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EVALUATION OF THE LONG TERM EFFECTS
OF IRRIGATION WITH WASTEWATER

by

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R. W. Miller, and L. R. Anderson*

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INTRODUCTION

Background

The application of municipal wastewater to the land or using the soil mantle as a wastewater treatment system has been practiced for many years. The history of land application dates back to ancient Athens. Sewage farming or the transportation of wastewater to rural areas for irrigation and disposal was practiced in Europe as early as 1559. The practice became fairly widespread in England, France, Germany, Poland, Austria, and the United States during the late 1800's [EPA, *et al.*, 1977].

However, during the early twentieth century, many land application systems were replaced with conventional wastewater treatment facilities. More recently, the number of land disposal systems has increased from approximately 304 reported systems serving 900,000 persons in 1940 to 571 reported systems serving 6,600,000 persons in 1972 [Thomas, 1973].

The enactment of stringent discharge standards (*i.e.*, PL 92-500) and the increasing cost of conventional wastewater treatment systems have created increasing usage of land disposal systems for wastewater

treatment. However, very little reliable information is available concerning the long term effects of applying wastewater to the land.

Objectives

The general objective of this paper is to present the results of a twenty-four month study to determine the long term effects of applying secondary treated municipal effluent to the land. The study compared data collected from a site which had been irrigated with wastewater effluent (treated site) since 1957 to data collected from an adjacent site which had received normal irrigation water (control site) for a similar period. The site is classified as a slow rate or crop irrigation land application system.

METHODS

Site Description

The study site was conducted at Tooele, Utah, (pop. 3,800 people) during 1976 and 1977. The community has a relatively large commercial district, but does not contain any major industries. The climate is semi-arid with an annual precipitation of 42 cm (16.5 inches).

The Tooele Wastewater Treatment Plant began operation in 1957 with a design capacity of 8327 m³/day (2.2 mgd). In 1957, the plant consisted of grit removal, primary sedimentation, conventional trickling filter, secondary sedimentation, chlorination, and anaerobic sludge digestion with sand drying beds. The average daily flow to the plant was less than 3028 m³/day (0.8 mgd) in 1957, but gradually increased to over 3785 m³/day (1.0 mgd) by 1961. During 1976 and 1977, the average daily flow was 5647 m³/day (1.492 mgd) and 2515.5 m³/day

(0.665 mgd). The reduced flow in 1977 was due to severe drought conditions.

Enactment of stringent effluent discharge standards by the State of Utah required the treatment plant to be upgraded. In the spring of 1977 the treatment plant was converted to a two stage trickling filter plant. Also, the secondary clarifier capacity was more than doubled.

The treatment plant effluent has been under contract to a local land owner since the plant began operation in 1957. This contract allows the land owner to use the plant effluent for crop irrigation and stock watering. The land owner controls approximately 486 ha (1200 acres) of crop and pasture land. Management of the wastewater has been directed toward crop production rather than wastewater disposal. Thus, the land owner attempts to irrigate as much land as possible with the treatment plant effluent. Frequently, since 1957, treatment plant effluent has been co-mingled with normal irrigation water to assist the crop production. However, the specific sites selected for this study had not received any co-mingled water.

Experimental System

The experimental system is shown in Figure 1. The treatment plant effluent flows approximately 0.40 km (0.25 mile) through an earthen ditch to the first holding reservoir which is approximately 0.2 ha (0.5 acre) in area and has an average depth of less than 1.8 m (6 feet). This reservoir provides minimum storage and was designed to settle solids which escaped the secondary clarifier. The reservoir is very shallow and suffers from hydraulic short circuiting.

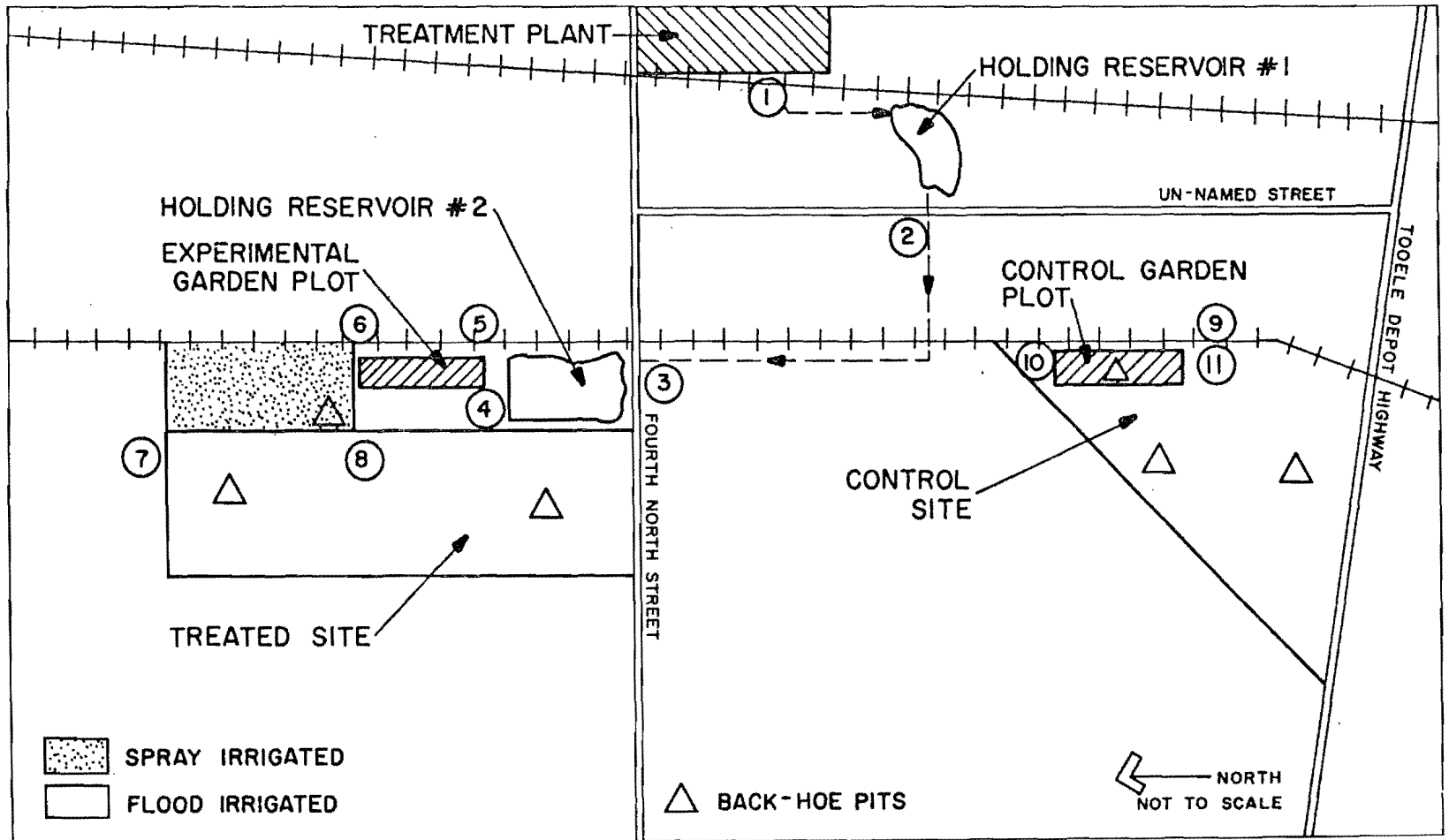


Figure 1. Schematic diagram of experimental system, location of water sampling stations, and soil sampling stations.

Near the outlet of the first holding reservoir is a pump station intake used to provide sprinkler irrigation for several adjacent fields. This point also provides the intake for effluent applied to the spray irrigation portion of the treated experimental site. Sprinkler irrigation of the treated site did not begin until 1976. Prior to 1976 the entire treated site was flood irrigated with treatment plant effluent from the second holding reservoir.

From the first holding reservoir the water flows approximately 1.6 km (1 mile) through an earthen ditch to the second reservoir which is approximately 0.05 ha (0.125 acre) and has an average depth greater than 3 m (10 feet). This holding reservoir is used primarily for storage and control of effluent application to various irrigated fields.

Treated Site

Historically, the treated site had been flood irrigated with treatment plant effluent stored in the second reservoir. However, as mentioned earlier, in 1976, a sprinkler irrigated line was installed near the outlet of the first holding reservoir and after that time a portion of the treated site was sprinkler irrigated with treatment plant effluent from the first reservoir.

The treated site is shown in Figure 1 and consists of 14 ha (34.5 acres) total. The treated site consists of the second holding reservoir, a 10.5 ha (25.2 acre) sprinkler irrigated portion, a 1.7 ha (4.2 acre) flood irrigation portion and an area [0.13 ha (0.32 acre)] set aside for experimental garden plots. The experimental garden plots were established specifically for this study to determine the

response of selected garden crops. Generally, the treated site was irrigated three or four times per season. Prior to 1957, the land was not cultivated or pastured. In 1976, a gravity flow sprinkler irrigation line from the first holding reservoir to the treatment site was installed. However, a portion of the site was maintained for flood irrigation to assist with this study. Measurements made during the study indicate that the average yearly flood irrigation application of water to the treated plot has been 9.4 cm/yr (23.95 in/yr). Thus, the site may be classified as a slow rate system.

The treated site is planted with a mixture of pasture grass and alfalfa hay. Generally, the first crop of grass and hay is cut, baled, and removed from the site. This is usually completed by the second week of June. During the remainder of the season, the area is pastured with cattle and sheep. This management practice was continued through this study.

Control Site

As shown in Figure 1, the control site is located about 0.8 km (0.5 mile) from the treated site and less than 1.6 km (1 mile) from the treatment plant. The control site consisted of a total of 9 ha (22.2 acres) which included a 0.15 ha (0.37 acre) garden plot, a 7.2 ha (17.8 acres) portion which had never received treated effluent from the treatment plant, and a 1.7 ha (4.2 acres) portion which had occasionally received treated effluent from 1957 to 1966. The exact amount of treated effluent applied to this portion of the control site is unknown, thus no soil samples were collected from this portion. The experimental garden plots were established to compare the response

of specific garden crops to those grown on the treated garden plots.

The control site has been cultivated for approximately fifty years. However, it has only been irrigated since 1966. Prior to 1966, this area was under dry farm cultivation. Construction of a storage reservoir in the mountains east of Tooele was completed in 1966 by the Settlement Canyon Irrigation Company. Water from this reservoir was used to irrigate the control site from 1966 to the present. The site has received three or four irrigations per season since 1966. Measurements made during this study indicate that the annual irrigation rate has been 6.2 cm/yr (15.62 in/yr).

The control site has been planted in alfalfa hay for the past few years. Generally, these crops of alfalfa hay are cut, baled, and removed from the site each year. During the late fall, winter, and early spring, the area is used for winter pasture and feed area for range cattle and sheep. During May to October of 1976 and 1977, no animals were pastured on the control site.

Water Quality and Quantity

Surface water sampling stations were established at the 11 locations shown in Figure 1 and described in Table 1.

Twenty-four hour composite samples were obtained with ISCO Model 1580 Composite samplers and stored at 2 C (24 F) in propane operated refrigerators at each sample station until collected and transported to the Utah Water Research Laboratory, Logan, Utah, for analysis. On those occasions when the sampling equipment malfunctioned, grab samples were collected and analyzed in place of the composite samples. The samples were collected and analyzed on a weekly basis for the

Table 1. Description of surface water sample stations.

Number	Description
1	Tooele Treatment Plant Effluent; Flow proportional 24-hour composite sample and flow recorder
2	Holding Reservoir #1 Effluent; 24-hour composite sample and flow recorder
3	Influent to Holding Reservoir #2; 24-hour composite sample and flow recorder
4	Effluent Holding Reservoir #2 and Influent for Flood Irrigation Portion of Treatment Stie; Flow proportional 24-hour composite sample and flow recorder
5	Influent to Treated Experimental Garden Plot; Composite sample and flow recorder
6	Effluent from Treated Experimental Garden Plot; Composite sample and flow recorder
7	Tailwater from Flood Irrigation Portion of the Treated Site; Flow proportional composite sample with flow recorder
8	Spray Irrigation Influent to Treated Site; Composite sample and flow meter
9	Control Experimental Garden Plot Influent; Composite sample and flow meter
10	Control Experimental Garden Plot Effluent; Composite sample and flow recorder
11	Influent to Control Site; Composite sample and flow meter

parameters shown in Table 2 during 1976. During 1977, the sample frequency was reduced for certain parameters. The sample frequency for each parameter during 1977 is shown in Table 3. All procedures conformed to Standard Methods [APHA, 1975] and EPA [1974].

Groundwater was not found within 30 m (100 feet) of the ground surface. Therefore, no groundwater samples were collected.

Soil Sampling

Subsurface investigation

The field investigation included 19 test pits and seven borings at the locations shown in Figure 1. Seven of the test pits were made on May 4 and 6, 1976, prior to the first irrigation for the 1976 growing season. The final six pits were opened on June 30, 1977. In

Table 2. Water quality parameters monitored at the Tooele, Utah, site during 1976 growing season (May to November, 1976).

Bacteriological	Chemical	Metals	Organic
Total Coliform	Alkalinity	Aluminum	Biochemical Oxygen Demand (BOD ₅)
Fecal Coliform	Calcium	Arsenic	Chemical Oxygen Demand
Fecal Streptococcus	†Chloride	Cadmium	‡Total Organic Carbon
	Hardness	Copper	Endrin
	Ammonia-Nitrogen	Chromium	Lindane
	Nitrite-Nitrogen	Iron	Methoxychlor
	Nitrate-Nitrogen	Lead	Toxaphene
	Total Kjeldahl Nitrogen	Magnesium	2,4-D
	Total Phosphorus	Manganese	2,4,5-TP (Silvex)
	Orthophosphorus	Mercury	HCB
	Total Soluble Phosphorus	Nickel	BHCB
	†Total Dissolved Solids	†Potassium	Aldane
	Suspended Solids	Silver	Oxychlor
	Volatile Suspended Solids	Sodium	Hept. epoxy
	Specific Conductance	Zinc	DDT
	†Sulfate		Organo-phosphorus
	Temperature		Seven
	pH		PCB
	Dissolved Oxygen		

† Monitored on monthly basis after 9/10/76.

‡ Eliminated from analysis due to suspended solids interference after 8/5/76.

successive samplings, new pits near previous sites were used. These test pits were logged; disturbed samples were taken of all strata for laboratory testing to determine moisture content, Atterberg Limits and grain-size distribution. Samples were also taken at depths of 1, 3, 10, 30, 100 and 300 centimeters (0.4, 1.2, 3.0, 11.8, 39.4, and 118.1 inches) for testing in accordance with the project requirements. Additional intermediate depths were sometimes collected especially at 50 cm (19.7 inches), 200 cm (78.7 inches), and at some apparently dark-colored buried surface soil layers.

Soil Classification

Laboratory tests were performed to classify the soils and to determine the natural moisture content of all significant strata at both the treatment site and control site. The laboratory tests

Table 3. Water quality parameters monitored and sample frequency during 1977 growing season (May to October, 1977) at the Tooele, Utah, site.

Sample Frequency	Bacteriological	Chemical	Metals	Organic
Weekly and/or during each irrigation application	Total Coliform Fecal Coliform	Ammonia-Nitrogen Nitrite-Nitrogen Nitrate-Nitrogen Total Kjeldahl Nitrogen Total Phosphorus Suspended Solids Volatile Suspended Solids Temperature pH Dissolved Oxygen		Biochemical Oxygen Demand (BOD ₅)
Bi-Weekly and/or during each irrigation application (every two weeks)		Specific Conductance	Copper Mercury Lead Cadmium Chromium Zinc	Chemical Oxygen Demand
Monthly and/or during each irrigation application	Fecal Streptococcus	Alkalinity Calcium Chloride Hardness Ortho-phosphate Total Soluble Phosphorus Total Dissolved Solids Sulfate		
Once at the beginning and end of the growing season and once during each irrigation application			Aluminum Arsenic Iron Magnesium Manganese Nickel Potassium Silver Sodium	
Once at the beginning and end of the growing season on Samples No. 1, 4, and 9 only				HCB Aldane Hept. epoxy DDT Organo-phosphorus PCB Lindane Methoxychlor 2,4-D 2,4,5-TP (Silvex) BHCB Oxychlor Seven Endrin Toxaphene

included natural moisture content in the first collection, specific gravity, Atterberg Limits, and hydrometer analysis (grain size). Standard ASTM laboratory test procedures were employed [ASTM, 1975].

Soil Chemical Analyses

The fraction of each soil material collected which was less than 2 mm (0.08 inches) diameter was determined by dry sieving in stainless steel sieves. All chemical analyses were done on these fine fractions.

Moisture constants were determined by the Utah Soil Testing Laboratory at Utah State University.

The various chemical analyses on the less than 2 mm (0.08 inch) fraction of the soils were performed according to "Methods of Soil Analyses" [Black, et al., 1965], except as noted below.

Salinity of water extracts were performed using a pipette conductivity cell [Bower and Wilcox, 1965]. Total nitrogen was determined by the Kjeldahl method [Bremner, 1965a]. Ammonium-nitrogen and nitrate-nitrogen were measured by the steam distillation [Bremner, 1965b]. Available phosphorus was measured as that extractable in either dilute acid-fluoride or in 0.5 normal sodium bicarbonate as described by Olsen and Dean [1965], except that color development involved the use of ascorbic acid rather than stannous chloride. Trace metals were extracted by digestion in a semi-reflux manner with an HNO_3 - HClO_4 acid mixture. After near dryness, the digest was dissolved in warm 0.5 normal HCl prior to analysis with an atomic adsorption spectrophotometer. Chelate-soluble zinc and copper were determined by extracting 5 g of soil in 50 ml of DTPA after shaking the mixture for 30 min on a horizontal shaker set for gentle shaking.

Plants

Alfalfa (Ranger - NK Source, Nampa, Idaho) and 11 other crop varieties were planted in randomized, replicate (4 replicates) field garden plots 2 × 12 meters (6 × 72 ft) [LeClerg, *et al.*, 1962] adjacent to the control and treated sites (see Figure 1) during the summer of 1976 and 1977. However, this paper will be limited to the results of the alfalfa crop, since that was the major crop grown on the main study site. Plants at the treated experimental garden plot were irrigated weekly (soil soaked to a depth of 15 to 20 cm (6 to 8 inches) with wastewater from the treatment plant and the control experimental garden plot with normal irrigation water.

The above ground plant samples were analyzed by atomic absorption spectrophotometer [Jones and Isaac, 1969] for cadmium, calcium, copper, iron, lead, nitrogen, phosphorus, potassium, sodium, and zinc. Chemical analyses were performed by the Soil Testing and Plant Analysis Laboratory, Utah State University, Logan, Utah. All data were subjected to standard analyses of variance and means compared by the *F* test [LeClerg, *et al.*, 1962].

RESULTS AND DISCUSSION

Treatment Plant Historical Performance

The historical performance of the treatment plant is shown in Table 4. The final effluent biochemical oxygen demand concentration (BOD₅) ranged from 16 mg/ℓ in 1977 to 36 mg/ℓ in 1969. The final effluent suspended solids concentration ranged from 9 mg/ℓ in 1971 and 1973 to 50 mg/ℓ in 1976. In general, the treatment plant is

Table 4. Yearly average effluent quality of the Tooele, Utah, wastewater treatment plant.

Year	Flow m ³ /day	BOD ₅ mg/ℓ	Suspended Solids mg/ℓ
1957	3191	-	-
1958	3691	-	-
1959	3160	-	-
1960	4129	-	-
1961	3974	-	-
1962	4046	-	-
1963	4610	-	-
1964	4576	-	-
1965	4614	-	-
1966	4799	-	-
1967	5204	-	-
1968	-	-	-
1969	5204	36	23
1970	4837	33	19
1971	5462	22	9
1972	4970	26	14
1973	5193	19	9
1974	5836	27	18
1975	5693	25	20
1976	5647	29	50
1977	2515	16	31

MGD = m³/day/3785

representative of trickling filter performance.

Land Application Water Quality

The quality of the water applied to the treated and control sites during 1976 and 1977 is shown in Tables 5 and 6. These data are considered representative of the quality of water applied to the treated site since 1957 and the control site since 1966.

The wastewater applied to the treated site is substantially better quality than the effluent at the treatment plant. The data clearly indicate that the effluent receives additional treatment as it flows through the earthen ditch and the two holding reservoirs. The average BOD₅ concentration of the effluent applied to the treated site was 14.1 mg/ℓ in 1976 and 16.0 mg/ℓ in 1977. This is significantly

Table 5. Comparison of average organic and inorganic concentrations of various parameters in water applied to the control and treated sites at Tooele, Utah.

	Treated Site (Sampling Station No. 4)		Control Site (Sampling Station No. 11)		Treated Site Significantly Different (95% Level) From Control Site*	Ratio: Treated Site Control Site	
	1976	1977	1976	1977		1976	1977
	Alkalinity, mg/l	256.3	257.2	201.1		197.7	Yes
Calcium, mg/l	235.9	243.8	176.1	146.2	Yes	1.3	1.7
Chloride, mg/l	138.0	152.4	21.2	22.0	Yes	6.5	6.9
Hardness, mg/l	269.5	247.9	224.4	179.8	Yes	1.2	1.4
NH ₃ -N, mg/l	5.61	3.60	0.05	0.06	Yes	112.2	60.0
NO ₂ -N, mg/l	1.00	0.84	0.004	0.014	Yes	250.0	60.0
NO ₃ -N, mg/l	4.89	6.71	0.50	0.42	Yes	9.78	16.0
TKN, mg/l	8.24	6.50	0.48	1.02	Yes	17.2	6.4
Tot. Phosphorus, mg/l	9.81	9.28	0.05	0.08	Yes	196.2	116.0
Tot. Sol. Phos., mg/l	8.97	7.94	0.03	0.03	Yes	299.0	264.7
Ortho-P, mg/l	8.69	7.38	0.02	0.02	Yes	434.5	369.0
Tot. Dis. Solids, mg/l	656.7	608.4	253.2	272.0	Yes	2.6	2.2
Tot. Susp. Solids, mg/l	30.9	59.2	2.2	5.8	Yes	14.1	10.2
Vol. Sus. Solids, mg/l	16.8	24.9	1.6	2.6	Yes	10.5	9.6
Sp. Cond., µmhos/cm	1087	1125	497	456	Yes	497.0	2.5
Sulfate, mg/l	59.0	63.7	22.7	18.5	Yes	2.2	3.4
BOD ₅ , mg/l	14.1	16.0	1.6	2.5	Yes	5.6	6.4
COD, mg/l	52.0	61.8	9.53	21.0	Yes	5.6	2.9

* Comparison based on combined 1976 and 1977 data.

Table 6. Comparison of average metals concentrations in water applied to the control and treated sites with recommended limits for irrigation water.

Parameter, Units	Treated Site (Sample Station No. 4)		Control Site (Sample Station No. 11)		Recommended Limit For 20 Year Use (EPA, 1973)	Treated Site Significantly Different (95% Level) From Control Site*	Ratio: Treated Site Control Site	
	1976	1977	1976	1977			1976	1977
	Aluminum, µg/l	95	120	154			224	20,000
Cadmium, µg/l	0.3	<4.8	0.2	<4.3	50	No	1.5	1.1
Chromium, µg/l	6	<13	5	<11	1,000	No	1.2	1.2
Copper, µg/l	9.0	<13.1	<1.8	<12.2	5,000	No	1.9	1.1
Iron, µg/l	26	102	23	23	20,000	No	1.1	4.4
Lead, µg/l	3.0	<1.6	2.8	0.9	10,000	No	1.1	1.8
Magnesium, mg/l	8.1	26.4	11.8	22.1	N.A.	No	0.7	1.2
Manganese, µg/l	15	<15	12	<6	10,000	No	1.3	2.5
Mercury, µg/l	3.8	<0.7	6.5	<4.6	N.A.	Yes	0.6	0.2
Potassium, mg/l	10.6	12.6	1.0	2.0	N.A.	Yes	10.6	6.3
Silver, µg/l	<1.0	<5.8	<1.0	<5.5	N.A.	No	1.0	1.1
Sodium, µg/l	120	137	18	20	SAR < 4-8	Yes	6.7	6.9
Zinc, µg/l	<18	20	<11	21	10,000	No ⁺	1.6	1.0
Arsenic, µg/l	-	1.8	-	14.8	2,000	Yes ⁺	-	-
Nickel	-	<4	-	<2	2,000	No	-	-

N.A. = Not available.

* = Comparison based on combined 1976 and 1977 data.

+ = Comparison based on 1977 data only.

more (95 percent level) than the BOD₅ concentration of the water applied to the control site. The average effluent suspended solids concentration of the effluent applied to the treated site was 30.9 mg/l in 1976 and 59.2 mg/l in 1977. This is significantly more (95 percent level) than the suspended solids concentration of the water applied to the control site. The increase in suspended solids in 1977 is due to algal growth in the second holding reservoir.

The effluent applied to the treated site was high in nutrients (see Table 5) and relatively low in heavy metals (see Table 6). The treated effluent contained significantly more nutrients than the water applied to the control site. However, heavy metals concentrations were similar in the two waters.

The water quality of the effluent applied to the treated experimental garden plot and the control experimental garden plot is shown in Table 7. The water applied to the garden plots was similar to the water applied to the experimental garden plots, but was sampled at different locations to maintain close experimental control. A comparison of the water quality applied to the garden plots is similar to that for the water applied to the treated and control sites, as discussed above.

Subsurface Soils

In general the soil profile consists of 1 m to 2 m (3.5 feet to 6.5 feet) of silt and silty clay overlaying gravelly silt. The gravelly silt overlays sandy gravel with cobbles and in some cases the gravel is cemented. Well logs from city wells near the sites indicate that the gravel may be up to several hundred feet deep.

Table 7. Summary of water quality of applied water to the control and treated garden plots at Tooele, Utah.

Parameter, Units	Treated Garden Plot				Control Garden Plot				Recommended Limit (EPA, 1973)
	Influent (Station No. 5)		Effluent (Station No. 6)		Influent (Station No. 9)		Effluent (Station No. 10)		
	1976	1977	1976	1977	1976	1977	1976	1977	
Alkalinity, mg/l	255.8	246.8	287.6	+	201.1	197.7	-	+	
Calcium, mg/l	221.9	205.3	227.7	+	176.1	146.2	170.0	+	
Chloride, mg/l	134.3	147.1	139.5	+	21.2	22.0	18.8	+	5-40 meq/l
Hardness, mg/l	263.3*	251.9	269.1	+	224.4	179.8	222.0	+	
NH ₃ -N, mg/l	5.95*	3.27	4.76	+	0.046	0.057	0.091	+	
NO ₂ -N, mg/l	1.069*	0.776	1.115	+	0.0044*	0.0143	0.0071	+	
NO ₃ -N, mg/l	5.79*	8.46	5.48	+	0.495	0.418	1.171	+	
TKN, mg/l	8.69*	6.31	13.41	+	0.48	1.02	7.34	+	
Total Phosphorus, mg/l	9.46	9.59	19.90	+	0.046	0.079	2.126	+	
Total Soluble Phosphorus, mg/l	8.75	8.84	8.29	+	0.027	0.030	0.084	+	
Ortho-phosphate, mg/l	8.41	8.56	8.30	+	0.018	0.022	0.065	+	
Total Dissolved Solids, mg/l	610.2	618.0	619.6	+	253.2	272.0	326.0	+	500-1000 mg/l
Total Suspended Solids, mg/l	64.6	18.8	1254.1	+	2.2	5.8	-	+	
Volatile Suspended Solids, mg/l	16.8	14.3	89.0	+	1.6	2.6	-	+	
Specific Conductance, μ mhos/cm	1113	1089	1106	+	497*	456	476	+	750-1500
Sulfate, mg/l	66.8	64.0	66.5	+	22.7	18.5	23.3	+	
BOD ₅ , mg/l	12.1	13.4	17.2	+	1.6	2.5	4.2	+	
COD, mg/l	60.1	60.5	196.8	+	9.53	21.02	181.4	+	
Temp, °C	20.7	20.6	22.3	+	16.3	29.2	15.0	+	
Dissolved Oxygen, mg/l	7.5	5.0	8.2	+	8.1	5.1	8.6	+	
pH, Units	7.6	7.2	7.8	+	7.4	7.3	7.0	+	4.5 - 9.0
Aluminum, μ g/l	150	111	190	+	154	224	330	+	20,000
Cadmium, μ g/l	0.3	<4.6	0.3	+	0.2*	<4.3	0.3	+	50
Chromium, μ g/l	22	<12	12	+	5	<11	2	+	1,000
Copper, μ g/l	13.8	<42.3	11.0	+	4.8*	<12.2	5.5	+	5,000
Iron, μ g/l	56	25	28	+	23	230	66	+	20,000
Lead, μ g/l	3.2	<0.9	3.0	+	2.8	<0.9	3.5	+	10,000
Magnesium, mg/l	10.1*	25.2	11.3	+	11.8*	22.1	13.2	+	-
Manganese, mg/l	21	10	15	+	12	<6	8	+	10,000
Mercury, μ g/l	8.3	<1.5	5.1	+	6.5	<4.6	3.6	+	-
Potassium, μ g/l	10.5*	12.5	11.1	+	1.0*	2.0	3.3	+	-
Silver, mg/l	<1.2	<5.7	<1.0	+	<1.0	<5.5	<1.0	+	-
Sodium, μ g/l	118*	139	122	+	18	20	19	+	SAR < 4-8
Zinc, μ g/l	<2.4	28	<20	+	<11	21	<13	+	10,000
Arsenic, μ g/l	†	1.6	†	+	†	14.8	†	+	2,000
Nickel, μ g/l	†	<4	†	+	†	<2	†	+	2,000

- No data

* 1976 mean is significantly different (95 percent level) from the 1977 mean

+ No runoff in 1977; plots were sprinkler irrigated

† Analysis not performed in 1976

The static water table in these wells is greater than 122 m (400 feet). A deep boring in the treatment site showed sandy gravel and silty gravel to a depth of 33 m (107 feet) interbedded with layers up to 3 m (10 feet) thick of moist silty clay. The depth to the sandy gravel stratum at the treatment site was greater than at the control site. The boring logs show that the depth to the sandy gravel stratum varies from 2.1 m to 2.5 m (7 feet to 8.3 feet) at the treated site and from 0.8 m to 2 m (2.5 feet to 6.4 feet) at the control site. In general there were more rock fragments throughout the soil profile at the control site.

The results of laboratory tests conducted on samples taken from both the treated site and control site to determine the Atterberg Limits, natural moisture content and grain size distribution of the soils are shown in Table 8. These tests were used primarily to classify the soils according to their general characteristics. Rather than taking samples on a predetermined interval, as was done for the other soil tests conducted for this study, the samples were obtained from the various strata as identified in the walls of the test pits. The test results were then used in evaluating the general soil profile. Samples obtained during the investigation of May 4 and 5, 1976 (beginning of the growing season), are indicated in Table 8 by test pit designations A, B, C, D, E, F, and G. Samples obtained during the investigation of September 20, 1976 (end of growing season), are indicated by test pit designations A', B', C', D', E', and F'. The test pits that were made at the end of the growing season were excavated at locations immediately adjacent to those made at the beginning of the growing season. Except for changes in the natural moisture content of the soil, there were no significant changes in the Atterberg Limits that could be attributed to irrigation activities during the summer.

Soil Chemistry

Nitrogen

The results of analyses of ammonium and nitrate (Figures 2 and 3) are not helpful in evaluating the expected nitrogen accumulation from effluent additions. This is mostly because levels of nitrate and ammonium in soils at any one time are usually a quite small part of

Table 8. Summary of physical soil properties.

Test Pit	Depth	Natural Moisture Content	Atterberg Limits			USDA Classification				Unified Classification Symbol
			Plastic Limit	Liquid Limit	Plastic Index	% Sand	% Silt	% Clay	Nomenclature	
A A'	34" - 7"	16.9 10.7	23.2 20.4	25.5 26.2	2.3 5.8	---	---	---	---	ML CL-ML
A A'	12" - 18"	16.6 9.4	20 25.8	24.4 26.0	4.4 0.2	39.5	47.5	13	Loam	CL-ML ML
A A'	36" - 42"	14.3 14.6	23.2 24.1	23.2 27.9	0 3.8	39.0	49.5	11.5	Loam	ML ML
A A'	57" - 61"	8.1 9.2	24.7 21.8	28.8 29.1	4.1 7.3					ML ML
A A'	63" - 68"	6.7 6.7	22.3 22.4	27.3 30.6	5.0 8.2					ML CL
B B'	0" - 10"	7.7 12.4	19.4 21.1	24.8 25.6	5.4 4.5					CL-ML CL-ML
B B'	15" - 20"	8.4 12.0	22.2 20.0	26.6 27.3	4.4 7.3					ML CL-ML
B B'	35" - 40"	12.2 6.8	20.7 24.2	26.8 34.2	6.1 10.0	33.5	51.5	15	Silty clay loam	CL-ML ML
B B'	53" - 60"	3.9 1.4								GW GW
B B'	90" - 93"	4.7 1.7								GW GW
C C'	10" - 15"	11.3 11.1	21.2 20.0	26.7 26.7	5.5 6.7					CL-ML CL-ML
C C'	42" - 45"	5.9 2.5								GW GW
Cl	12" - 18"	17.4	22.6	28.3	5.7	24	63	13	Silty loam	ML
D D'	15" - 20"	16.5 17.2	21.1 23.0	25.9 26.7	4.8 3.7	35	52	13	Silty loam	CL-ML ML
D D'	27" - 33"	11.3 8.5								GM GM
D D'	37" - 42"	12.3 6.3								GM GM
D D'	50" - 60"	19.3 8.9	21.0 20.3	26.3 24.7	4.7 4.4					CL-ML CL-ML
D D'	66" - 70"	15.9 9.4								ML ML
D D'	80" - 85"	12.2 6.9								GM GM
D D'	110" - 114"	5.1 5.1								GW GW
E E'	20" - 25"	19.1 18.0	21.0 20.0	28.0 26.5	7.0 6.5	28	58.5	13.5	Silty loam	CL-ML CL-ML
E E'	40" - 45"	24.7 11.9	21.9 20.5	27.5 23.8	5.6 3.3					CL-ML CL
E E'	64" - 68"	10.3 18.5	22.6 19.3	30.8 26.8	8.2 7.5					CL CL
E E'	90" - 95"									GW GW
E'	120" - 124"	18.0	21.1	32.6	11.5					GL
G G'	16" - 20"	21.2 9.2	23.2 21.0	31.0 28.0	7.8 7.0	23.5	61.5	15	Silty loam	ML CL-ML
G G'	36" - 40"	16.3 1.9	20.8	22.1	1.3	44	46.5	9.5	Loam	ML
G G'	52" - 56"	22.2 4.7	21.0	25.2	4.2					CL-ML
G G'	67" - 71"	30.9 20.7	23.2 22.0	30.8 31.0	7.6 9.0					ML CL
G G'	77" - 82"	11.6 12.2	20.5 22.2	29.6 30.5	9.1 8.3					CL CL
G G'	122" - 124"	24.4 15.2	22.0 19.6	32.6 29.9	10.6 10.3					CL CL

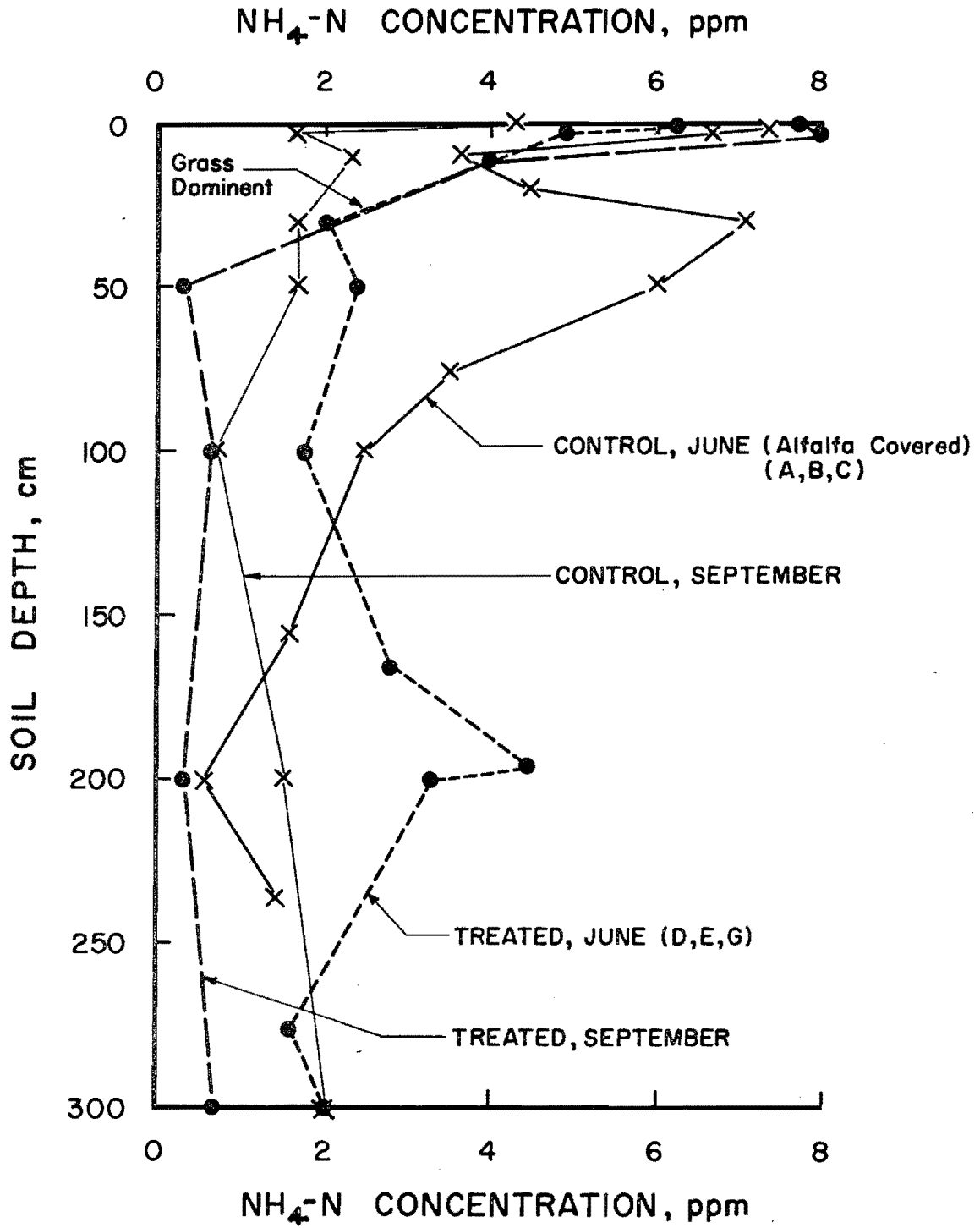


Figure 2. The $\text{NH}_4\text{-N}$ content in Tooele soil collected in June 1976 and in September 1976.

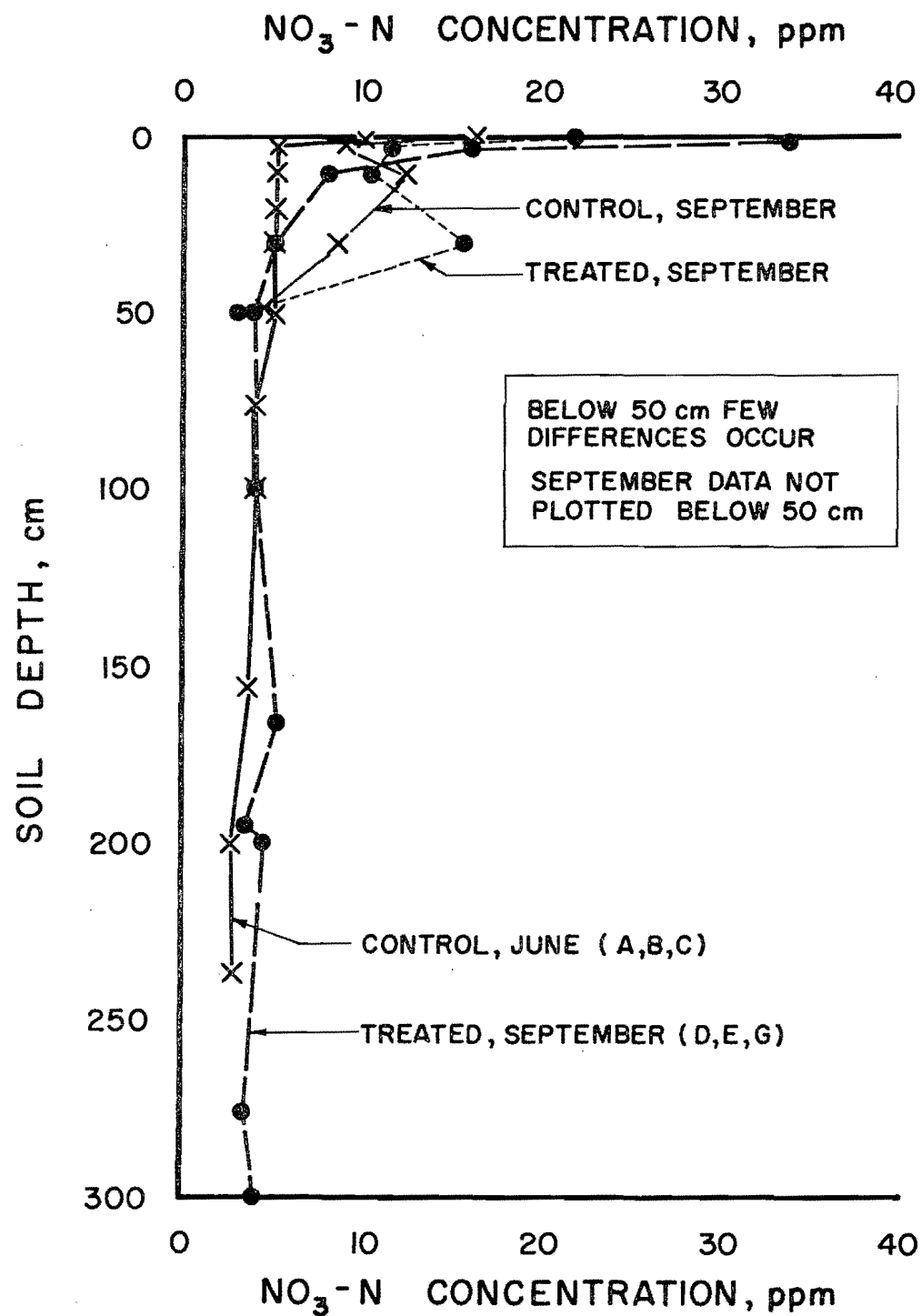


Figure 3. The $\text{NO}_3\text{-N}$ content in Tooele soil collected in June 1976 and September 1976.

total nitrogen in the soil. Also, the control site has a good alfalfa crop (increases soil nitrogen) and the treatment site is mostly a close-grazed pasture grass (uses up nitrogen). Any nitrogen buildup expected from the effluent additions are apparently masked by this crop variation.

The high values in the September control sites samples for ammonium are possibly a result of the alfalfa at the sites. Older alfalfa roots and their nitrogen-fixing nodules would supply a good source of organic nitrogen to be mineralized as the weather warmed. The soil contents at the end of summer were higher in nitrate. This is not unusual because the sampling date was at the end of the summer. The cover crops would have had time to initiate growth and adsorb the ammonium and nitrate but also the organic matter decomposition and root depth would have been greater. By September the plants grow little and nitrate accumulates.

The high values in the treated site samples may be a result of warming action and cattle. The area could have more accumulation of feces and urine (sources of nitrogen). In the summer of 1976 animals milled around the total effluent-treated area. Nitrogen as nitrate was high in the treated site (Figures 2 and 3).

The total Kjeldahl nitrogen content of the soils at the control and treated sites is illustrated in Figure 4.

The totals are lower for the control sites; the difference is 465 ppm, which is 7.9 percent greater than the average in the controls. This is a relatively small increase but is equivalent to an accumulation of about 1,040 kg N per hectare (930 lbs/acre) for those 6 cm (2.4 inches) of the top soil. This would be equivalent to the

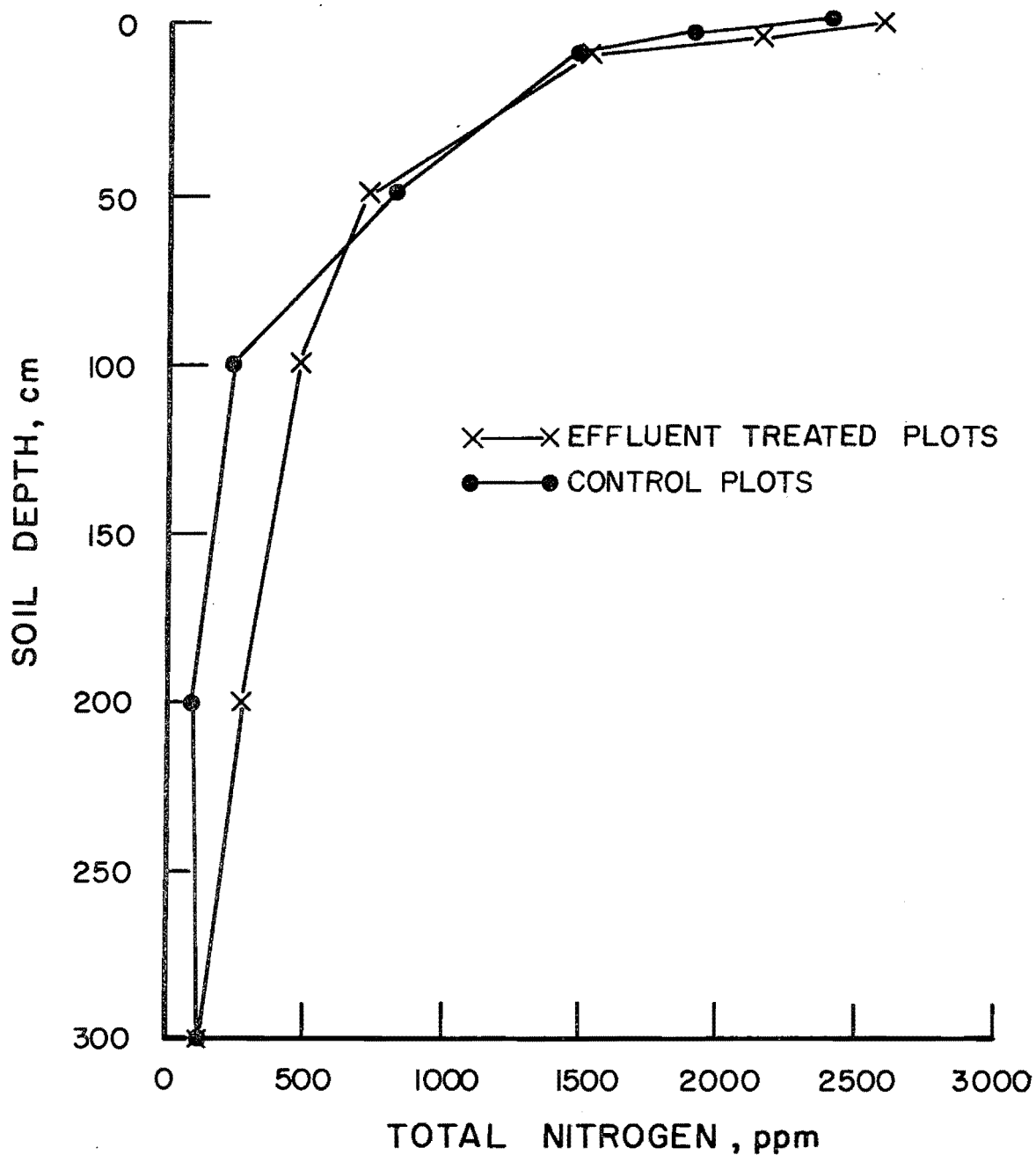


Figure 4. The total Kjeldahl nitrogen in control and effluent treated plots in the Tooele study area for sampled soils in September 1976 and June 1977.

difference (by accumulation) of soils humus content of about one percent, an appreciable difference.

The increase in total Kjeldahl nitrogen at the deeper depths is due to contents in the 100 cm and 200 cm depths (39 to 79 inches). The extreme variation in amount of fine material at these deeper depths makes interpretation difficult. However, it would seem evident that there is accumulation of nitrogen in the top two meters (6 feet) of soil but a definite lack of data or evidence to justify any assumption that appreciable quantities of nitrogen are moving beyond the 3 meters (10 feet) depth. Even nitrate-N measurements (Figures 2 and 3) have only 1 to 3 ppm N at these deeper depths, values which are normal in soils of the area.

The conclusion is that nitrogen is accumulating in the top 2 to 3 meters (6.5 to 10 feet) of soil but does not seem to be moving in appreciable quantities to deeper depths [Reynolds, et al., 1978a].

Available phosphorus

The greatest difference chemically between the control and the treated site was in the available phosphorus content of the soils as shown in Figure 5. The normal phosphorus levels considered to be adequate for plants are values larger than about 10 to 15 parts per million. The phosphorus in the control plots is adequate for most crops. However, that in the effluent-treated plots is 5 to 6 times higher, to depths of 50 cm (20 inches). Even to 300 cm deep (10 feet) the phosphorus levels are appreciable in the treated site.

Such phosphate movement and concentration deep in the soil profile is unusual and unexpected. Phosphates readily form various

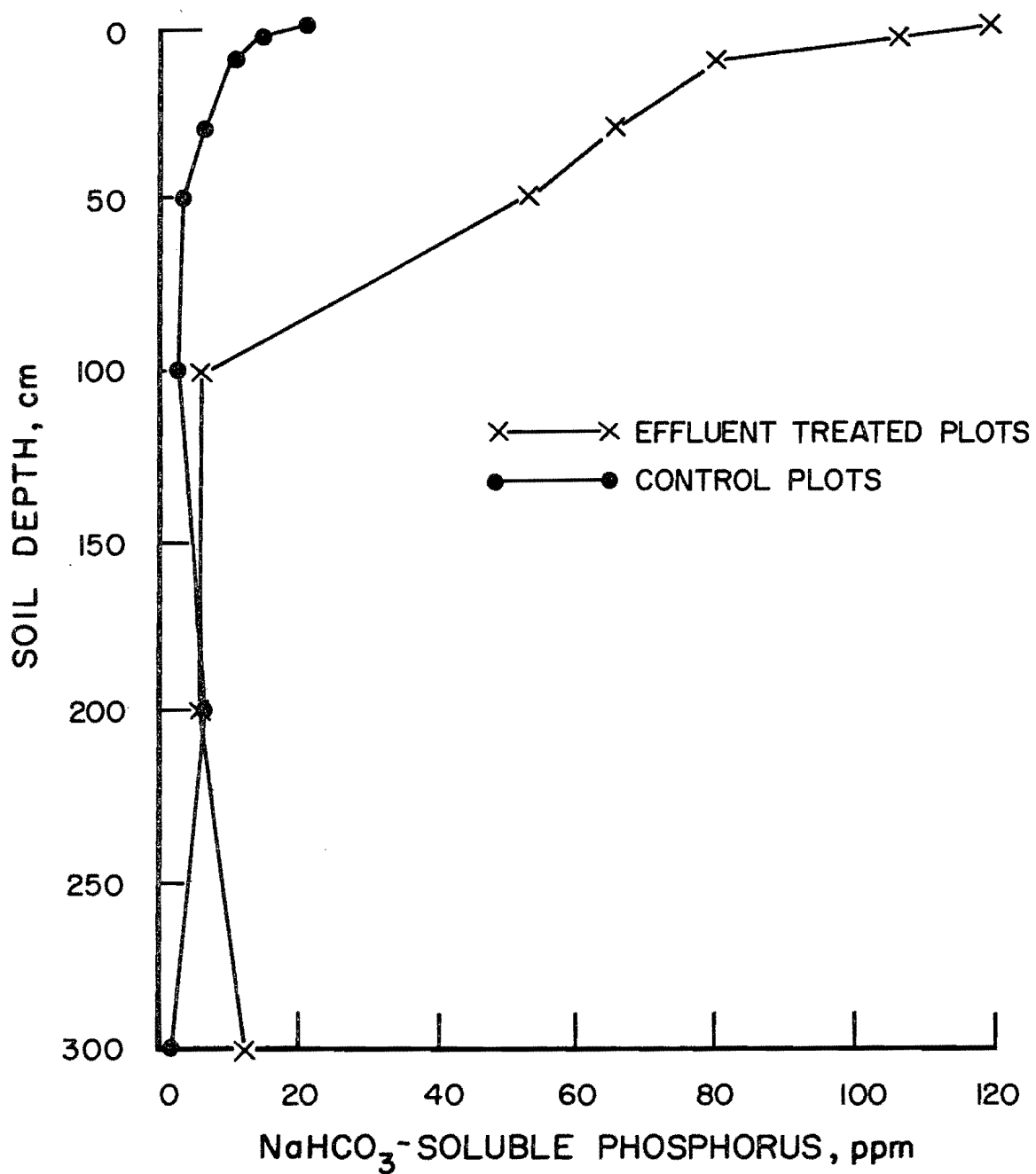


Figure 5. Sodium bicarbonate-soluble phosphorus extracted from Tooele control plots and sewage effluent-treated plots. Sampled June 1976.

insoluble phosphates. As a result, phosphorus seldom moves very far in soils. Even in water, it is of low solubility and usually moves in large quantities only as a suspended particle (piggy-back on clays or organic colloids). It is not too surprising to find phosphorus accumulated in surface layers of the treated site but the deep soil buildup is unexplained.

Although there seems to be an accumulation to even 3 meters (10 feet) deep, the values at deeper depths are greatly confounded by differences in texture and by crop cover. Alfalfa (control site) is a known deep-rooted crop and heavy feeder on phosphorus; grasses (treated site) are shallow-rooted and poorer extractors of phosphorus. The alfalfa on the control site may keep "available P", which this procedure measures, quite low. In contrast the grass mixture on the treated site would not use as much phosphorus. This may partly explain the lower P values in deeper layers of the control site.

The phosphorus in the top 50 cm (20 inches) of the treated site is probably an accumulation from application sources, one or all of these being the wastewater effluent. Animal manures may be an additional cause. The deep accumulation is partly caused by tillage in the past 20 years.

Metals

Table 9 contains the average content of lead, nickel, zinc, copper, and chromium found in the soil of the control and treated sites. In general, these values are greater than normally occurring in natural soils. For example, typical concentrations of lead in natural soils range from 10-20 ppm. The high metal content in the study area soils is probably due to two metal smelters located within

Table 9. Average perchloric-nitric acid extractable trace metals in Tooele soils sampled June 1976, September 1976, and June 1977. Average of 9 site replications and with duplicate analyses per collected sample.¹

Sample Depth	Trace Metal (ppm)					
	Lead	Nickel	Zinc	Copper	Chromium	Cadmium ²
Control Plots -- No Added Effluent						
0-2	43.7	23.0	108.2	27.1	25.3	3.7
2-4	37.9	22.5	106.1	25.2	24.7	2.2
9-11	33.1	21.0	100.7	24.5	27.0	3.7
28-32	14.7	19.7	85.8	16.1	26.2	2.2
45-55	13.6	22.5	81.1	13.0	27.0	2.5
95-105	12.2	15.8	58.6	12.9	21.1	4.0
195-205	8.1	20.5	36.2	9.0	14.2	-
295-305	10.6	22.2	44.0	10.7	16.5	-
Totals	174	167	621	138	18.2	18.3
Sewage Effluent Treated Plots						
0-2	41.0	23.4	116.9	28.2	26.8	3.4
2-4	38.6	20.6	109.0	27.8	27.3	3.3
9-11	28.5	25.4	105.9	22.3	26.4	2.8
28-32	17.5	24.0	92.3	17.2	30.1	3.0
45-55	15.7	23.3	82.2	15.0	26.3	3.9
95-105	16.0	26.4	77.5	14.3	26.5	2.3
195-205	12.3	19.5	61.6	12.3	22.6	-
205-305	12.1	19.6	36.6	11.4	16.7	-
Totals	182	182	682	148	20.3	21.1

¹ Some deeper depths of 45-55 cm and deeper have fewer than 9 site replications.

² June 1976 and September 1976 samples only, average of 6 site replications.

cm × 0.39 = inch

32 km (20 miles) of the study area. For approximately fifty years prior to 1960 (when smelting operations were drastically curtailed), these smelters emitted vaporized forms of trace metals which may have accumulated, due to fallout, in the soils of the study area.

As shown in Table 9, the concentration of lead, copper, chromium, and zinc near the soil surface of both the control and treated site was greater than the concentration of these metals below 11 cm (4 inches). There appears to be little variation with depth in the nickel and cadmium concentration of both the control and treated site soils.

Because there is considerable variation in the rock content and the texture of the less than 2 mm (0.08 inch) soil fraction at depths below 50 cm (20 inches) at both the treated and control sites, it is difficult to compare the total metals content of the two sites. However, Table 10 is a comparison of the total metal content in the control and treated site soils to a depth of 50 cm (20 inches). The comparison indicates that the concentration of nickel, zinc, copper, and chromium was slightly higher in the treated site soils. However, these differences are probably not significant and may be due to the limited accuracy of the soil sampling and testing procedure. These small differences between the control and treated sites indicate that metal accumulation due to irrigation with wastewater effluent is not substantial.

A statistical analysis of the soil content of lead, zinc, copper, chromium and nickel at depths ranging from 0-300 cm (0-118 inches) is reported in Table 11. Cadmium was not included in this analysis due to the limited number of samples. The results of this statistical

Table 10. Comparisons of profile totals from 0 to 50 cm of replication averages for trace metals in the control and sewage-effluent-treated sites in Tooele, Utah.

Site	Lead	Nickel	Zinc	Copper	Chromium	Cadmium
	ppm	ppm	ppm	ppm	ppm	ppm
Control	143	109	482	106	130	14
Treated	141	117	506	110	137	16

cm \times 0.39 = inch

Table 11. Statistical summary for analysis of variance for the trace metal content and less-than-2 mm portions for all soil depths to 300 cm of soils in the Tooele sewage-effluent disposal study.

Source	Source dif.	Source mean square	Error mean square	Error dif.	F-ratio
Date of sampling (are data of one sampling different than from others)					
Lead, ppm	2	192.517	57.8191	95	3.330*
Zinc, ppm	2	2456.897	112.7072	95	21.799**
Copper, ppm	2	211.938	7.7105	95	27.487**
Chromium, ppm	2	192.027	11.2145	95	17.123**
Nickel, ppm	2	247.334	20.8489	95	11.863**
% less than 2mm	2	708.461	201.0146	95	3.524*
Treatment (Do controls differ from effluent plots)					
Lead, ppm	1	0.742	57.8191	95	1.284
Zinc, ppm	1	1562.043	112.7072	95	13.859**
Copper, ppm	1	22.386	7.7105	95	2.903
Chromium, ppm	1	164.048	11.2145	95	14.628**
Nickel, ppm	1	128.751	20.8489	95	6.175*
% less than 2mm	1	795.159	201.0146	95	3.956*
Depth (Do changes occur with depth)					
Lead, ppm	7	2,227.768	57.8191	95	38.530**
Zinc, ppm	7	7,636.285	112.7072	95	67.753**
Copper, ppm	7	600.594	7.7105	95	77.892**
Chromium, ppm	7	136.986	11.2145	95	12.215**
Nickel, ppm	7	28.662	20.8489	95	1.375
% less than 2mm	7	1,558.669	201.0146	95	7.754**
*Significant difference at the 95% confidence level					
**Significant difference at the 99% confidence level					

cm \times 0.39 = inch

analysis include that:

i. All metals concentrations determined were significantly different from samples collected on the different sampling dates. This suggests that considerable variation occurs in the field sampling and that the date of sampling was really a condition of non-uniformity within the soil.

ii. Only zinc and chromium contents varied at the 99 percent level between control and treated samples. Nickel was significantly different at the 95 percent level. Both copper and lead are not statistically different between the control and treated sites.

iii. All metals concentrations change with depth (*i.e.*, concentration decreased with depth) except nickel. This result is possible if no appreciable nickel is applied to the soil in effluent. However, this does not likely show a true picture. The metals are given only as concentrations in the less than 2 mm (0.08 inches) soil. Concentrations per soil volume would decrease enormously because of rock content unless the rocks also had these levels of nickel (or other metals).

Because of the problems of variable rock contents and soil texture in the deeper soil profile, it was decided to statistically test only the 0 to 30 cm (0-12 inch) soil profile. This range of depths includes four samples. The soils are of similar texture, and this is the major depth of accumulation for most metals. The statistical summary is presented in Table 12. The results of this analysis test are given below, and some are different than those of the previous analysis which included all depths (Table 11).

i. In testing only the top 30 cm (12 inches), the zinc contents

Table 12. Statistical summary for split plot analysis of variance for the trace metal content and less-than-2 mm portions for the top four depths of soils in the Tooele sewage-effluent disposal study.†

Source	Source dif.	Source mean square	Error mean square	Error dif.	F-ratio
Date of sampling (are data of one sampling different than from other)					
Lead, ppm	2	254.562	69.5768	12	3.659*
Zinc, ppm	2	191.259	197.8043	12	0.967
Copper, ppm	2	180.578	12.3073	12	19.672**
Chromium, ppm	2	73.679	10.4443	12	7.054**
Nickel, ppm	2	263.572	42.7997	12	6.158*
% less than 2mm	2	260.389	107.7083	12	2.418
Treatment (Do controls differ from effluent plots)					
Lead, ppm	1	51.173	69.5768	12	0.735
Zinc, ppm	1	641.417	197.8043	12	3.242
Copper, ppm	1	8.750	12.3073	12	0.711
Chromium, ppm	1	61.420	10.4443	12	5.881*
Nickel, ppm	1	56.889	42.7997	12	1.329
% less than 2mm	1	1,275.125	107.7083	12	11.838**
Depth (Do changes occur with depth)					
Lead, ppm	3	2221.769	54.2511	36	40.953**
Zinc, ppm	3	1813.152	35.2678	36	51.411**
Copper, ppm	3	442.816	4.3470	36	101.867**
Chromium, ppm	3	17.423	8.9312	36	1.951
Nickel, ppm	3	13.408	16.5245	36	0.811
% less than 2mm	3	52.643	18.4676	36	2.851
*Significant difference at the 95% confidence level					
**Significant difference at the 99% confidence level					

†Because some deeper samples were missing, only 0-2, 2-4, 9-11, and 28-32 cm depths are included in this comparison.

cm x 0.39 = inch

did not vary between sampling data; however, all other metals contents did vary with sampling date.

ii. In the top 30 cm (12 inches) only the chromium concentration was significantly different (95 percent level) in the control samples than in the treated samples. This indicates that wastewater additions have apparently not caused any easily measurable buildup of trace metals, except possibly chromium, in the two sites.

iii. Even with little rock or gravel in the top 30 cm (12 inches), there is enough so that a highly significant difference exists between the percentages of less-than-2 mm (0.08 inches) soil in the control and treated sites.

iv. In the top 30 cm (12 inches) significant changes in metal concentrations with depth occur only with lead, zinc, and copper.

These results indicate that there is no clear evidence of increased nitrogen, lead, copper, zinc, nickel, chromium, or cadmium in the soil of the treated site when compared to the control site. There was however, a measurable increase of available phosphorus in the treated soils compared to the control soils [Reynolds, et al., 1978a].

Plants

A comparison of the chemical analysis of alfalfa grown on the control and treated sites is presented in Table 13. There was no significant difference in the quality of hay produced on the control and treated sites. However, there was a significant difference in the growth rate, production, and iron and sodium concentrations of alfalfa grown on experimental garden plots located on the control and treated sites [Reynolds, et al., 1978b]. Generally, the levels

Table 13. Average mean value in percent and ppm (parts per million) for calcium (Ca), potassium (K), nitrogen (N), phosphorus (P), cadmium (Cd), copper (Cu), iron (Fe), sodium (Na), lead (Pb), and zinc (Zn), respectively, for the various plants tested.

Plant Species	Plant Part	Treat	Percent				PPM					
			Ca	K	N	P	Cd	Cu	Fe	Na	Pb	Zn
Alfalfa (Field Site)	Hay	C	1.18	2.20	2.20	0.19	10	8.00	60.00	240.00	40	31.00
		T	2.50	1.20	2.52	0.12	10	8.00	90.00	380.00	40	31.00

† C = control, T = treated or effluent site.

*, ** = significantly different at 0.05 or 0.01 levels, respectively.

of heavy metals observed in the plants in this study were lower than amounts reportedly harmful [Kirkham, 1975; Jones, et al., 1975; Cunningham, et al., 1975a, 1975b, 1975c]. The element most consistently higher in plants grown on the effluent site than in those on the control site was Na. Higher levels of Na may have resulted from detergents in the domestic sewage effluents [Judy, et al., 1973]. On occasion, higher amounts of N, P, and K were noted in plants grown on the effluent site [Reynolds, et al., 1978b].

SUMMARY AND CONCLUSIONS

A comparison between a site which had received treated municipal effluent for 20 years and a site which had been irrigated with normal irrigation water was conducted over a two year period. Analysis of water quality, soil characteristics and plant characteristics was made to determine the long term effects of land application of wastewater. This paper emphasizes the long term effects on plant growth and uptake of heavy metals.

Based on the results of this study, the following conclusions can be made.

1. The secondary treated municipal effluent was of a significantly poorer quality than the normal irrigation water.
2. The quality of the secondary treated municipal effluent was acceptable for crop irrigation.
3. There was no accumulation of nitrogen, lead, copper, zinc, nickel, chromium, or cadmium in the soil of the treated site compared to the soil of the control site.
4. There was a measurable increase in the available phosphorus concentration in the soil of the treated site compared to the soil of the control site.
5. There was a decrease in metals concentrations with depth in the soil of both the control and treated sites.
6. In general, there were no harmful accumulations of heavy metals in alfalfa grown on the treated site compared to alfalfa grown on the control site.
7. In general, there were no serious harmful effects determined as a result of long term irrigation with wastewater at the Tooele test site.

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