greenhouse pot cultures and Table 6 for the outdoor soil frames.

Soil in greenhouse pots was treated with sludge in the fall of 1951. The crops shown in Table 8 were grown in the soil. Total nitrogen and organic carbon were increased by 4 to more than 80 per cent over the checks, but the carbon-nitrogen ratio was not affected. Total soluble salts increased markedly. Cation exchange capacity was increased in the greenhouse pot soil up to a maximum of 27 per cent, and in the soil frames to 146 per cent. The amount of aggregates greater than 1 mm. was raised in practically all cases and more or less in relation to the rate of sludge application. The maximum in the greenhouse pots was 365 per cent and in the soil frames, 78 per cent. Both New Haven and West Haven sludges were more effective in increasing aggregation than was Torrington sludge.

Bulk density was decreased appreciably by sludge. Non-capillary pore space in the soils in the frames was increased somewhat (8 to 19 per cent), as was moisture equivalent and field-moisture capacity.

Changes in soil reaction depended largely on the pH of the sludges applied. Acid sludges usually lowered the pH and neutral to alkaline sludges raised it. However, the changes were not proportional to the rate of application.

Of special interest are the effects of modification in the soil frame treatments. Early in 1954 manure and woodchips were applied as shown in Table 4 to add more organic matter and at the same time reduce the amount of available nitrogen initially released. It was estimated that 50 cu.yds. of New Haven sludge added 225 pounds of nitrogen, and the same volume of Torrington sludge added 780 pounds, and of manure 320 pounds of nitrogen. Analyses of soil samples collected following the 1954 crop reported are reported in Table 5.

All treatments with organic matter produced increases in the properties measured — not significant in cation exchange capacity, but highly significant in field-moisture capacity, loss-on-ignition, and aggregates 1 to 2 mm. and over 2 mm. in size.

No quantitative data were obtained on soil properties in the field as influenced by sludge treatment. Usually the effect is less pronounced and more difficult to measure in the field.

Small-scale treatments of garden soils, however, have markedly improved the physical condition of the soils.

Table 3. Effect of Torrington and West Haven sludges on soil properties

Greenhouse experiment II, Hartford loamy sand

Sampling dates	Acid series							"Neutral" series[2]						
		Torrington sludge[1]			West Haven sludge				Torrington sludge			West Haven sludge		
	Check	65	130	260	65	130	260	Check	65	130	260	65	130	260
	pH													
Jan. 1952	5.0	5.1	5.2	5.3	4.9	4.8	5.1	5.9	6.1	6.2	6.2	5.6	5.5	5.5
June 1952	5.7	5.6	5.7	5.7	5.4	5.2	5.4	6.7	6.5	6.4	6.5	6.6	6.3	6.1
Feb. 1953	5.7	5.5	5.4	5.3	5.3	5.2	5.1	6.2	6.4	6.4	6.4	6.0	6.7	6.7
June 1953	5.5	5.3	5.4	5.5	5.4	5.3	5.7	6.5	6.6	6.6	6.5	6.5	6.7	6.7
	Total N, per cent													
June 1952	.070	.093	.103	.126	.085	.085	.114	.077	.077	.094	.121	.079	.083	.102
June 1953	.062	.084	.085	.119	.079	.078	.088	.062	.071	.092	.122	.080	.083	.104
Ave. Rel.	100	134	142	186	124	123	153	105	112	141	184	120	141	156
	Organic C, per cent													
June 1952	0.75	1.04	1.09	1.42	.77	.77	0.97	0.73	0.81	0.77	1.14	0.87	1.08	1.38
June 1953	0.88	.97	1.07	1.37	.93	1.03	1.17	.81	.95	1.06	1.38	.91	1.04	1.32
Ave. Rel.	100	123	133	171	104	110	134	94	108	112	155	109	130	166
	Total soluble salts as a per cent of the 715 p.p.m. in the check													
June 1953	100	154	124	175	114	222	298	222	211	211	298	224	315	336
	Cation exchange capacity as a per cent of the 5.42 me./100 g. in the check													
June 1953	100	105	111	122	105	99	114	109	109	115	125	110	116	127
	Aggregates >1 mm. as a per cent of the 1.39 per cent in the check													
June 1952	100	105	197	242	130	282	442	91	90	215	258	224	239	465

[1]Cubic yards per acre.

[2]Limed to reduce the danger of trace element toxicity.

Table 4. Original and revised treatments in the soil frames

Cheshire loam

Series I and III: Original treatments	Series I and III: Revised treatments 1954	Series II and IV: Original treatments	Series II and IV: Revised treatments 1954
	pounds or cu.yds. per acre		
Check	Check	Check	Check
200 lbs. of nitrogen	170 lbs. of nitrogen[1]	400 lbs. of nitrogen	170 lbs. of nitrogen
New Haven sludge 100 cu.yds.	New Haven sludge, 50 cu.yds.	New Haven sludge, 100 cu.yds. plus 200 lbs. N.	New Haven sludge, 50 cu.yds. plus oak chips, 20 cu.yds.
New Haven sludge 200 cu.yds.	New Haven sludge, 50 cu.yds. plus oak chips, 20 cu.yds.	New Haven sludge, 200 cu.yds. plus 400 lbs. N.	New Haven sludge, 50 cu.yds.
Torrington sludge 77 cu.yds.	Torrington sludge, 50 cu.yds.	Torrington sludge, 77 cu.yds. plus 200 lbs. N.	Torrington sludge, 50 cu.yds. plus oak chips, 20 cu.yds.
Torrington sludge 154 cu.yds.	Torrington sludge, 50 cu.yds. plus oak chips, 20 cu.yds.	Torrington sludge, 154 cu.yds. plus 200 lbs. N.	Torrington sludge, 50 cu.yds.
Birch chips 50 cu.yds.	Manure, 50 cu.yds.	Birch chips, 50 cu.yds. plus 200 lbs. N.	Oak chips mulch, 50 cu.yds.
Birch chips 100 cu.yds.	Oak chips mulch, 50 cu.yds.	Birch chips, 100 cu.yds. plus 400 lbs. N.	Manure, 50 cu.yds.
Pine chips 80 cu.yds.	Manure, 50 cu.yds. plus oak chips, 20 cu.yds.	Pine chips, 80 cu.yds. plus 200 lbs. N.	Pine chips, 50 cu.yds. plus 90 lbs. N.[2]
Pine chips 160 cu.yds.	Pine chips, 50 cu.yds. plus 90 lbs. N.	Pine chips, 160 cu.yds. plus 400 lbs. N.	Manure, 50 cu.yds. plus oak chips, 20 cu.yds.

[1]Nitrogen equivalent to the amount used with 50 cu.yds. oak chips, i.e. 0.75% of dry weight of oak chips.

[2]Nitrogen equivalent to the amount used with 50 cu.yds. pine chips, i.e. 0.75% of dry weight of pine chips.

Table 5. Effect of manure and sewage sludge, with and without woodchips, on soil properties, 1954

Soil frame experiment, Cheshire loam

	Check	+ chips	Manure	+ chips	New Haven sludge	+ chips	Torrington sludge	+ chips
	Sampled Oct. 1954							
Field moisture capacity as a per cent of 22.8% dry weight in the check.[1]	100	97	113	115	108	115	121	124
Cation exchange capacity as a per cent of 0.93 me./100 g. in the check.[2]	100	106	111	110	109	125	117	108
Loss-on-ignition as a per cent of 5.15% in the check.[1]	100	103	117	116	112	119	132	131

[1]Highly significant differences (1% point).

[2]No significant differences.

Effect of Sludge on Plants

Seed germination

In the first experiment with sewage sludge, a parallel series was prepared and used to determine what effect, if any, sludge had on germination of lettuce and radish seed. Also the seedling roots were examined for possible injury. Two sludges – New Haven and Torrington – were used in 2-gallon pots at the rate of 10 tons of dry matter per acre.

Both sludges had an adverse effect as shown by the following percentages of germination:

First trial:

Check: 51%; New Haven sludge 31%; Torrington sludge 21%

Second trial:

Check: 70% New Haven sludge 3% Torrington sludge 30%

No injury to seedling roots could be detected.

Following these trials, a laboratory experiment was conducted with aqueous extracts of sludge. Samples of both New Haven and Torrington sludges, and, for comparison, rye grass and woodchips, were incubated 11 and 31 days, after which 20 lettuce seeds were placed on heavy blotting paper and treated with each of the several extracts. A water extract of fresh, unincubated material was included.

The general outcome of these tests was as follows: (a) New Haven sludge caused the greatest reduction in germination, with Torrington

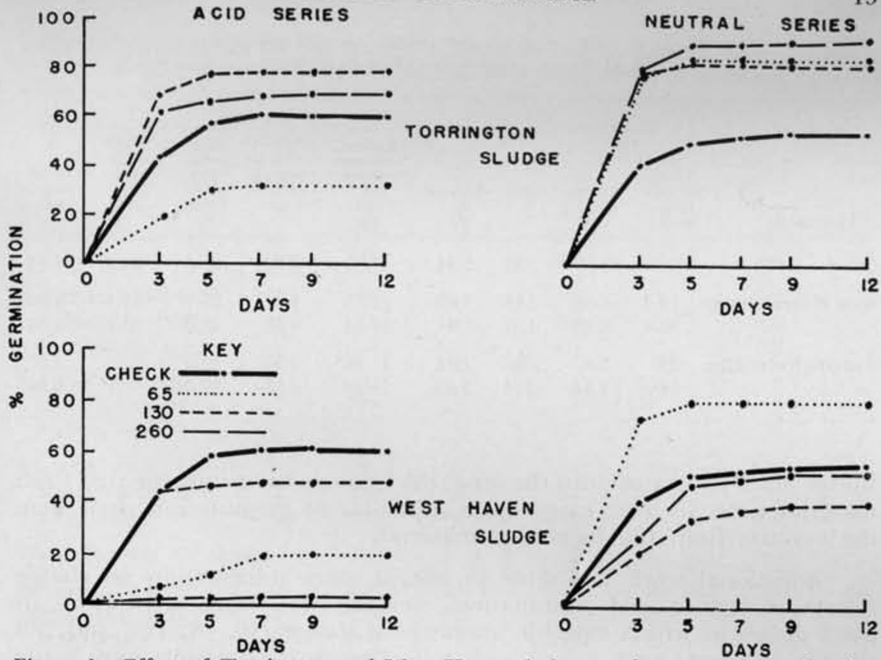

Figure 1. Effect of Torrington and West Haven sludges on lettuce seed germination in the greenhouse pots used in Experiment II, September 1952. The rates of application were 65, 130, and 260 cu.yds. per acre.

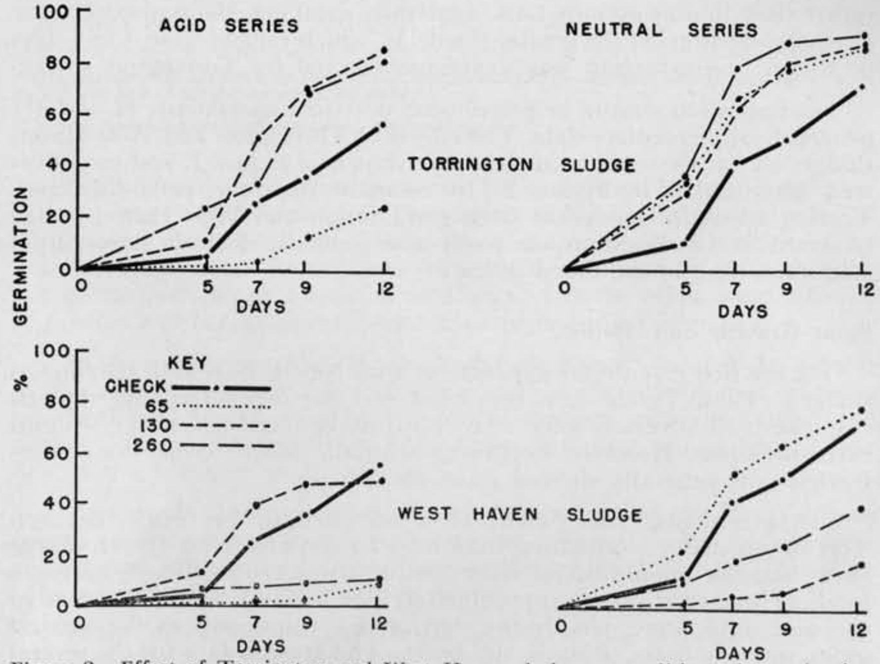

Figure 2. Effect of Torrington and West Haven sludges on radish seed germination in the greenhouse pots used in Experiment II, September 1952. The rates of application were 65, 130, and 260 cu.yds. per acre.

Table 6. Effect of sewage sludge on soil properties
Soil frame experiment, Cheshire loam

Treatments	Tons per acre (dry basis)	August 1950 pH	1952 sampling: Total N %	Organic C %	Cation exchange capacity me./100 gm.	Aggregates > 1 mm. %	Non-capillary pore space %	Field moisture capacity %	Bulk density (water = 1.0)
Check		5.77	.126	1.41	11.57	5.26	25.3	24.3	1.13
New Haven sludge	18.4	6.68	.144	1.69	12.33	8.04	27.7	25.1	1.09
	36.8	6.88	.170	1.98	12.61	9.39	28.5	25.8	1.07
Torrington sludge	29	5.67	.180	1.98	11.93	6.57	30.0	27.2	1.05
	58	5.44	.214	2.53	11.88	6.21	29.8	29.9	0.99

sludge next, and woodchips the least, (b) Extracts from unincubated fresh material were, in most cases, more injurious to germination than were the extracts from the incubated material.

Additional work was done to obtain more information on sludge effects on lettuce seed germination. Several trials were carried out in petri dishes in which variable amounts of sludge (16, 48, 144, and 288 cu. yds. per acre) were mixed with soil. Germination counts were made at intervals ranging up to a maximum of 21 days.

These trials showed that the principal effect of sludge was to delay rather than inhibit germination. Generally speaking, the higher the rate of sludge application the greater the delay, which ranged from 4 to 7 days or longer. Germination was sometimes favored by Torrington sludge.

Germination counts in greenhouse pots in Experiments II and III provided supplementary data. The effects of Torrington and West Haven sludges on lettuce seed germination are shown in Figure 1, and on radish seed germination in Figure 2. In common with the petri-dish tests, Torrington sludge tended to favor germination and West Haven sludge to retard it. Germination was lower and generally delayed more in the acid series than in the limed series.

Plant Growth and Yields

In the first greenhouse experiment with New Haven and Torrington sludges, (Table 7), the first beet crop and the two succeeding spinach crops were all adversely affected by both sludges, either with or without extra nitrogen. However, beginning with the fourth crop, the sludge-treated pots generally showed increases.

In greenhouse Experiment II a comparison was made between Torrington sludge (containing industrial wastes) and West Haven sludge (with little or no industrial waste), using three rates of each, and two levels of soil reaction, — approximately pH 5.4 and 6.5. The crops in the acid series were oats, beans, oats, and turnips, and in the neutral series, spinach, beets, spinach, and beets. The growth data for the several successive crops are given in Table 8.

Table 7. Yields of five successive crops on Cheshire loam in greenhouse experiment I
Fresh weight in grams, averages of three or six replicates as indicated

	Inorganic nitrogen applied[1]	Check: Entire plant	Check: Roots only	New Haven sludge: Entire plant	New Haven sludge: Roots only	Torrington sludge: Entire plant	Torrington sludge: Roots only
1st crop, BEETS	0	229	90	220	31	207	25
March—June 1949	½	275	109	214	33	267	39
3 replicates	1	320	114	203	25	240	30
2nd crop, SPINACH	0	33	......	1.2	....	2.3	....
Aug.—Nov. 1950	½	28	......	0.6	....	1.3	....
3 replicates	1	32	......	1.7	....	0.9	....
3rd crop, SPINACH	0	32	......	11	....	8	....
Jan.—March 1950	½	25	......	11	....	11	....
6 replicates	1	29	......	10	....	9	....
4th crop, BEETS	0	97	33	161	44	172	39
March—June 1950	½	132	59	167	51	134	41
6 replicates	1	137	67	178	53	176	58
5th crop beets, no results							
6th crop, BEETS	0	165	65	253	89	254	75
Feb.—May 1951	½	159	77	223	89	259	83
3 replicates	1	200	78	242	91	252	80
7th crop, SPINACH Nov.—Dec. 1951	[2]	20	....	66	....	66	....
8th crop, BEETS Jan.—May 1952	[2]	166	36	236	57	247	36

[1]Extra nitrogen was applied only prior to the first planting. The nitrogen rate was equivalent to ½ or to 1 per cent of the dry matter in the sludges.

[2]The pots containing the three rates were combined into one.

In 62 of 66 comparisons shown in Table 8, West Haven sludge produced higher yields than did Torrington sludge. Comparing rates of application, the highest rate resulted in a dropping off of yields of oats, beans, and spinach. Bean leaves were made chlorotic by both sludges, but particularly by that from West Haven. On the other hand, growth of turnips and beets increased with each increase in sludge rate.

In the soil frames, New Haven sludge more than doubled the growth of the first beet crop, and did almost as well in the second crop, but was not beneficial to the third crop. Extra nitrogen without sludge gave almost as large increases, thus indicating that most of the benefit was due to the nitrogen in the sludge.

Torrington sludge, however, had a toxic effect on the plants due to copper and zinc that were soluble in the acid soil. This toxicity was accentuated when extra nitrogen was included with the sludge. However, it largely disappeared for the third crop.

When soil acidity was corrected with lime, the plants treated with Torrington sludge made somewhat better growth than was made on the other treatments.

Table 8. Yields of four successive crops on Hartford loamy sand in greenhouse experiment II, relative fresh weights, averages of two replicates[1], treatments in cu.yds. to the acre

Acid series

	Check	Torrington sludge 65	Torrington sludge 130	Torrington sludge 260	West Haven sludge 65	West Haven sludge 130	West Haven sludge 260
OATS, entire above ground part, Jan. 1952 as a per cent of 39.5 g. from the check pot.	100	165	182	125	223	250	157
BEANS, harvested beans plus plants after harvest May 1952 as a per cent of 150 g. from the check.	100	116	139	108	121	149	87
OATS, entire above ground part, Jan. 1953 as a per cent of 88 g. from the check.	100	99	97	59	106	110	80
TURNIPS, entire plant May 1953 as a per cent of 190 g. from the check.	100	117	139	180	116	151	320
Turnip roots as a per cent of 24 g. from the check.	100	92	96	275	146	216	700

"Neutral" series

	Check	Torrington sludge 65	Torrington sludge 130	Torrington sludge 260	West Haven sludge 65	West Haven sludge 130	West Haven sludge 260
SPINACH, entire above ground part, Dec. 1951 as a per cent of 16.3 g. from the check.	100	67	55	34	91	88	47
BEETS, entire plant May 1952 as a per cent of 259 g. from the check.	100	116	135	152	146	159	160
Beet roots as a per cent of 79 g. from the check.	100	100	128	158	140	108	108
SPINACH, entire plant above ground, Feb. 1953 as a per cent of 10.5 g. from the check.	100	102	107	41	122	168	258
BEETS, entire plant May 1953 as a per cent of 69 g. from the check.	100	163	197	284	171	302	322
Beet roots as a per cent of 16 g. from the check.	100	171	238	287	216	358	358

[1]Initially intended to be a preliminary trial, only 2 replicates were used. The good agreement obtained in the yield and analytical data indicate reliable differences between treatments in most instances.

A snapdragon crop in the soil frames in 1953 showed considerable variation between replicates and the average yield of the sludge-treated plants was appreciably lower than the checks. There was no evidance either in weights of flowers and plants, height of stem, or number of blooms per plant, that the sludge treatments were in any way beneficial to the crop. Possibly the rate of fertilization was too high.

Before sowing the final crop (beets), woodchips were applied to some of the sludge-treated frames, and manure – both alone and with chips – to other frames previously treated with chips. The yield data are given in Table 9. Best yields were obtained from manure. Chips reduced yields of the manure and the New Haven sludge treatments but resulted in some increase when combined with Torrington sludge.

Table 9. Effect of manure and sewage sludge on beet yields
Soil frames, 1954 (Cheshire loam), averages of four replicates

	Check	Check + N	Manure	Manure + chips	New Haven sludge	New Haven sludge + chips	Torrington sludge	Torrington sludge + chips
	Fresh weight per frame(.0001 of an acre)							
Whole plant as a per cent of 1079 g. from the check	100	162	190	162	173	98	119	137
Beet roots as a per cent of 719 g. from the check	100	155	185	155	145	92	97	119

In the field, New Haven sludge applied in December on a rye cover crop, at the rates of 67 and 133 cu. yds. to the acre had a conspicuously beneficial effect on growth and color prior to plowing under in the spring. Following the rye, there were three successive corn crops on the same land (with no additional sludge treatment). The first crop yields were increased 26 to 36 per cent by sludge (highly significant). The second crop showed a significant, 10 to 13 per cent lower yield than the checks; in the third year there was a small increase on the sludge plots.

Additional plots treated later with either 10 tons of New Haven sludge or 17.5 tons of Torrington sludge per acre had no beneficial effect on corn yields. Unusually favorable growing conditions the second year undoubtedly accounted for the lack of response to sludge treatment.

The application of Torrington sludge to forest nursery beds at rates of 50 and 150 cu.yds. per acre resulted in no consistent increase in seedling growth (white pine, red pine, Norway spruce, and white spruce). Here again, soil acidity was an important factor – the pH being generally below 5.2. Also, the fertility level was fairly high due to the rather high rates of fertilization.

The last field experiment was carried out in a commercial nursery on Hartford sandy loam. Sludge from the Wallingford treatment plant was applied in October 1951 at rates of 50 and 150 cu.yds. per acre, and one treatment consisted of 50 cu.yds. of sludge and 50 cu.yds. of white pine woodchips. Approximately 500 lbs. of 7-7-7 fertilizer per acre were applied to all plots in the spring of 1952 and again in 1953.

Budded one-year apple trees were planted in the spring of 1952. They were cut back to within 2 or 3 inches of the ground level in the spring of 1953. Early in September total height and stem diameter at 12 inches above the cut-back point were measured. In most instances, 7 to 10 trees were measured on each plot. The fewest in any one plot was four.

In March 1954 the trees were again cut back, this time to 3-1/2 feet, and the 1954 growth was measured in September of that year.

The trees on the plots included a number of varieties, some of which were on different root stocks. Unfortunately, no one variety occurred on all four series. Measurements were confined to two varieties on two different root stocks on Series I and II; and seven varieties all on the same root stock on Series III and IV.

Growth data in the 1953 measurements are given in Table 10. The data show that growth of *Macoun*, *Cortland*, and *Baldwin* varieties, all on standard root stock, and *McIntosh* on Malling IX was increased by sludge, the gains being 15 to 21 per cent. One variety, *Red Spy* on standard, showed slightly adverse effects. The remaining six varieties showed very slight increases — all three treatments averaging less than 5 per cent.

Table 10. Effect of treatment on growth of young apple trees, 1953, Hartford sandy loam, averages of two series (replicates)

Variety	Root stock	Growth, in feet: Check	Wallingford sludge: 50 yds.A.	Wallingford sludge: 150 yds.A.	Sludge 50 yds. + Chips 50 yds.A.
Varieties showing moderate increases					
Macoun	Standard	2.66	3.08	3.47	3.50
Cortland	Standard	2.89	3.04[1]	3.85	3.85
Baldwin	Standard	3.65	4.05	3.96	3.91
McIntosh	Malling IX	2.59	3.33	2.97[1]	2.98
	Average	2.94	3.38	3.56	3.56
	Relative	100	115	121	121
Varieties showing slight increases					
Rox Russett	Standard	3.63	4.05	3.83[1]	3.86[1]
Delicious	Standard	3.33	3.39	3.83	3.44
Gallia Beauty	Standard	3.20	3.22	3.44[1]	3.73
Delicious	Malling IX	2.86	3.23	2.68	2.85
McIntosh	Malling VII	3.48	3.35	3.90	3.35
Delicious	Malling VII	3.33	3.40	3.02	3.32
	Average	3.30	3.44	3.45	3.43
	Relative	100	104	104	104
Varieties showing slightly adverse effects					
Red Spy	Standard	3.46	3.37	3.35	3.02
	Relative	100	98	97	87

[1]Replicates variable, treatment differences are not significant.

Growth measurements in 1954 largely confirmed the results given in Table 10, although there were a few changes in order of response.

Measurements of stem diameters are omitted. They merely confirmed the height measurements so far as response to treatment is concerned.

Under the conditions of this experiment, the sludge used was clearly beneficial to the growth of some varieties of apple trees but not to others.

Plant Composition

At the conclusion of some of the experiments the plants were analyzed on the spectrograph. Table 11 gives the chemical composition of greenhouse-grown spinach and two crops of beets, as affected by New Haven and Torrington sludges. Analyses showed that sludge increased greatly the concentration of zinc, and to a lesser extent, copper. Calcium was increased where New Haven sludge was used.

Table 11. Composition of spinach and beet tops, greenhouse experiment I, loam, (Averages of the three extra N levels)

Treatments	P %	K %	Ca %	Mg %	Fe ppm	Al ppm	B ppm	Cu ppm	Mn ppm	Zn ppm
Spinach (2nd crop) Nov. 1949										
Check	0.43	3.7	2.6	1.3	900	......	43	....	200	500
New Haven sludge	.56	4.9	8.4	0.7	2300	......	52	....	700	1200
Torrington sludge	.49	3.5	9.5	0.8	1400	......	40	....	400	1000
Beet tops (4th crop) June 1950										
Check	.47	3.6	2.9	1.2	600	500	32	22	376	167
New Haven sludge	.39	2.5	3.2	1.4	500	400	26	49	380	1530
Torrington sludge	.44	3.2	2.8	1.3	400	300	23	42	275	1275
Beet tops (6th crop) May 1951										
Check	.33	4.6	2.3	1.4	300	200	46	16	173	157
New Haven sludge	.29	4.0	3.0	1.6	200	200	40	26	290	1027
Torrington sludge	.33	3.6	2.8	1.6	200	200	46	27	247	833

In Table 12 we see that Torrington and West Haven sludges both caused a decrease in potassium, iron, and aluminum in oats and spinach, and an increase in calcium. West Haven sludge resulted in very large increases in manganese in both crops, although the sludge contained less manganese than any of the other sludges for which analyses are given in Table 2. The zinc content of oats was increased more by Torrington than by West Haven sludge; the reverse was true of spinach.

Table 12. Composition of oats and spinach

Greenhouse experiment II, Dec. '51 and Jan. '52, loamy sand

Treatments	Cu.yds. per A.	P %	K %	Ca %	Mg %	Fe ppm	Al ppm	B ppm	Cu ppm	Mn ppm	Zn ppm
Oat crop, acid soil series											
Check	....	0.35	7.1	0.80	0.69	1120	1650	39	65	240	240
Torrington sludge	65	.37	7.2	1.03	.67	405	300	35	54	280	575
	130	.34	6.4	0.97	.70	310	240	35	57	250	835
	260	.29	5.6	1.20	.75	280	255	30	54	400	1185
West Haven sludge	65	.37	7.6	0.82	.53	570	465	30	41	355	245
	130	.42	7.2	0.85	.47	580	310	31	43	475	255
	260	.47	6.6	1.21	.43	295	135	29	40	665	385
Spinach crop, "neutral" soil series											
Check	....	0.41	11.4	0.94	3.07	405	425	40	23	190	525
Torrington sludge	65	.42	9.8	1.15	3.51	370	345	42	53	160	660
	130	.39	9.4	1.32	3.86	375	405	42	49	140	765
	260	.33	5.2	1.97	4.56	265	225	39	65	150	815
West Haven sludge	65	.44	9.6	1.34	3.30	520	515	47	34	365	755
	130	.43	9.2	1.52	3.30	425	400	41	35	825	830
	260	.43	8.7	2.35	2.30	365	335	41	46	2280	1200

Finally in Table 13 are shown the mineral composition and the nitrogen content of turnip greens and beets. So far as minerals are concerned, the picture is similar to the previous findings. Nitrogen decreased percentagewise in some treatments and increased in others, but the total amount of nitrogen in the crop always increased with an increase in sludge application.

Comparative Leaching Qualities of Sludge and Manure

In carrying out these experiments the writer was impressed by the apparent stability of sludge as compared with manure. To test the validity of this observation, a measured volume (1½ to 2 pints) of moist New Haven sludge, Torrington sludge, and cow manure were placed (in duplicate) in conical glass percolators of about 1 liter capacity. These organic materials were from the same supply used in the 1954 soil frame experiment.

In addition, samples of the two sludges were allowed to air dry and were then placed in other percolators. For comparison, one sample each of moist material was likewise put in percolators and kept moist without leaching.

The samples were leached with 500 ml. of distilled water and the process repeated at intervals for a total of 14 leachings, equivalent to about 38.5 inches of rain.

Table 13. Composition, including nitrogen, of turnips and beets

Greenhouse Experiment II May 1953, loamy sand

Treatment	cu.yds. per A.	P %	K %	Ca %	Mg %	Fe ppm	Al ppm	B ppm	Cu ppm	Mn ppm	Zn ppm	N %	N g. in crop
Turnip greens, acid soil series													
Check	....	0.48	5.03	2.35	0.35	465	590	53	62	70	[1]	2.50	0.35
Torrington sludge	65	.72	6.00	4.00	0.54	345	270	53	90	80	385	2.44	.38
	130	.66	3.95	3.00	.66	250	195	53	70	120	500	2.16	.45
	260	.58	4.58	3.25	.74	210	220	50	80+	120	800	2.26	.57
West Haven sludge	65	.43	4.18	2.95	.41	315	295	51	46	80	185	2.30	.37
	130	.49	3.06	3.20	.51	385	240	51	45	150	340	1.96	.43
	260	.56	2.72	3.50	.40	360	295	48	60	190	355	2.85	1.14
Beets (blades and petioles), "neutral" soil series													
Check	....	0.39	8.0+	1.90	1.00	500	760	59	51	90	[1]	2.11	0.12
Torrington sludge	65	.48	8.0+	1.08	1.45	315	315	36	54	75	85	2.22	.18
	130	.49	7.40	1.33	1.85	340	385	42	80+	100	195	2.41	.21
	260	.38	5.30	1.29	1.95	375	430	42	95+	95	230	2.99	.26
West Haven sludge	65	.49	8.0+	2.05	1.48	465	520	58	39	135	[1]	2.11	.17
	130	.52	8.0+	2.85	1.60	500	635	54	69	130	[1]	3.13	.44
	260	.47	6.20	2.65	2.03	390	295	35	100+	100	160	3.18	.47

[1]Too low to read.

The first leaching took place on March 1 and the last two on June 15. The first leachate was analyzed on the spectrograph. The pH was determined on the first and last three leachates; nitrates on the first and last six; and total soluble salts on every leaching. At the end of the experiment the dry weights of the organic materials and their spectrographic analysis and total nitrogen content were obtained.

The dry matter and total nitrogen contents of the samples are shown in Figure 3. It is evident that the sludges decomposed at a much slower rate than manure; and Torrington sludge lost its nitrogen more slowly than did either manure or New Haven sludge.

A partial analyses of some of the leachates are given in Table 14. The moist New Haven sludge produced the most alkaline leachate at the start but the differences largely disappeared toward the end. Torrington sludge leachate was slightly acid throughout.

Leachate from manure showed no nitrates until the 11th leaching when it contained 58 p.p.m. The nitrate content dropped to a fairly low level for the last two leachings. New Haven sludge contained no nitrates until the last day. Torrington sludge leachate varied considerably in nitrate content for the various leachings, the concentration tending to build up between leachings.

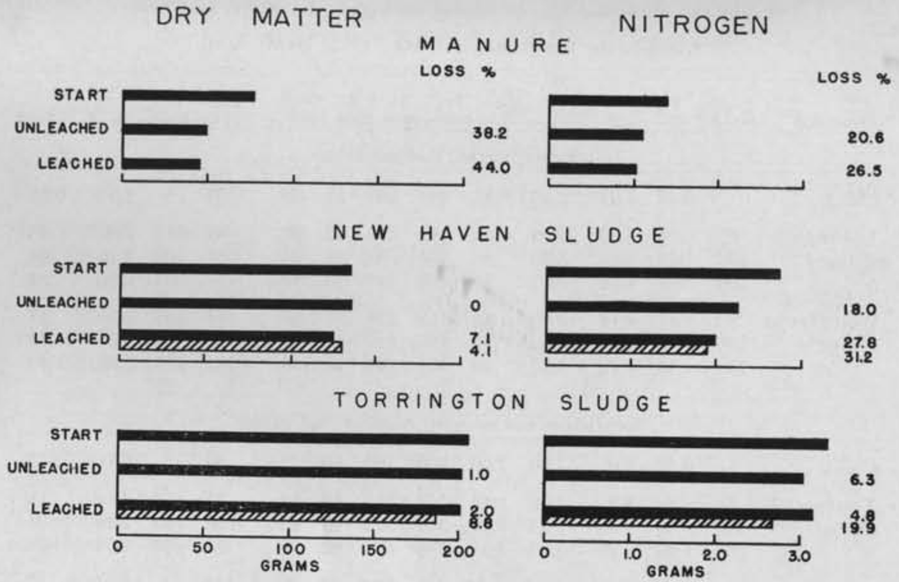

Figure 3. The effect of leaching on the amount of dry matter and nitrogen in manure and sewage sludge. The cross-hatched bars pertain to those sludge samples which were air dried before leaching, 1954.

Table 14. pH, nitrates, and total soluble salts of manure and sludge leachates

Material	1st 3/1	7th 3/30	11th 5/17	13th 6/15	14th 6/15
		pH			
Manure	8.50	......	7.15	7.60	7.55
New Haven sludge	11.60	......	7.85	7.70	7.60
New Haven sludge, dry[1]	9.80	......	7.66	7.62	7.40
Torrington sludge	6.40	......	6.89	6.50	6.46
Torrington sludge, dry	6.20	......	6.83	6.30	6.60
		Nitrate-nitrogen p.p.m.			
Manure	......	......	58	5	8
New Haven sludge	......	......	....	1	1
New Haven sludge, dry	......	......	....	20	5
Torrington sludge	6	144	34	117	17
Torrington sludge, dry	4	239	40	131	11
		Total soluble salts p.p.m.			
Manure	2200±	420	495	102	97
New Haven sludge	1500	2500±	430	225	170
New Haven sludge, dry	1450	1490	315	218	160
Torrington sludge	1155	310	265	280	61
Torrington sludge, dry	2200±	430	315	240	50

[1]Sludge air dried prior to leaching.

The soluble salt content was very high in the initial leaching and varied considerably in subsequent leachings. New Haven sludge leachings were on the whole higher in salts than either manure or Torrington sludge.

The absence of nitrates in the leachates from manure and New Haven sludge indicates that these materials in themselves are not good media for nitrification. Only when incorporated into the soil does the nitrification process proceed normally. Why Torrington sludge proceded nitrates under the same conditions is not clear. Perhaps the higher ash content of the latter has a bearing on this difference in response.

Some interesting data were obtained when the leachate from the first 500-ml. leaching, March 1, was analyzed on the spectrograph. Table 15 shows the principal results.

In comparison with manure, the leachates from both sludges were low in phosphorus, magnesium, potash, and boron, and high in calcium. New Haven sludge leachate was highest in calcium, copper, and lowest in manganese and zinc. Its color was a pale red as compared with the yellowish-brown leachate from manure and pale brown from Torrington sludge. Torrington sludge leachate was highest in manganese and zinc. The low manganese and zinc concentration in New Haven leachate can be ascribed chiefly to its initially high pH, which kept these materials largely insoluble in spite of the higher concentration in the sludge itself (Table 2). This explanation fails, however, in reference to copper. Although New Haven *sludge* contained a little more copper than Torrington sludge (Table 2), the amount in the New Haven *leachate* was about five times that in the Torrington leachate.

Table 15. Composition of the first leachate from manure and sewage sludge

	In parts per million							
	P	Ca	Mg	K	B	Cu	Mn	Zn
Manure	15	<50	20	605	0.24	0.55	0.2	2.7
New Haven sludge	<10	355	5	<100	<0.1	5.0±	<0.2	<1.0
Torrington sludge	<10	240	10	<100	<0.1	0.5	1.7	9.5

The analysis for aluminum and iron showed essentially no differences between the three materials.

Table 16 gives the composition of the residual manure and sludges at the end of the leaching period. New Haven sludge differed from manure in having a higher concentration of calcium, iron, aluminum, boron, copper and zinc; and a lower content of nitrogen, organic carbon, and magnesium. Torrington sludge was lower in nitrogen, organic carbon, calcium, magnesium, and manganese than manure. The chief difference between the two sludges lay in their organic carbon, calcium, zinc, and manganese contents and their carbon-nitrogen ratios, all of which were higher in New Haven sludge.

There was no consistent difference between leached and unleached materials on a percentage or p.p.m. basis.

Table 16. Composition of the manure and sewage sludges at the end of the leaching period

	N %	C %	C/N	P %	Ca %	Mg %	K %	Fe %	Al %	B p.p.m.	Cu p.p.m.	Mn p.p.m.	Zn p.p.m.
Manure, leached	2.3	47	21	0.55	1.5	0.33	<0.40	0.15	0.10	45	55	200	240
unleached	2.2	43	19	.90	1.4	0.60	0.70	.12	.05	40	80	150	150
New Haven sludge leached	1.6	24	16	0.80	6.5	0.24	<0.40	1.70	0.57	160	1650	180	4300
unleached	1.6	25	15	.54	5.0	.16	<0.40	1.90	.48	140	1400	130	4200
Torrington sludge, leached	1.7	16	10	0.61	1.0	0.08	<0.40	0.66	0.29	100	625	100	1300
unleached	1.6	18	12	1.20	0.8	.06	<0.40	1.30	1.00	70	1400	70	2700

DISCUSSION

This work has shown that digested sewage sludges as produced in Connecticut treatment plants contain relatively high concentrations of copper and, especially, of zinc. Under some conditions these sludges are toxic to plants. The toxicity may be due to the presence of the metals *per se* or, what is more likely, to a combination of factors one of which is a deficiency in iron. It is known that increasing the concentration of these heavy metals is apt to lower the concentration of iron, causing chlorosis in the plants. The spectrographic analyses of the plants indicated in general a lower iron content where sludges were used.

Injury to the plants can usually be eliminated by making sure that the pH of the soil is above 6.0 or 6.5 (8), depending on the rate of sludge application. If the injury is primarily iron chlorosis, it is quite probable that the condition in acid soils can be corrected by the use of iron chelates (13). At the present time little is known as to the susceptibility of "acid-loving" plants such as rhododendron, laurel, and azalea to sludge injury. For such plants it would seem advisable to use sludge with great caution, probably applying not more than about 20 cu.yds. to the acre or 1 bu. to 100 sq.ft. and being prepared to treat the plants with iron chelates if chlorosis appears.

Preliminary work with potatoes and tobacco (9) had shown that sludge was somewhat harmful to plant growth and yields, inasmuch as the soil had to be maintained in an acid condition for these crops. Perhaps iron chelates would have corrected the difficulty, although there was no evidence of chlorosis.

Torrington Sludge Compared with West Haven Sludge

The more favorable effect of West Haven sludge on plant growth as compared with Torrington sludge was undoubtedly due to the absence of industrial waste in the West Haven product. Pound for pound of dry matter, West Haven sludge contained not more than one-third as much copper and zinc as did Torrington sludge.

The one exception is the bean crop which showed injury ascribable to excess manganese. Identical symptoms resulting from manganese toxicity have been described by Löhnis (7). Although analysis of the two sludges showed a little less manganese in West Haven sludge, for some reason the growing bean plants in the West Haven sludge-treated soil contained 1½ to 16 times as much manganese as did the Torrington sludge-treated plants. Spinach plants showed similar differences.

In the presence of manganese an appreciable increase in soil acidity would cause manganese toxicity but there was no such difference in soil reaction in this experiment. Analysis of beet tops growing in very acid Torrington sludge-treated soil in the soil frames showed little or no increase in manganese content.

Seed Germination

In the germination studies it was found that the general effect of digested sewage sludge was to delay and in some cases reduce seed germination. There were exceptions, notably Torrington sludge. Where this material had weathered 6 months to a year, it tended to favor germination as compared with sludge that was only a month old.

On the other hand year-old New Haven sludge had a more adverse effect on germination than did fresh New Haven sludge. The reason or reasons for these differences are obscure. Study of the data obtained in this work leads to the tentative conclusion that the adverse effect of sludge is due largely to the high total soluble salt concentration in the soil as result of the sludge treatment. Manure or commercial fertilizer will do the same thing. The reaction of the medium does not appear to have any bearing on the results. Also the action appears to be independent of the trace-element composition of the sludge, which is the principal cause of poor growth and low yields of growing plants on acid soils.

Pot and Frame Cultures Compared with Field Plots

In general, sludge treatments were more beneficial to plant growth in the greenhouse and soil-frame experiments than they were in the field. This difference is due in part to better control in the former tests. In the field, weather conditions frequently eliminate treatment differences, as was believed to have occurred the second and third season tests with corn. In the forest nursery, high acidity which aggrevated copper and zinc toxicity (and/or iron deficiency) was undoubtedly the controlling factor. In the apple tree nursery, response was linked with varietal differences. Five of the eleven varieties showed definitely greater growth as result of sludge treatments.

Soil Improvement

The several experiments have shown that sewage sludges improve the soil. The greatest benefit, generally speaking, was in aggregation of the soil particles. Changes in cation exchange capacity, water-holding capacity, and non-capillary porosity were usually rather low. In this connection reference should be made to a direct comparison of the water-holding capacity of various organic materials themselves. The results obtained by two different methods are shown in Table 17.

Table 17. Comparative water-holding capacities of sludges and other kinds of organic matter

Organic matter	Water held at 60 cm. tension	Water held following 24 hours draining on paper
	% (Water free basis)	%
Peat moss	778	343
West Haven sludge	312	179
Compost, oak chips	295	255
Pine chips	267	225
New Haven sludge	207	137
Wallingford sludge	200	159
Oak-hickory chips	145	109
Torrington sludge	123	74
Leaf compost	113	103
Milorganite	91	58

Most effective of all the materials used was peat moss. Of the four digested sludges tested, West Haven was the best and Torrington the poorest. Indications are that the sludges compare favorably with composts and woodchips with respect to water-holding capacity.

Although the data have shown relatively small improvement in cation capacity, water-holding capacity, and similar properties, there are indications that repeated applications of sludge over the years would bring about very appreciable improvements in all of the physical properties of the soil. Such improvement is evident in the author's home-garden experience where, for example, the soil in a flower border has been conspicuously improved in physical condition as a result of repeated sludge treatments.

From the experience gained in the handling of sludges, it is evident that better results are likely to be obtained and, certainly, ease of handling is improved where the sludge is allowed to weather for six months to a year or longer before being applied. Such treatment promotes granulation and greatly facilitates spreading or screening of the material.

Sources of Trace Elements

Sludges made from sewage containing industrial wastes can be expected to contain appreciable amounts of metallic trace elements. But where do industrial waste-free sludges such as those from state institutions get the trace elements?

Galvanized piping contributes a little zinc but it is very doubtful if this is sufficient to account for the amounts found in sludge, particularly in the light of the wide usage of copper and brass piping nowadays.

There are indications that foodstuffs contribute trace elements, especially zinc. Bertrand and Benzon (4) reported zinc in fresh material ranging from less than 1 p.p.m. in peaches, plums, and melons to 50 p.p.m. in legumes.

Hegsted el al (6) reporting data from others, show that ordinary foods contain variable amounts of zinc, ranging up to 145 p.p.m. on a dry basis. Yeast, mushrooms, and seafoods are high, and oysters may contain as much as 2300 p.p.m. The daily intake of zinc in a normal diet averages about 10 mg. per capita, but it would be possible to eat a meal of selected foods which would supply 225 to 275 mg. of zinc. Practically all zinc ingested is excreted, of which over 90 per cent is in the feces.

It is estimated (5) that the daily production of digested sludge per capita on a dry basis is about 31 pounds. If the zinc content of sludge averages 0.32 per cent, the 31 pounds of sludge would contain about 0.1 pound of zinc or 45 grams. As this is 450 times the 10 mg. average daily intake of zinc in foodstuffs per capita it is necessary, obviously, to look elsewhere for the major source of zinc. So far the answer has not been found.

SUMMARY AND CONCLUSIONS

Experiments were initiated in 1949 to explore further the suitability of digested sewage for soil improvement and as a fertilizer. The work was done in greenhouse pots, outdoor soil frames, and field plots.

The general procedure was to apply the sludge once, usually at several different rates, and grow successive crops on the same soil without further sludge treatment. Lime and fertilizer were applied as needed. The results are summarized as follows:

1. The rate of application of digested sewage sludges should be governed more by their nitrogen content than by the amount of organic matter they contain. High applications may supply too much nitrogen.

2. Sludge improves the physical condition of the soil, particularly its aggregation of particles greater than 1 mm. The improvement is readily observable in practice as well as measurable by laboratory techniques.

3. Sludges differ rather widely in their properties, depending upon the character of the sewage and the kind of processing used in the treatment plant. Most sludges are acid but some are highly alkaline. The organic matter content ranges from 25 or 30 to over 60 per cent. Some come from sewage containing industrial wastes.

4. All of the sludges tested contain relatively large amounts of zinc and considerable copper and boron in comparison with other common types of organic matter. Industrial wastes increase the concentration of these metals.

5. In acid soils, sludge is frequently toxic to plants, the degree of toxicity varying with the type of sludge, the rate of application, the soil, and the kind of plant. The toxic effects can usually be prevented by raising the soil pH to 6 or higher.

6. Of the several kinds of plants grown spinach was most susceptible to injury, seldom showing any favorable effects from sludge treatment. Grasses and grains suffered the least from trace elements, and they usually responded to fairly heavy applications of sludge even on acid soils.

7. In a greenhouse experiment, where Torrington and West Haven sludges were applied at 65, 130, and 260 cu.yds. per acre, maximum growth of oats, beans, and spinach occurred at the medium rate. Beets and turnips on the other hand, showed maximum growth at the 260 yd. rate. West Haven sludge, being lower in trace elements, produced the largest plants; but it also caused bean and spinach plants to have 1½ to 16 times as much manganese as was found in Torrington sludge-treated plants.

8. In general, sewage sludge treatments delayed seed germination, particularly lettuce and radishes, although under some conditions Torrington sludge favored germination. It appears that the effect of sludge on germination is associated with the increase in total soluble-salt content, hence a similar result can come from fertilizers or manure.

9. In some situations the inclusion of a moderate amount of woodchips or sawdust (25 to 30 per cent by volume) favors seed germination and plant growth as compared with sludge alone.

10. Heat-dried sludges, whether raw or digested, are slow to nitrify, hence may cause temporary nitrogen deficiency similar to straw or sawdust. None of the sludges nitrify as rapidly as does commercial dried manure with which they were compared.

It is concluded, on the basis of the results obtained in these experiments, that digested sewage sludge as produced in Connecticut treatment plants improves the physical condition of the soil and has a more lasting effect than does manure.

It also supplies nitrogen and some phosphorus and trace elements. When used under proper conditions sludge improves current crop yields. High applications may delay seed germination, but they seldom lessen the final germination count.

Because the various sludges differ in reaction and in composition, it is important to know the nature of the sludge to be used. The acid sludges, especially those from sewage containing industrial wastes, may have severe adverse effects on plants. Usually such toxicity, which is due to copper or zinc, or both, and probably to iron deficiency induced by these metals, can be avoided by liming the soil to pH 6.0 or higher. Applications of sludge as high as 150 to 250 cu.yds. per acre can be used under some conditions, especially for such crops as grains and grasses even on acid soils. However, 50 cu.yds. is a safer rate.

Where the crop requires a fairly to strongly acid soil, the application of sludges for soil improvement must be made with caution, if at all. This is particularly true where the response of the crop to relatively high concentrations of copper and zinc is unknown. Light applications, i.e. 15 or 20 cu.yds. per acre, may be permissible.

The Connecticut State Department of Health does not advocate the use of fresh digested sludge on crops that are to be eaten raw. If the sludge is applied and worked into the soil six months or so prior to seeding such a crop, no health hazard is involved.

REFERENCES

1. ANDERSON, M. S. Sewage sludge for soil improvement. U.S.D.A. Circ, 972, 1955,

2. ANONYMOUS, The agricultural use of sewage sludge and sludge composts. Tech. Communication No. 7, Ministry of Agric. and Fisheries, Gr. Brit. Oct. 1948 (Abstr. in Sewage and Industrial Wastes 23(11):1467, 1951.

3. BEAR, FIRMAN E. AND PRINCE, ARTHUR L. Agricultural value of sewage sludge. N.J. Agric. Expt. Sta. Bul. 733, 1947.

4. BERTRAND, G. AND BENZON, B. The control of zinc in the principal foods of vegetable origin. Bul. Soc. Sci. Hyg. Aliment. 16:457-463, 1928 and Ann. Inst. Pasteur 43:386-393. 1929. (Abs. seen in Bibl. Minor Elements 4th Ed. Vol. I-938. 1948).

5. COMMITTEE ON SEWAGE WORKS PRACTICE, Federation of Sewage Works Association, Manual of Practice No. 2. Federation of Sewage Works Assns. Champaign, Illinois. 1946.

6. HEGSTED, D. MARK, MCKIBBIN, JOHN M. AND DRINKER, CECIL K. The biological hygenic and medical properties of zinc and zinc compounds. Supplement No. 179 to the Public Health Reports, U.S. Public Health Service, Washington, D.C. 1945.

7. LÖHNIS, MARIE P. Manganese toxicity in field and market crops. Plant and Soil 3:193-222. 1951.

8. LOTT, W. L. The relation of hydrogen-ion concentration to the availability of zinc in soil. Soil Sci. Soc. Proc. 3:115-121. 1938.

9. LUNT, HERBERT A. Preliminary greenhouse studies of digested sludge as a fertilizer. Sewage Works J. 18:46-53. 1946.

10. ——— The use of woodchips and other wood fragments as soil amendments. Conn. Agr. Expt. Sta. Bul. 593. 1955.

11. ROST, C. O. The manurial value of sewage sludge. Minn. Univ. Soil Ser., No. 33, (processed) 1950.

12. SCIARONI, R. H. and LUNT, O. R. Sewage sludges for agriculture. California Agriculture, pp. 13 + 15, Nov. 1957.

13. STEWART, IVAN and LEONARD, C. D. Chelates as sources of iron for plants growing in the field. Science 116:564-566. 1952.

14. TOTH, S. J. and KELLY, W. H. Complete study of farm uses for organic wastes. New Jersey Agriculture 38(4):13-15. July-Aug. 1956.

15. VAN KLEECK, LEROY W. The use of digested sewage sludge for fertilizer in war emergency. Water Works and Sewerage 90:5, 177. 1943.

16. WYLIE, J. C. Composting. Surveyor 110:373 + 443, 1951. (Abstr. in Sewage and Industrial Wastes 24(5):685-686, 1952).