DENVER LIQUID SEWAGE SLUDGE: ITS AGRICULTURAL BENEFITS AND ITS EFFECT ON THE METAL COMPOSITION OF WHEAT GROWN AT THE WATKINS TEST SITE, ADAMS COUNTY, COLORADO

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Abstract

Sludge from the Metropolitan Denver Sewage Disposal District No. 1 was added to a Truckton loamy sand near Watkins, Colorado, at rates equivalent to 0, 20, 40, and 55 tons/acre (dry-weight basis), to assess the effect on dryland production and on the element composition of hard winter wheat (*Triticum aestivum* L. cv. Wichita). Yields from the 1974 crop increased significantly ($p<.05$), from 13 bu/acre for the control plots to 22 bu/acre for each group of treatment plots; and highly significant increases ($p<.01$) in the protein content resulted from the sludge additions. The mean for the control plots was 12.7% protein compared to the means for the treated plots of >15.2%. These obvious benefits must be weighed, however, against highly significant increases in the amounts of cadmium, nickel, and zinc in the grain. Concentrations of these heavy metals in all samples from the treated plots exceeded the central 95% expected ranges, which were based upon a suite of 12 wheat samples collected across the Northern Great Plains. Manganese and selenium also showed significant increases in samples from the sludge plots, but the concentrations for selenium were within the range expected in wheat. An additional geochemical impact was a visible increase in the amounts of copper, lead, mercury, silver, tin, and zinc, and a decrease in pH in the soils of the treated plots.

Introduction

The reason for a study of this nature was expressed clearly by Beeson in his recent article on sewage studies and the food chain (1976, p. 23), as follows:

> Of primary concern to agronomists with respect to the use of municipal waste as a source of plant nutrients is the possible phytotoxic effects of the several heavy metals contained in these materials and originating, in many instances, from industrial effluents. Agronomists are increasingly aware, however, of the possibility of these elements entering the food chain. Hence, in addition to measurement of crop yields, much time and effort is being devoted to obtaining data on the composition of plant tissue. These data are of interest to the nutritionist.

The main objective of this report is to release the analytical results on samples of wheat grains and sludge-altered soils from selected experimental plots established by Dr. Burns Sabey, agronomist at Colorado State University, and by the research staff of the Metropolitan Denver Sewage Disposal District No. 1 (MDSDD) to assess the effects of sewage-sludge application on dryland wheat production.

Experimental design

In collaboration with Dr. Burns Sabey and MDSDD, we obtained samples of wheat and plow-zone soils from 72 test plots following the 1974 harvest. The plots were arranged in a randomized block design, as described by Sabey and Hart (1972); at the time of the 1974 sampling, it included plots with no treatment as well as plots with sewage-sludge loadings ranging from the equivalent of 9 to 90 tons (dry weight) per acre. Twelve of the 72 plots were treated with sewage filter cake at rates of 12 to 50 tons per acre. The reports by Sabey and Hart (1972, 1975) were based on one sludge treatment applied in May 1971. Following the initial experimental wheat harvest in 1972, however, those plots with low and intermediate loadings received amounts of sludge comparable to the initial treatments.

Because of laboratory and cost constraints, we selected a subset of 31 samples from the 72 plot samples. Formal assessment of the response of wheat to several levels of sludge additions was based on 24 samples--six selected at random from plots with no loading (control or check plots), and six each from plots with loadings of 20, 40, and 55 tons per acre. Only one plot had a loading equivalent to 90 tons per acre; samples from this plot were included in our study to see what effects the maximum treatment had on the production of wheat. In addition, six samples were chosen from the 12 plots that had been treated with filter cake. Three pairs of plots receiving very similar treatments were selected; that is, 17-18, 28-29, and 45-46 tons per acre. An estimate of the magnitude of the analytical error was based on "splits" or duplicate analyses of 10 samples that were randomly selected from the 24 samples in the analysis of variance design. In effect, these duplicate analyses constituted a third and lowest level of the sampling design. All 41 samples were analyzed in a formally randomized sequence in order to circumvent any effects of systematic analytical bias.

In addition to the 41 samples of wheat from the Watkins' site, we received a ½-pint sample of wheat (cv. Wichita) harvested in 1974 from the Lowry disposal site. It was sent to us by Dr. David Cohen, who was then director of the research program at MDSDD. Analytical results of that sample are included in this report and represent the effects of maximum, although unspecified, sludge loadings.

Sampling procedures and sample materials

Prior to harvesting and soil sampling, the 72 sample plots, each 10x32 ft in dimension, had been marked at their corners with flags. The wheat was harvested July 12, 1974, with a special combine that cut two adjacent 4-ft swaths from the center of each plot. Soils were sampled July 16-17.

Preliminary tests showed that about twenty 6-in. soil plugs were needed to attain a quart-sized sample, the volume we judged ample for the study. The previously harvested area, about 8x30 ft, was visually divided into ten 4x6-ft subplots, and two soil plugs were taken essentially at random from within each subplot. Plugs were collected with a stainless-steel corer capable of extracting a 10-in. core that is 1 inch in diameter. At most sites, however, the sampler would not penetrate more than about 6 inches, the plow-zone depth. The soil plugs were broken up by hand in a plastic pail and mixed to form a composite sample. The resulting samples, we felt, were quite representative of the soil from each plot. Descriptions of the soil and sludge are detailed in Sabey and Hart (1975).

The wheat from each plot was bagged in a large paper sack, and the yield was later calculated by Dr. Sabey at Colorado State University following standard cleaning procedures. One-quart samples were then obtained from the bulk samples for element and ash analyses conducted at the Denver laboratories of the U.S. Geological Survey.

Analytical methods

Protein percentages were determined in the wheat laboratory at Colorado State University under the supervision of Dr. Sabey, using an improved dye method for estimating protein (Udy, 1971).

A weighed portion of each grain sample was burned to ash in a muffle furnace in which the heat was increased 50°C per hour to a temperature of 550°C and held at this temperature for 14 hours. The resulting ash was then weighed to determine the ash yield of the dry grains. The methods of analysis and the elements determined in ash follow: atomic absorption spectroscopy--cadmium, cobalt, lithium, sodium, copper, lead, calcium, nickel, potassium, and zinc; and colorimetric--phosphorus. In order to determine the concentrations of those elements that would be volatilized and lost by burning, weighed aliquots of the dried grains were "wet ashed" according to methods described by Harms and Papp (1975). Methods of analysis used for these volatile elements were atomic absorption for arsenic, turbidimetric for total sulfur, flameless atomic absorption for mercury, and fluorimetric for selenium. The remaining elements reported here were analyzed by emission spectrography using ashed material.

The element composition of the soils is expressed on a total, not available basis. Most of the elements reported for the soils were determined by emission spectrography. Copper, lead, lithium, magnesium, sodium, and zinc were determined by flame atomic absorption spectroscopy (Huffman, 1975). Mercury was determined by a flameless atomic absorption method (Huffman, 1975), and fluorine analyses were by a selective-ion electrode method (Huffman, 1975). Measurements of soil pH were conducted by C. E. Papp: a slurry was made from 4 g of soil and 10 ml distilled water. Readings were made after 2 minutes of continuous stirring; they did not differ by more than one-tenth of a pH unit from several checks that were run by a more conventional method for determining soil pH.

Results and discussion

The analytical data for the wheat samples and associated soil samples are given in tables 1 and 2, respectively. Results of an analysis of variance, which tests for differences among treatment groups (including controls), are available for only the wheat data. Those factors that showed significant differences are summarized in table 3. Differences among treatments for some of the elements given in table 1 were not tested by analysis-of-variance procedures because of complete or unacceptable degrees of censoring (reported values below the limits of detection). The elements so affected are arsenic, cobalt, lead, lithium, mercury, niobium, silver, sulfur, and titanium.

Logtransforms of the data were made because most element concentrations in natural materials tend to be lognormally distributed. The geometric means and geometric deviations given in table 3, therefore, are antilogs of the arithmetic means and standard deviations, respectively, of the logarithms of the analytical values. The geometric mean is a measure of central tendency of the frequency distribution and, as such, is an estimate of the typical or most common concentration for the element.

Analysis of variance and Duncan's multiple range technique showed that, for the most part, only two groupings in the data can be demonstrated--samples from the control plots and samples from plots that received three levels of sludge loadings. The most striking differences were the fivefold increases in the heavy metals cadmium and nickel.

Nickel is of particular interest in that a recent report on the element composition of sewage sludges from 16 municipalities across the United States (Furr and others, 1976) lists Denver's sludge as being notably high in nickel (562 ppm). Concentrations from all cities ranged from 36.4 to 562 ppm, with a median of 169 ppm. Other analyses of sludge from Metropolitan Denver Sewage Disposal District No. 1, however, indicate nickel concentrations very close to, or slightly higher than, the median given above (H. Tourtelot, unpublished data, 1974; Sabey and Hart, 1975). The apparent slight increase in soil pH (table 2)--the latter effect tending to mobilize nickel--would account for the anomaly of this metal in the grain samples.

A very critical question comes to mind at this point: Just how representative is the control wheat, chemically, to hard wheat in general? This can be answered, to some degree, by looking at the trace-element composition of 12 samples of wheat collected from across the Northern Great Plains (Shacklette and others, in press). These samples--11 of them hard wheat and 1 durum--were obtained in the field at harvest time, 1974, from a region that included southeastern Wyoming, eastern Montana, western North Dakota, and northwestern South Dakota. Baselines for four of the five metals (manganese excepted) that showed a treatment effect in the Watkins' wheat are given as follows:

Metal	Geometric mean	Expected range or baseline
Cadmium	.047	.018-.12
Nickel	.31	.13-.76
Selenium	.45	.096-2.1
Zinc	30	17-52

The geometric mean is the most typical value expected in the material in question, whereas the expected range is the central 95% range defined as $GM/(GD)^2$ and $GM \cdot (GD)^2$. In normal environments, then, the element concentration of only about one sample in 50 will occur above the 95% range solely by chance. We feel that the expected range is equally important, if not more so, than a measure of central tendency in assessing suspected metal pollution. (This concept of baseline is discussed in considerable detail by Tidball and Ebens, 1976.)

By comparing the observed ranges of the metals in wheat samples from the treated plots with the ranges expected in wheat (the baselines), it is apparent that only cadmium and nickel are anomalous. Averages from the control plots compare favorably with the averages for the Northern Great Plains (above), and the values of the samples from the control plots are well within the expected ranges. On the other hand, the treated plot averages for these two metals are five times higher than the averages established for the controls, and all of the sample concentrations exceeded the expected ranges. For selenium, all samples, including those from the plots with maximum sludge loadings, gave concentration values within the central 95% range.

Despite the highly significant increases in cadmium and nickel to levels judged anomalous, the levels do not appear to be potentially detrimental to either plants or animals, including man (Underwood, 1971; Gough and Shacklette, 1976).

We were unable to test the differences between treatment groups of soils data for inclusion in this report. Yet some differences are so obvious that significance tests may be unnecessary. Elements that show marked increases due to sludge additions include copper, lead, mercury, silver, tin, and zinc; more subtle increases seem to have occurred for antimony, arsenic, chromium, and nickel. The change in soil pH from an alkaline condition in the control plots to neutral or slightly acid conditions in the sludge-treated plots agrees with a similar change in soil reaction reported by Sabey and Hart (1972, p. 12-13).

Because of the limited samples drawn from the filter-cake plots, only very provisional conclusions can be made. Effects of the filter cake on the soil chemistry tend to be more subtle than those caused by the application of sludge; the exception was pH, which increased considerably in comparison to the pH measured in the control plots of the main experiment. Some of the elements that appear to have increased in the soils as a result of the filter-cake application are chromium, copper, mercury, nickel, and zinc. The strongly alkaline reaction of the soils, however, would tend to immobilize these metals and to decrease their availability to wheat. Apparently this was the case, for the only obvious effect of the filter-cake application was an increase in yield (table 1).

Conclusions

In light of the yield and protein enhancement demonstrated in table 3, the potential role of liquid sewage sludge as a plant nutrient is quite high, certainly of more than the "moderate" importance assumed in the summary draft environmental impact statement (U.S. Environmental Protection Agency, 1976a, table B, p. 17). Conversely, the problem of heavy metal contamination may be a deterrent to the plans for using sludges in feed and food production (U.S. Environmental Protection Agency, 1976a, p. 8) unless sludge utilization is carefully managed. Although the buildup of metals in wheat grown on the sludge-altered soils does not appear to be hazardous under the conditions of the Watkins' experiment, some statements made by the EPA in its impact assessment may require further consideration. As one example, it stated (U.S. Environmental Protection Agency, 1976a, p. 23): "Certain crops are also susceptible to heavy metal uptake. Swiss chard, lettuce, spinach and sugar beets are among the most efficient accumulators of heavy metals. By contrast, the use of sludge on sod farms and certain irrigated and dry farm lands may pose fewer problems." We believe our evidence has demonstrated that wheat may also be a fairly efficient heavy metal accumulator, at least under the conditions of the experiment. Further, because of the magnification of heavy metals in the food chain, the statement (U.S. Environmental Protection Agency, 1976b, p. D28-29) that "Most irrigated and non-irrigated crops grown in the study area are either not consumed by humans or are processed to such a degree that sludge contaminations are removed" should probably be confirmed through experimentation. Baxter and others (1976) have just published the results of a study that assessed the cycling of heavy metals from sludge-altered soils through forage to various kinds of tissue in cattle. They reported a significant increase in cadmium levels in kidney and lead in bone. However, the metal contents of muscle and fat tissues was unaffected by the treatment.

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[Element concentrations are expressed on a dry-weight basis; they are significant to only two figures, though more may be given. A sample with an "X" suffix is a duplicate of the preceding sample. ND indicates no data; B's or L's following data indicate concentrations below the detection level]

SAMPLE	YIELD BU/A	%PROTEIN	ASH %	AG PPM	AL %	AS PPM	B PPM	BA PPM	CA %	CD PPM
WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION										
W0105	10	13,6	2,3	0,01150	0,00092	0,05L	1,12	6,9	0,046	0,03
W1847	16	11,3	2,2	0,01144	0,00216	0,05L	1,14	9,3	0,044	0,04
W2527	11	12,5	2,2	0,00000B	0,00123	0,05	0,88	6,1	0,044	0,04
W2537X	ND	ND	2,2	0,01012	0,00181	0,05	1,57	8,8	0,044	0,04
W3348	11	13,3	2,2	0,01188	0,00201	0,05	1,02	5,9	0,048	0,04
W3407	11	13,5	2,3	0,00000B	0,00106	0,05L	1,23	7,2	0,046	0,05
W3420X	ND	ND	2,2	0,00000B	0,00112	0,05L	1,38	7,7	0,044	0,04
W4453	21	12,1	2,1	0,01134	0,00175	0,05L	0,83	6,2	0,046	0,04
WATKINS! SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION										
W0510	25	14,7	2,3	0,00000B	0,00118	0,05L	1,07	6,2	0,051	0,25
W0512X	ND	ND	2,2	0,00000B	0,00099	0,05L	0,98	9,7	0,053	0,22
W0659	17	16,3	2,4	0,01056	0,00215	0,05	1,35	5,2	0,067	0,22
W1746	18	16,1	2,3	0,01104	0,00258	0,05	1,27	8,3	0,055	0,22
W3506	35	15,2	2,3	0,00000B	0,00087	0,05L	1,12	6,6	0,046	0,17
W3533X	ND	ND	2,3	0,00000B	0,00121	0,05	0,62	6,7	0,051	0,20
W4645	35	13,1	2,2	0,00000B	0,00158	0,05	1,12	8,8	0,044	0,22
W4629X	ND	ND	2,2	0,01012	0,00096	0,05L	1,06	7,7	0,040	0,24
W6644	14	17,6	2,3	0,00000B	0,00199	0,05L	1,27	6,6	0,060	0,32
WATKINS! SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION										
W0325	18	14,2	2,2	0,00000B	0,00096	0,05L	1,16	7,9	0,048	0,26
W3601	22	15,6	2,3	0,01104	0,00097	0,05	1,11	4,9	0,055	0,21
W4558	45	13,8	2,2	0,00000B	0,00165	0,05L	1,10	9,3	0,046	0,29
W4518X	ND	ND	2,1	0,01176	0,00123	0,05L	1,03	7,4	0,055	0,27
W5330	18	16,2	2,5	0,00000B	0,00100	0,05	0,96	5,7	0,065	0,27
W5317X	ND	ND	2,4	0,01440	0,00120	0,05L	1,39	9,5	0,058	0,24
W5609	16	15,0	2,2	0,01496	0,00099	0,05	1,01	5,9	0,053	0,29
W5624X	ND	ND	2,2	0,01012	0,00000B	0,05L	0,77	5,5	0,053	0,29
W6138	20	16,3	2,3	0,01886	0,00160	0,09	1,48	6,6	0,055	0,39
WATKINS! SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION										
W1455	21	17,6	2,4	0,00000B	0,00150	0,05	1,20	6,5	0,058	0,17
W2635	46	15,1	2,3	0,00000B	0,00127	0,05L	1,18	7,4	0,051	0,22
W4043	29	16,7	2,3	0,01012	0,00158	0,05L	1,17	12,5	0,060	0,28
W4326	21	17,4	2,2	0,01452	0,00097	0,10	1,58	1,0	0,053	0,70
W4303X	ND	ND	2,5	0,00000B	0,00118	0,09	1,33	1,5	0,060	0,20
W6061	18	15,6	2,2	0,01232	0,00178	0,05L	0,92	7,5	0,044	0,22
W7131	14	17,6	2,5	0,01150	0,00103	0,07	1,30	5,8	0,070	0,30
W7136X	ND	ND	2,5	0,00000B	0,00255	0,06	1,72	8,9	0,070	0,30
WATKINS! SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION										
W5834	28	16,2	2,3	0,00000B	0,00182	0,05	1,08	7,2	0,055	0,25

Table 1.--Analyses of wheat from Metropolitan Denver Sewage District's 1974 experimental crop.--Continued

SAMPLE	CO PPM	CU PPM	FE %	HG PPM	K %	LI PPM	MG %	MN PPM	MO PPM	NA %
WATKINS! SITE CONTROL PLOTS - NO SLUDGE APPLICATION										
W0105	0.000B	5.3	0.00260	0.01L	0.48	0 B	0.11	18	1.8	0.00149
W1847	0.000B	4.8	0.00000B	0.01L	0.51	0 B	0.07	12	1.1	0.00099
W2527	0.000B	5.3	0.00257	0.01L	0.48	0 B	0.08	20	1.3	0.00132
W2537X	0.000B	5.3	0.00317	0.01L	0.48	0 B	0.14	21	1.8	0.00134
W3348	0.000B	5.7	0.00315	0.01L	0.53	0 B	0.10	20	0.7	0.00128
W3407	0.000B	5.7	0.00294	0.01L	0.53	0 B	0.11	18	1.4	0.00133
W3420X	0.000B	5.5	0.00290	0.01L	0.51	0 B	0.13	22	1.4	0.00119
W4453	0.000B	4.8	0.00194	0.01L	0.44	0 B	0.10	19	1.7	0.00130
WATKINS! SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION										
W0510	0.000B	5.3	0.00212	0.01L	0.51	0 B	0.10	35	1.2	0.00129
W0512X	0.000B	5.5	0.00266	0.01L	0.51	0 B	0.12	37	1.5	0.00128
W0659	0.000B	6.2	0.00343	0.01L	0.53	0 B	0.11	25	1.3	0.00264
W1746	0.000B	5.5	0.00354	0.01L	0.53	0 B	0.13	42	0.7	0.00126
W3506	0.000B	4.6	0.00269	0.01L	0.53	0 B	0.08	38	0.6	0.00143
W3533X	0.000B	5.1	0.00000B	0.01L	0.51	0 B	0.05	13	0.2	0.00138
W4645	0.000B	4.6	0.00330	0.01L	0.48	0 B	0.14	41	0.9	0.00119
W4629X	0.000B	5.1	0.00290	0.01L	0.44	0 B	0.10	39	0.7	0.00128
W6844	0.023	6.0	0.00363	0.01L	0.48	0 B	0.11	37	1.0	0.00113
WATKINS! SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION										
W0325	0.000B	5.9	0.00282	0.01L	0.51	0 B	0.10	40	1.3	0.00154
W3601	0.046	4.6	0.00345	0.01L	0.55	0 B	0.09	46	0.8	0.00126
W4558	0.000B	5.1	0.00330	0.01L	0.48	0 B	0.13	37	2.7	0.00130
W4518X	0.000B	4.6	0.00378	0.01L	0.46	0 B	0.14	41	1.5	0.00122
W5330	0.025	6.5	0.00213	0.01L	0.57	0 B	0.05	25	0.6	0.00150
W5317X	0.024	6.2	0.00353	0.01L	0.55	0 B	0.14	37	0.9	0.00143
W5609	0.000B	5.7	0.00227	0.01L	0.51	0 B	0.09	28	1.9	0.00130
W5624X	0.000B	5.7	0.00000B	0.01L	0.51	0 B	0.07	22	2.1	0.00132
W6138	0.023	6.7	0.00267	0.01L	0.51	0 B	0.10	34	0.8	0.00129
WATKINS! SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION										
W1455	0.000B	6.2	0.00322	0.01L	0.53	0 B	0.15	23	0.5	0.00144
W2635	0.000B	5.5	0.00317	0.01L	0.46	0 B	0.12	29	1.2	0.00126
W4043	0.000B	6.2	0.00278	0.01L	0.51	0 B	0.11	19	0.8	0.00129
W4326	0.000B	6.4	0.00356	0.01L	0.46	0 B	0.08	30	2.6	0.00154
W4303X	0.000B	6.8	0.00353	0.01L	0.55	0 B	0.11	26	0.9	0.00175
W6061	0.000B	5.7	0.00297	0.01L	0.44	0 B	0.09	25	0.6	0.00095
W7131	0.000B	6.5	0.00270	0.01L	0.57	0 B	0.10	21	0.7	0.00137
W7136X	0.000B	6.3	0.00377	0.01L	0.52	0 B	0.15	24	0.7	0.00135
WATKINS! SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION										
W5834	0.000B	6.0	0.00306	0.01L	0.51	0 B	0.11	23	1.5	0.00122

Table 1.--Analyses of wheat from Metropolitan Denver Sewage District's 1974 experimental crop.--Continued

SAMPLE	NB PPM	NI PPM	P, PPM	PB PPM	TOTAL S%	SE PPM	SR PPM	Y PPM	ZN PPM
WATKINS! SITE CONTROL PLOTS - NO SLUDGE APPLICATION									
W0105	0.10	0.3	4140	0 B	0.01L	0.30	1.8	0.11	51
W1647	0.22	0.4	3960	0 B	0.01L	0.40	2.0	0.09	46
W2527	0.17	0.3	3960	0 B	0.01L	0.25	1.7	0.11	51
W2537X	0.00B	0.3	3960	0 B	0.01L	0.20	2.3	0.08	53
W3348	0.21	0.3	3960	0 B	0.01L	0.25	2.1	0.10	55
W3407	0.00B	0.3	4140	0 B	0.01L	0.25	1.7	0.09	48
W3420X	0.33	0.4	3960	0 B	0.01L	0.45	1.7	0.09	53
W4453	0.14	0.3	3780	0 B	0.01L	0.30	1.2	0.09	42
WATKINS! SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION									
W0510	0.12	1.5	4140	0 B	0.01L	0.35	1.6	0.09	80
W0512X	0.21	1.4	3960	0 B	0.01L	0.35	2.4	0.10	79
W0659	0.00B	1.2	4320	0 B	0.01L	0.20	2.4	0.10	70
W1746	0.26	1.5	4140	0 B	0.01L	0.30	2.4	0.00B	71
W3506	0.00B	1.0	2760	0 B	0.01L	0.45	2.3	0.10	55
W3533X	0.00B	1.1	4140	0 B	0.01L	0.30	1.8	0.00B	60
W4545	0.00B	1.1	3960	0 B	0.01L	0.35	2.3	0.11	70
W4629X	0.25	1.2	3960	0 B	0.01L	0.30	2.2	0.10	75
W6844	0.35	1.6	4140	0 B	0.01L	0.25	2.2	0.10	87
WATKINS! SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION									
W0325	0.00B	1.6	3960	0 B	0.01L	0.25	1.7	0.09	77
W3601	0.23	1.8	4140	0 B	0.01L	0.25	1.8	0.10	62
W4558	0.27	1.5	3960	0 B	0.01L	0.35	2.5	0.10	79
W4516X	0.14	1.5	3780	0 B	0.01L	0.30	2.2	0.11	80
W5330	0.22	2.4	4500	0 B	0.01L	0.20	2.3	0.08	83
W5317X	0.00B	2.3	4320	0 B	0.01L	0.45	3.4	0.09	77
W5609	0.29	1.4	3960	0 B	0.01L	0.30	2.1	0.08	81
W5674X	0.00B	1.5	3960	0 B	0.01L	0.25	1.2	0.09	90
W6138	0.00B	2.2	4140	0 B	0.01L	0.25	2.3	0.09	92
WATKINS! SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION									
W1455	0.00B	1.7	4320	0 B	0.01L	0.40	2.2	0.11	72
W2635	0.26	1.1	4140	0 B	0.01L	0.50	2.6	0.10	80
W4043	0.13	1.8	4140	0 B	0.01L	0.35	5.5	0.09	83
W4326	0.44	1.5	3960	0 B	0.01L	0.40	1.1	0.11	75
W4303X	0.00B	1.6	4500	0 B	0.01L	0.35	1.2	0.11	85
W6061	0.00B	1.3	3960	0 B	0.01L	0.35	2.5	0.00B	77
W7131	0.13	1.8	4500	0 B	0.01L	0.60	1.2	0.10	93
W7136X	0.29	1.8	4500	0 B	0.01L	0.60	2.6	0.10	95
WATKINS! SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION									
W5834	0.14	1.7	4140	0 B	0.01L	0.30	2.0	0.09	87

Table 1.--Analyses of wheat from Metropolitan Denver Sewage District's 1974 experimental crop.--Continued

SAMPLE	YIELD BU/A	%PROTEIN	ASH %	AG PPM	AL %	AS PPM	B PPM	BA PPM	CA %	CD PPM
LOWRY SEWAGE-DISPOSAL SITE										
WLOWRY	ND	ND	1,8	0,00828	0,00084	0,05L	1,35	7,0	0,061	0,11
WATKINS' SITE FILTER-CAKE PLOTS - CA, 20 TONS/ACRE APPLICATION										
W1349	27	13,4	2,1	0,00000B	0,00175	0,05L	0,84	6,4	0,046	0,06
W4816	20	12,4	2,1	0,00000B	0,00124	0,05L	0,80	7,8	0,046	0,04
WATKINS' SITE FILTER-CAKE PLOTS - CA, 30 TONS/ACRE APPLICATION										
W3121	31	13,4	2,1	0,00000B	0,00097	0,05L	1,03	7,5	0,042	0,04
W6611	19	14,7	2,3	0,00000B	0,00121	0,05L	0,93	6,8	0,051	0,07
WATKINS' SITE FILTER-CAKE PLOTS - CA, 45 TONS/ACRE APPLICATION										
W1114	23	13,7	2,2	0,00000B	0,00068	0,05L	0,76	5,9	0,053	0,04
W3002	36	14,1	2,2	0,00000B	0,00057	0,05L	1,00	7,4	0,053	0,07

SAMPLE	CO PPM	CU PPM	FE %	HG PPM	K %	LI PPM	MG %	MN PPM	MO PPM	NA %
LOWRY SEWAGE-DISPOSAL SITE										
WLOWRY	0,036	6,5	0,00347	0,01L	0,38	0 B	0,08	27	1,0	0,00162
WATKINS' SITE FILTER-CAKE PLOTS - CA, 20 TONS/ACRE APPLICATION										
W1349	0,000B	4,6	0,00267	0,01L	0,44	0 B	0,09	17	1,1	0,00109
W4816	0,000B	4,6	0,00225	0,01L	0,46	0 B	0,10	17	1,7	0,00120
WATKINS' SITE FILTER-CAKE PLOTS - CA, 30 TONS/ACRE APPLICATION										
W3121	0,000B	4,6	0,00239	0,01L	0,44	0 B	0,11	18	1,4	0,00109
W6611	0,000B	6,4	0,00276	0,01L	0,51	0 B	0,10	15	2,6	0,00120
WATKINS' SITE FILTER-CAKE PLOTS - CA, 45 TONS/ACRE APPLICATION										
W1114	0,000B	4,8	0,00182	0,01L	0,51	0 B	0,07	18	1,4	0,00125
W3002	0,000B	4,8	0,00266	0,01L	0,48	0 B	0,11	17	1,6	0,00121

Table 1.--Analyses of wheat from Metropolitan Denver Sewage District's 1974 experimental crop.--Continued

SAMPLE	NB PPM	NI PPM	P PPM	PB PPM	TOTAL S%	SE PPM	SR PPM	Y PPM	ZN PPM
				LOWRY SEWAGE-DISPOSAL SITE					
WLOWRY	0.19	0.9	3240	0 B	0.01L	0.15	5.8	0.06	52
				WATKINS! SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION					
W1349	0.19	0.3	3780	0 B	0.01L	0.30	1.5	0.08	38
W4816	0.29	0.3	3780	0 B	0.01L	0.45	1.7	0.09	42
				WATKINS! SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION					
W3121	0.008	0.3	3780	0 B	0.01L	0.45	2.6	0.09	44
W6611	0.20	0.4	4140	0 B	0.01L	0.50	1.4	0.09	62
				WATKINS! SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION					
W1114	0.35	0.4	3960	0 B	0.01L	0.40	1.6	0.05	44
W3002	0.17	0.4	3960	0 B	0.01L	0.35	2.4	0.09	33

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.

[Element concentrations are expressed on a total, not available basis; they are significant to only two figures, though more may be given. A sample with an "X" suffix is a duplicate of the preceding sample. L's following data indicate concentrations below the indicated detection level; G's (for some silicon data), greater than the indicated detection limit]

SAMPLE	PH	AG PPM	AL %	AS PPM	AU PPM	B PPM	BA PPM	BE PPM	BI PPM	CA %
WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION										
0301	7.4	0.46L	6.6	1.0	6 L	8.5	801	1.6	10 L	0.38
5418	7.0	0.26	7.1	2.4	6 L	10.2	942	2.3	10 L	0.33
6625	7.3	0.41	5.4	0.5	6 L	8.7	821	2.3	10 L	0.43
8525X	7.3	0.22L	5.9	0.1L	6 L	5.4	827	2.2	10 L	0.39
6233	7.2	0.27	6.2	0.8	6 L	8.1	782	1.9	10 L	0.64
3034	7.5	0.26	5.3	0.3	6 L	11.2	771	1.9	10 L	0.29
3134X	7.4	0.22L	6.6	1.0	6 L	12.6	706	2.0	10 L	0.36
0644	7.5	0.22	5.3	0.1L	6 L	10.6	740	2.0	10 L	0.34
WATKINS' SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION										
2405	7.2	0.76	6.8	0.9	6 L	7.5	668	2.2	10 L	0.21
7405X	7.3	0.65	4.8	0.5	6 L	6.0	666	1.9	10 L	0.28
9406	6.9	0.92	7.0	0.7	6 L	13.9	836	2.5	10 L	0.29
5217	6.4	0.56	6.2	0.6	6 L	10.8	970	2.2	10 L	0.31
3935	7.1	0.30	7.4	0.8	6 L	10.3	867	1.9	10 L	0.41
6935X	7.1	0.43	7.4	1.1	6 L	8.2	735	2.2	10 L	0.31
1246	7.0	0.71	5.9	0.9	6 L	8.7	794	2.4	10 L	0.44
4546X	6.7	0.33	5.5	0.9	6 L	6.5	7	1.9	10 L	0.56
2268	6.8	0.78	7.0	0.8	6 L	7.3	849	1.8	10 L	0.49
WATKINS' SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION										
2703	7.2	1.04	4.9	0.1L	6 L	3.3	756	1.8	10 L	0.40
8636	6.7	0.94	5.5	0.1L	6 L	14.5	875	1.9	10 L	0.49
2045	7.0	0.41	5.4	0.5	6 L	8.5	726	2.1	10 L	0.39
5645X	7.2	0.77	6.1	0.7	6 L	9.1	754	2.3	10 L	0.37
3353	7.0	0.71	5.8	0.8	6 L	5.9	729	2.2	10 L	0.41
9553X	6.8	5.25	5.9	0.8	6 L	6.0	771	8.3	10 L	0.41
0456	7.2	1.23	5.4	0.7	6 L	5.4	701	1.7	10 L	0.44
2156X	7.1	1.22	5.3	2.2	6 L	6.9	727	1.5	10 L	0.50
1861	6.6	0.78	5.8	0.2	6 L	7.7	777	2.3	10 L	0.27
WATKINS' SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION										
0214	6.6	1.62	6.6	1.1	6 L	25.2	835	2.0	10 L	0.42
1026	6.8	0.56	4.9	1.9	6 L	5.8	791	1.5	10 L	0.39
4140	7.2	1.11	5.6	1.2	6 L	5.8	808	1.7	10 L	0.41
1443	6.8	0.22L	3.9	0.4	6 L	2.2	702	1.3	10 L	0.26
4843X	6.7	0.97	6.6	1.4	6 L	6.7	767	1.9	10 L	0.44
4360	6.5	1.79	7.2	0.9	6 L	6.7	640	2.1	10 L	0.48
2971	6.6	0.75	6.0	1.5	6 L	8.7	838	1.6	10 L	0.26
3571X	6.6	1.05	6.0	1.3	6 L	8.1	704	2.2	10 L	0.27
WATKINS' SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION										
5758	7.1	0.22L	5.2	0.8	6 L	3.1	629	1.8	10 L	0.24

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	CD PPM	CO PPM	CR PPM	CU PPM	DY PPM	ER PPM	EU PPM	F %	FE %	GA PPM
WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION										
0301	1 L	2.6	13	11	46 L	46 L	10 L	0.04L	0.60	7.0
5418	1 L	2.8	12	10	46 L	46 L	10 L	0.04L	0.76	7.9
6625	1 L	2.4	13	10 L	46 L	46 L	10 L	0.05	0.66	6.4
8525X	1 L	2.8	13	11	46 L	46 L	10 L	0.04L	0.67	8.0
6233	1 L	3.4	14	10 L	46 L	46 L	10 L	0.04	0.72	9.7
3034	1 L	3.2	12	10	46 L	46 L	10 L	0.04L	0.78	7.0
3134X	1 L	2.6	14	10 L	46 L	46 L	10 L	0.06	0.83	6.4
0644	1 L	3.4	15	10	46 L	46 L	10 L	0.04L	0.80	6.3
WATKINS' SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION										
2405	1 L	2.1	13	16	46 L	46 L	10 L	0.04L	0.73	6.2
7405X	1 L	2.9	14	16	46 L	46 L	10 L	0.06	0.70	5.4
9406	1 L	2.6	14	16	46 L	46 L	10 L	0.04L	0.69	7.6
5217	1 L	2.7	15	14	46 L	46 L	10 L	0.04L	0.78	7.9
3935	1 L	3.3	16	11	46 L	46 L	10 L	0.04L	0.79	7.0
6935X	1 L	2.8	14	14	46 L	46 L	10 L	0.04L	0.82	6.9
1246	1 L	3.3	19	14	46 L	46 L	10 L	0.06	0.82	8.9
4546X	1 L	2.8	15	11	46 L	46 L	10 L	0.04L	0.70	7.7
2268	1 L	3.1	20	18	46 L	46 L	10 L	0.05	0.68	7.9
WATKINS' SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION										
2703	1 L	1.9	14	14	46 L	46 L	10 L	0.04	0.49	4.8
8636	1 L	3.0	16	21	46 L	46 L	10 L	0.06	0.72	6.4
2045	1 L	3.1	16	15	46 L	46 L	10 L	0.04L	0.83	6.7
5645X	1 L	3.7	23	15	46 L	46 L	10 L	0.04	0.87	6.9
3353	1 L	2.2	13	17	46 L	46 L	10 L	0.04L	0.71	5.7
9553X	1 L	2.3	14	15	46 L	46 L	10 L	0.04	0.65	5.5
0456	1 L	2.8	15	18	46 L	46 L	10 L	0.04L	0.66	5.7
2156X	1 L	2.1	18	19	46 L	46 L	10 L	0.04	0.57	10.1
1861	1 L	2.5	12	16	46 L	46 L	10 L	0.04L	0.68	8.5
WATKINS' SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION										
0214	1 L	3.2	21	24	46 L	46 L	10 L	0.04	0.75	6.1
1026	1 L	2.3	15	14	46 L	46 L	10 L	0.04L	0.66	7.0
4140	1 L	2.5	15	19	46 L	46 L	10 L	0.04L	0.65	7.0
1443	1 L	2.1	16	20	46 L	46 L	10 L	0.11	0.51	3.3
4843X	1 L	2.6	18	20	46 L	46 L	10 L	0.04	0.67	5.9
4360	1 L	2.6	18	23	46 L	46 L	10 L	0.04L	0.60	6.6
2971	1 L	2.5	14	16	46 L	46 L	10 L	0.04L	0.61	6.1
3571X	1 L	2.5	16	16	46 L	46 L	10 L	0.04L	0.70	6.0
WATKINS' SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION										
5758	1 L	2.3	13	20	46 L	46 L	10 L	0.04L	0.70	4.7

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	GD PPM	GE PPM	HF PPM	HG PPM	HO PPM	IN PPM	IR PPM	K %	LA PPM	LI PPM
WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION										
0301	20 L	1.4	100 L	0.01	10 L	50 L	46 L	4.4	46 L	7
5418	20 L	1.6	100 L	0.02	10 L	50 L	46 L	3.7	49	9
6625	20 L	1.0	100 L	0.01L	10 L	50 L	46 L	4.1	46 L	8
8525X	20 L	0.1L	100 L	0.01	10 L	50 L	46 L	4.1	46 L	8
6233	20 L	0.6	100 L	0.02	10 L	50 L	46 L	4.3	46 L	8
3034	20 L	1.0	100 L	0.01	10 L	50 L	46 L	3.7	46 L	8
3134X	20 L	1.3	100 L	0.01	10 L	50 L	46 L	3.8	46 L	8
0644	20 L	0.6	100 L	0.02	10 L	50 L	46 L	3.7	46 L	8
WATKINS' SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION										
2405	20 L	0.8	100 L	0.08	10 L	50 L	46 L	3.7	46 L	9
7405X	20 L	0.9	100 L	0.09	10 L	50 L	46 L	3.8	46 L	8
9406	20 L	1.1	100 L	0.07	10 L	50 L	46 L	3.7	46 L	8
5217	20 L	1.4	100 L	0.06	10 L	50 L	46 L	4.0	46 L	8
3935	20 L	1.1	100 L	0.05	10 L	50 L	46 L	3.9	46 L	8
6935X	20 L	1.3	100 L	0.05	10 L	50 L	46 L	3.8	46 L	8
1246	20 L	1.2	100 L	0.07	10 L	50 L	46 L	3.9	46 L	9
4546X	20 L	1.4	100 L	0.07	10 L	50 L	46 L	3.8	46 L	8
2268	20 L	1.0	100 L	0.09	10 L	50 L	46 L	3.8	46 L	8
WATKINS' SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION										
2703	20 L	0.5	100 L	0.09	10 L	50 L	46 L	3.8	46 L	6
8636	20 L	0.6	100 L	0.12	10 L	50 L	46 L	3.9	49	9
2045	20 L	1.1	100 L	0.07	10 L	50 L	46 L	3.6	50	9
5645X	20 L	0.8	100 L	0.07	10 L	50 L	46 L	3.9	46 L	9
3353	20 L	1.0	100 L	0.07	10 L	50 L	46 L	3.6	46 L	7
9553X	20 L	1.3	100 L	0.09	10 L	50 L	46 L	3.7	46 L	7
0456	20 L	1.1	100 L	0.13	10 L	50 L	46 L	3.7	46 L	7
2156X	20 L	1.0	100 L	0.14	10 L	50 L	46 L	4.3	46 L	8
1861	20 L	0.5	100 L	0.07	10 L	50 L	46 L	3.8	46 L	7
WATKINS' SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION										
0214	20 L	1.4	100 L	0.16	10 L	50 L	46 L	3.8	46 L	8
1026	20 L	1.2	100 L	0.07	10 L	50 L	46 L	4.2	46 L	8
4140	20 L	1.4	100 L	0.12	10 L	50 L	46 L	3.8	46 L	8
1443	20 L	0.5	100 L	0.16	10 L	50 L	46 L	3.7	46 L	7
4843X	20 L	1.2	100 L	0.14	10 L	50 L	46 L	4.2	46 L	7
4360	20 L	1.0	100 L	0.12	10 L	50 L	46 L	4.0	46 L	7
2971	20 L	1.3	100 L	0.09	10 L	50 L	46 L	3.8	46 L	7
3571X	20 L	1.3	100 L	0.12	10 L	50 L	46 L	3.6	171	7
WATKINS' SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION										
5758	20 L	1.2	100 L	0.19	10 L	50 L	46 L	3.4	46 L	8

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	LU PPM	MGO %	MN PPM	MO PPM	NA2O %	NB PPM	ND PPM	NI PPM	OS PPM	P %
		WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION								
0301	7 L	0.20	185	1.0L	1.6	8.2	46 L	5.8	22 L	0.3L
5418	7 L	0.28	187	1.0	1.8	9.0	46 L	4.2	22 L	0.3L
6625	7 L	0.25	199	1.3	1.7	8.9	46 L	4.4	22 L	0.3L
8525X	7 L	0.24	153	1.0L	1.6	9.5	46 L	4.6	22 L	0.3L
6233	7 L	0.27	180	1.7	1.7	6.6	46 L	5.7	22 L	0.3L
3034	7 L	0.27	197	1.1	1.7	9.5	46 L	5.2	22 L	0.3L
3134X	7 L	0.28	174	1.0L	1.8	3.6	46 L	3.7	22 L	0.3L
0644	7 L	0.26	182	1.5	1.7	11.0	46 L	5.9	22 L	0.3L
		WATKINS' SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION								
2405	7 L	0.28	172	1.0L	1.6	9.4	46 L	4.9	22 L	0.3L
7405X	7 L	0.27	169	1.0	1.5	12.4	46 L	5.6	22 L	0.3L
9406	7 L	0.24	175	1.3	1.7	10.5	46 L	5.7	22 L	0.3L
5217	7 L	0.26	187	1.0	1.8	9.9	49	5.6	22 L	0.3L
3935	7 L	0.30	179	1.2	1.8	6.1	46 L	5.8	22 L	0.3L
6935X	7 L	0.30	198	1.4	1.8	7.3	46 L	5.2	22 L	0.3L
1246	7 L	0.31	212	1.8	1.8	9.2	46 L	7.1	22 L	0.3L
4546X	7 L	0.29	182	1.6	1.6	3.4	46 L	6.3	22 L	0.3L
2268	7 L	0.27	272	1.2	1.7	2.6	46 L	6.3	22 L	0.3L
		WATKINS' SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION								
2703	7 L	0.17	146	1.0L	1.5	7.3	50	4.6	22 L	0.3L
8636	7 L	0.27	174	1.4	1.7	9.3	46 L	6.5	22 L	0.3L
2045	7 L	0.28	214	1.3	1.7	13.2	46 L	6.5	22 L	0.3L
5645X	7 L	0.29	223	1.5	1.7	7.2	46 L	5.6	22 L	0.3L
3353	7 L	0.25	283	1.0L	1.7	3.5	46 L	4.7	22 L	0.3L
9553X	7 L	0.22	188	1.2	1.7	8.5	46 L	4.9	22 L	0.3L
0456	7 L	0.19	176	1.0L	1.6	13.1	46 L	5.0	22 L	0.3L
2156X	7 L	0.21	147	1.0L	1.6	7.5	46 L	5.2	22 L	0.3L
1861	7 L	0.22	263	1.0	1.7	13.9	46 L	4.6	22 L	0.3L
		WATKINS' SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION								
0214	7 L	0.28	198	1.0L	1.7	4.3	46 L	6.3	22 L	0.3L
1026	7 L	0.27	171	1.0L	1.6	15.9	46 L	5.2	22 L	0.3L
4140	7 L	0.26	165	1.0L	1.6	3.5	46 L	5.6	22 L	0.3L
1443	7 L	0.23	133	1.0L	1.6	4.9	46 L	4.0	22 L	0.3L
4843X	7 L	0.22	210	1.3	1.6	8.8	46 L	6.4	22 L	0.3L
4360	7 L	0.24	204	1.0L	1.7	13.5	46 L	7.5	22 L	0.3L
2971	7 L	0.19	171	1.0L	1.7	7.7	46 L	5.1	22 L	0.3L
3571X	7 L	0.23	180	1.0L	1.7	10.3	46 L	4.1	22 L	0.3L
		WATKINS' SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION								
5758	7 L	0.26	139	1.0L	1.7	8.8	46 L	4.8	22 L	0.3L

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	PB PPM	PD PPM	PR PPM	PT PPM	RE PPM	RH PPM	RU PPM	SB PPM	SC PPM	SE PPM
		WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION								
0301	29	2 L	22 L	10 L	26 L	1 L	22 L	0.8	5 L	0.1L
5418	26	2 L	22 L	10 L	26 L	1 L	22 L	1.1	5 L	0.1L
6625	20	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
8525X	22	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.2
6233	31	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
3034	24	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
3134X	20	2 L	22 L	10 L	26 L	1 L	22 L	1.4	5 L	0.1
0644	20	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
		WATKINS' SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION								
2405	28	2 L	22 L	10 L	26 L	1 L	22 L	0.4	5 L	0.2
7405X	29	2 L	22 L	10 L	26 L	1 L	22 L	0.5	5 L	0.1L
9406	36	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
5217	30	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
3935	23	2 L	22 L	10 L	26 L	1 L	22 L	0.6	5 L	0.1L
6935X	25	2 L	22 L	10 L	26 L	1 L	22 L	0.4	5 L	0.1L
1246	32	2 L	22 L	10 L	26 L	1 L	22 L	1.1	5 L	0.1L
4546X	25	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
2268	29	2 L	22 L	10 L	26 L	1 L	22 L	1.3	5 L	0.1L
		WATKINS' SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION								
2703	34	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
8636	28	2 L	22 L	10 L	26 L	1 L	22 L	1.7	5 L	0.1L
2045	25	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
5645X	34	2 L	22 L	10 L	26 L	1 L	22 L	0.1	5 L	0.1L
3353	23	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
9553X	31	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
0456	44	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
2156X	46	2 L	22 L	10 L	26 L	1 L	22 L	1.8	5 L	0.1L
1861	36	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
		WATKINS' SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION								
0214	31	2 L	22 L	10 L	26 L	1 L	22 L	0.7	5 L	0.1L
1026	30	2 L	22 L	10 L	26 L	1 L	22 L	1.7	5 L	0.2
4140	31	2 L	22 L	10 L	26 L	1 L	22 L	0.9	5 L	0.1L
1443	35	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1
4843X	29	2 L	22 L	10 L	26 L	1 L	22 L	1.2	5 L	0.1L
4360	39	2 L	22 L	10 L	26 L	1 L	22 L	0.3	5 L	0.2
2971	30	2 L	22 L	10 L	26 L	1 L	22 L	5.5	5 L	0.1L
3571X	36	2 L	22 L	10 L	26 L	1 L	22 L	4.3	5 L	0.1L
		WATKINS' SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION								
5758	28	2 L	22 L	10 L	26 L	1 L	22 L	0.4	5 L	0.1L

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	SI %	SM PPM	SN PPM	SR PPM	TA PPM	TB PPM	TE PPM	TH PPM	TI %	TL PPM
		WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION								
0301	46 G	464 L	1.4	183	500 L	100 L	1000 L	300 L	0.13	46 L
5418	46 G	464 L	1.3	206	500 L	100 L	1000 L	300 L	0.20	46 L
6625	43	464 L	0.4	199	500 L	100 L	1000 L	300 L	0.16	46 L
8525X	45	464 L	0.1L	199	500 L	100 L	1000 L	300 L	0.09	46 L
6233	46 G	464 L	0.3	196	500 L	100 L	1000 L	300 L	0.17	46 L
3034	45	464 L	1.5	184	500 L	100 L	1000 L	300 L	0.18	46 L
3134X	38	464 L	0.8	187	500 L	100 L	1000 L	300 L	0.19	46 L
0644	40	464 L	1.7	197	500 L	100 L	1000 L	300 L	0.20	46 L
		WATKINS' SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION								
2405	41	464 L	1.0	171	500 L	100 L	1000 L	300 L	0.17	46 L
7405X	37	464 L	1.9	166	500 L	100 L	1000 L	300 L	0.10	46 L
9406	46 G	464 L	1.9	205	500 L	100 L	1000 L	300 L	0.16	46 L
5217	44	464 L	2.4	215	500 L	100 L	1000 L	300 L	0.19	46 L
3935	44	464 L	1.3	196	500 L	100 L	1000 L	300 L	0.16	46 L
6935X	43	464 L	1.4	189	500 L	100 L	1000 L	300 L	0.18	46 L
1246	46	464 L	1.1	192	500 L	100 L	1000 L	300 L	0.21	46 L
4546X	37	464 L	1.6	177	500 L	100 L	1000 L	300 L	0.18	46 L
2268	44	464 L	1.9	210	500 L	100 L	1000 L	300 L	0.18	46 L
		WATKINS' SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION								
2703	42	464 L	0.8	166	500 L	100 L	1000 L	300 L	0.08	46 L
8636	40	464 L	2.3	183	500 L	100 L	1000 L	300 L	0.19	46 L
2045	43	464 L	1.3	180	500 L	100 L	1000 L	300 L	0.19	46 L
5645X	46	464 L	1.1	186	500 L	100 L	1000 L	300 L	0.20	46 L
3353	38	464 L	1.5	179	500 L	100 L	1000 L	300 L	0.18	46 L
9553X	42	464 L	1.4	174	500 L	100 L	1000 L	300 L	0.19	46 L
0456	45	464 L	2.2	184	500 L	100 L	1000 L	300 L	0.10	46 L
2156X	44	464 L	2.2	171	500 L	100 L	1000 L	300 L	0.15	46 L
1661	46	464 L	0.5	187	500 L	100 L	1000 L	300 L	0.10	46 L
		WATKINS' SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION								
0214	40	464 L	4.2	193	500 L	100 L	1000 L	300 L	0.19	46 L
1026	41	464 L	1.6	179	500 L	100 L	1000 L	300 L	0.09	46 L
4140	43	464 L	2.1	186	500 L	100 L	1000 L	300 L	0.17	46 L
1443	35	464 L	0.9	158	500 L	100 L	1000 L	300 L	0.16	46 L
4843X	42	464 L	3.3	179	500 L	100 L	1000 L	300 L	0.16	46 L
4360	45	464 L	2.4	178	500 L	100 L	1000 L	300 L	0.21	46 L
2971	44	464 L	3.1	189	500 L	100 L	1000 L	300 L	0.14	46 L
3571X	46	464 L	3.0	174	500 L	100 L	1000 L	300 L	0.18	46 L
		WATKINS' SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION								
5758	38	464 L	2.5	164	500 L	100 L	1000 L	300 L	0.10	46 L

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	TM PPM	U PPM	V PPM	W PPM	Y PPM	YB PPM	ZN PPM	ZR PPM
WATKINS' SITE CONTROL PLOTS - NO SLUDGE APPLICATION								
0301	5 L	464 L	14	150 L	23	3.9	28	192
5418	5 L	464 L	21	150 L	27	3.8	39	313
6625	5 L	464 L	16	150 L	23	3.9	29	274
8525 X	5 L	464 L	17	150 L	16	3.8	28	185
6233	5 L	464 L	20	150 L	30	4.8	29	236
3034	5 L	464 L	20	150 L	25	3.0	30	231
3134 X	5 L	464 L	25	150 L	23	2.9	31	350
0644	5 L	464 L	21	150 L	43	7.9	31	313
WATKINS' SITE SLUDGE PLOTS - CA. 20 TONS/ACRE APPLICATION								
2405	5 L	464 L	17	150 L	16	2.3	51	241
7405 X	5 L	464 L	19	150 L	27	4.5	51	224
9406	5 L	464 L	17	150 L	54	8.1	51	323
5217	5 L	464 L	19	150 L	20	3.1	43	197
3935	5 L	464 L	18	150 L	19	2.9	47	219
6935 X	5 L	464 L	19	150 L	26	5.0	48	270
1246	5 L	464 L	23	150 L	22	3.5	47	285
4546 X	5 L	464 L	19	150 L	20	3.2	38	317
2268	5 L	464 L	18	150 L	22	3.6	56	227
WATKINS' SITE SLUDGE PLOTS - CA. 40 TONS/ACRE APPLICATION								
2703	5 L	464 L	14	150 L	16	2.1	42	167
8636	5 L	464 L	20	150 L	21	3.5	59	295
2045	5 L	464 L	24	150 L	28	3.6	42	255
5645 X	5 L	464 L	23	150 L	32	3.5	42	373
3353	5 L	464 L	17	150 L	33	3.6	51	329
9553 X	5 L	464 L	19	150 L	37	4.4	47	291
0456	5 L	464 L	15	150 L	20	3.0	54	243
2156 X	5 L	464 L	15	150 L	19	2.5	64	145
1861	5 L	464 L	18	150 L	21	3.4	47	255
WATKINS' SITE SLUDGE PLOTS - CA. 55 TONS/ACRE APPLICATION								
0214	5 L	464 L	20	150 L	35	4.7	75	240
1026	5 L	464 L	17	150 L	18	3.7	44	222
4140	5 L	464 L	18	150 L	29	3.6	63	249
1443	5 L	464 L	15	150 L	21	3.4	60	204
4843 X	5 L	464 L	15	150 L	15	3.6	64	360
4360	5 L	464 L	17	150 L	17	3.2	74	330
2971	5 L	464 L	15	150 L	20	2.6	55	276
3571 X	5 L	464 L	17	150 L	23	2.9	59	288
WATKINS' SITE SLUDGE PLOT - CA. 90 TONS/ACRE APPLICATION								
5758	5 L	464 L	16	150 L	19	5.2	69	216

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	PH	AG PPM	AL %	AS PPM	AU PPM	B PPM	BA PPM	BE PPM	BI PPM	CA %
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION								
8913	7.8	0.36	5.4	1.1	6 L	7.8	670	2.4	10 L	0.45
9948	7.5	0.26	4.7	0.7	6 L	4.8	852	1.9	10 L	0.38
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION								
1131	7.6	0.52	8.3	1.1	6 L	27.8	757	3.0	10 L	0.85
2666	7.6	0.22L	6.8	1.3	6 L	6.4	1000	1.8	10 L	0.57
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION								
1611	8.2	0.22L	6.4	0.9	6 L	15.0	727	2.2	10 L	0.48
4030	8.6	0.58	5.6	1.6	6 L	6.3	616	2.1	10 L	0.43

SAMPLE	CD PPM	CO PPM	CR PPM	CU PPM	DY PPM	ER PPM	EU PPM	F %	FE %	GA PPM
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION								
8913	1 L	3.4	18	17	46 L	46 L	10 L	0.06	1.03	7.6
9948	1 L	33.6	16	12	46 L	46 L	10 L	0.04L	0.71	5.3
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION								
1131	1 L	5.0	24	18	46 L	46 L	10 L	0.04	1.23	12.0
2666	1 L	2.8	15	13	46 L	46 L	10 L	0.04L	0.66	8.7
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION								
1611	1 L	2.7	21	17	46 L	46 L	10 L	0.04L	0.79	6.5
4030	1 L	2.8	18	19	46 L	46 L	10 L	0.04L	0.73	5.5

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	GD PPM	GE PPM	HF PPM	HG PPM	HO PPM	IN PPM	IR PPM	K %	LA PPM	LI PPM
WATKINS' SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION										
8913	20 L	1.1	100 L	0.04	10 L	50 L	46 L	3.5	46 L	12
9948	20 L	1.2	100 L	0.03	10 L	50 L	46 L	11.9	46 L	9
WATKINS' SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION										
1131	20 L	0.8	100 L	0.05	10 L	50 L	46 L	1.8L	46 L	12
2666	20 L	1.2	100 L	0.03	10 L	50 L	46 L	4.4	46 L	7
WATKINS' SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION										
1611	20 L	1.3	100 L	0.07	10 L	50 L	46 L	3.5	46 L	8
4030	20 L	1.4	100 L	0.09	10 L	50 L	46 L	3.6	46 L	10

SAMPLE	LU PPM	MGO %	MN PPM	MO PPM	NA2O %	NB PPM	ND PPM	NI PPM	OS PPM	P %
WATKINS' SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION										
8913	7 L	0.42	230	1.6	1.7	8.5	46 L	7.8	22 L	0.3L
9948	7 L	0.29	167	1.3	1.7	5.2	46 L	6.1	22 L	0.3L
WATKINS' SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION										
1131	7 L	0.43	245	2.7	1.7	8.6	46 L	11.3	22 L	0.3L
2666	7 L	0.23	195	1.0L	1.7	6.3	46 L	4.9	22 L	0.3L
WATKINS' SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION										
1611	7 L	0.30	178	1.3	1.6	5.3	46 L	6.6	22 L	0.3L
4030	7 L	0.34	184	1.0L	1.6	2.2L	46 L	5.9	22 L	0.3L

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	PB PPM	PD PPM	PR PPM	PT PPM	RE PPM	RH PPM	RU PPM	SB PPM	SC PPM	SE PPM
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION								
8913	20	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.1L
9948	18	2 L	22 L	10 L	26 L	1 L	22 L	1.7	5 L	0.3
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION								
1131	28	2 L	22 L	10 L	26 L	1 L	22 L	0.3	5 L	0.1L
2666	32	2 L	22 L	10 L	26 L	1 L	22 L	0.1L	5 L	0.2
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION								
1611	25	2 L	22 L	10 L	26 L	1 L	22 L	0.1	5 L	0.1L
4030	18	2 L	22 L	10 L	26 L	1 L	22 L	0.2	5 L	0.1L

SAMPLE	SI %	SM PPM	SN PPM	SR PPM	TA PPM	TB PPM	TE PPM	TH PPM	TI %	TL PPM
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION								
8913	37	464 L	1.4	187	500 L	100 L	1000 L	300 L	0.18	46 L
9948	40	464 L	0.7	180	500 L	100 L	1000 L	300 L	0.17	46 L
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION								
1131	45	464 L	0.8	205	500 L	100 L	1000 L	300 L	0.27	46 L
2666	44	464 L	1.4	199	500 L	100 L	1000 L	300 L	0.21	46 L
		WATKINS' SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION								
1611	42	464 L	2.5	178	500 L	100 L	1000 L	300 L	0.19	46 L
4030	35	464 L	2.3	174	500 L	100 L	1000 L	300 L	0.17	46 L

Table 2.--Analyses of soils from Metropolitan Denver Sewage District's 1974 crop experiment.--Continued

SAMPLE	TM PPM	U PPM	V PPM	W PPM	Y PPM	YB PPM	ZN PPM	ZR PPM
WATKINS' SITE FILTER-CAKE PLOTS - CA. 20 TONS/ACRE APPLICATION								
8913	5 L	464 L	25	150 L	18	3.2	54	266
9948	5 L	464 L	18	150 L	18	2.9	32	229
WATKINS' SITE FILTER-CAKE PLOTS - CA. 30 TONS/ACRE APPLICATION								
1131	5 L	464 L	28	150 L	23	3.6	46	382
2666	5 L	464 L	19	150 L	26	4.0	38	335
WATKINS' SITE FILTER-CAKE PLOTS - CA. 45 TONS/ACRE APPLICATION								
1611	5 L	464 L	21	150 L	25	3.2	55	361
4030	5 L	464 L	21	150 L	21	2.6	61	323

Table 3.--Summary statistics for yield, protein content, and concentrations of metals that showed significant increases in hard winter wheat (cv. Wichita) produced from sludge-altered soils, Watkins, Colorado.

[Data are based on six replicated plots per application rate. Yield is expressed as bu/acre; protein contents, as %; and element concentration, as parts per million. Differences in yield are significant ($p<.05$); all others are highly significant ($p<.01$)]

Factor	Application rate											
	None (control)			20 tons/acre			40 tons/acre			55 tons/acre		
	Geometric mean	Geometric deviation	Observed range	Geometric mean	Geometric deviation	Observed range	Geometric mean	Geometric deviation	Observed range	Geometric mean	Geometric deviation	Observed range
Yield-----	13	1.33	10-21	22	1.49	14-35	22	1.46	16-45	23	1.52	14-46
Protein---	12.7	1.08	11.3-13.6	15.4	1.11	13.1-17.6	15.2	1.07	13.8-16.3	16.6	1.07	15.1-17.6
Cadmium---	.042	1.11	.034-.046	.23	1.23	.17-.32	.28	1.23	.21-.39	.23	1.24	.17-.30
Manganese-	18	1.21	12-20	36	1.21	25-42	34	1.26	25-46	24	1.19	19-30
Nickel----	.32	1.18	.29-.44	1.3	1.20	1.0-1.6	1.8	1.22	1.4-2.4	1.5	1.20	1.1-1.8
Selenium--	.29	1.20	.25-.40	.31	1.33	.20-.45	.26	1.21	.20-.35	.42	1.24	.35-.60
Zinc------	49	1.10	42-55	72	1.17	55-87	78	1.14	62-92	80	1.09	72-92