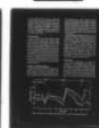AD-A059 994   COLD REGIONS RESEARCH AND ENGINEERING LAB   HANOVER N H   F/G 14/2
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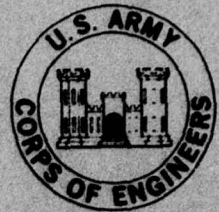UNCLASSIFIED   CRREL-SR-78-12   NL

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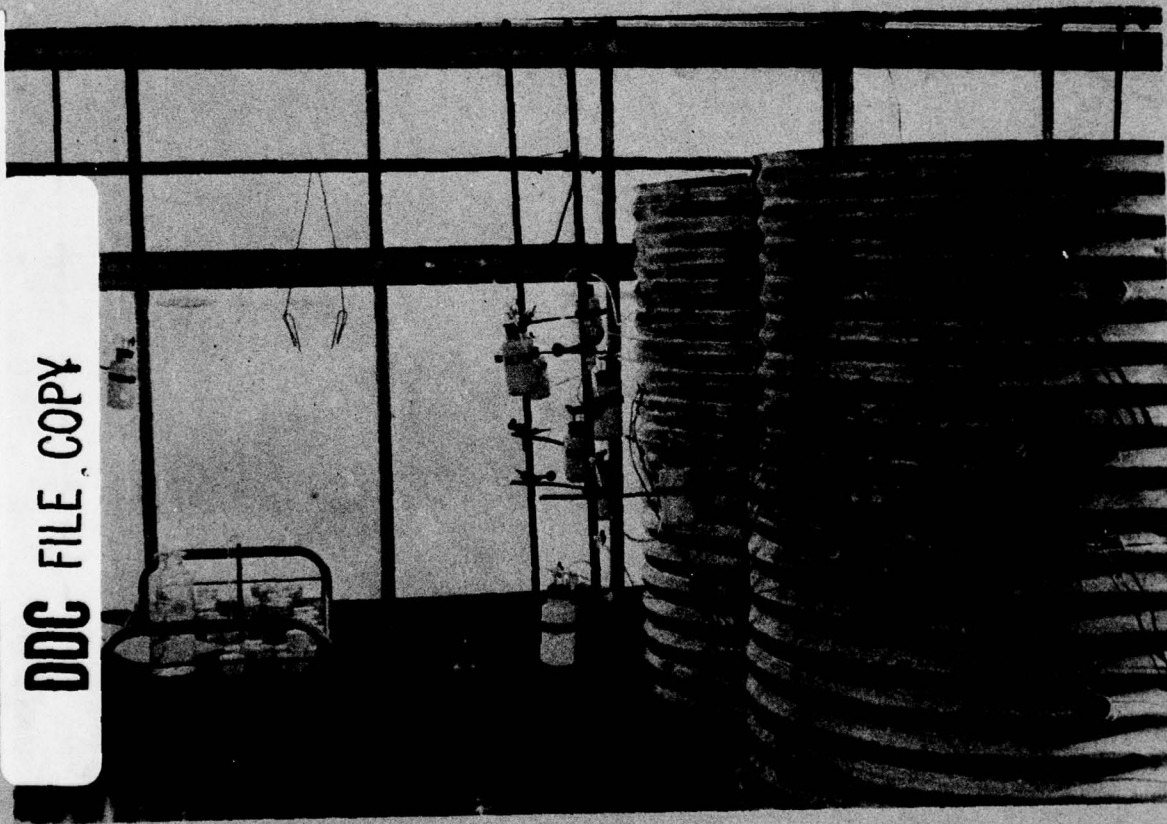DATE
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SOIL LYSIMETERS FOR VALIDATING MODELS OF WASTEWATER RENOVATION BY LAND APPLICATION
CONSTRUCTION, OPERATION AND PERFORMANCE

I.K. Iskandar and Y. Nakano

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Cover: Soil lysimeters, showing soil solution collection bottles.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report describes the construction, operation and performance of large-scale (90-cm-inside diameter and 150-cm-high) lysimeters. These lysimeters can continuously monitor soil moisture flow, soil temperature and redox potential with depth, and sample soil water and soil air with depth. The rate of soil water movement to the groundwater was continuously monitored by a rain gage and a recorder. To simulatate field conditions, an automatic spray system was developed; this system is also described in this report. The total cost of one lysimeter is approximately $650 (1975 estimate). The lysimeters are being used to validate a biophysical-chemical model of wastewater renovation by application to land. Detailed blueprints of the lysimeters are kept at CRREL and are available on request.

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SUMMARY

The purpose of this report is to describe the construction, operation, and performance characteristics of soil lysimeters instrumented for continuous monitoring of soil solution chemistry. The lysimeters are used to validate computer simulation models of wastewater renovation by application on land. They are made of corrugated aluminum culverts, are 150 cm high, and have an approximately 90-cm inside diameter. Soils were removed from the field, air dried, sieved to 2-mm size, and compacted in the lysimeters to their field bulk densities. Suction plates and stainless steel pipes were installed at depth to collect soil solution and soil air samples respectively. Soil temperature and the redox potential of the soil at depth were obtained to monitor the changes and the probes were connected with a data logger system. The rate of water movement and the soil moisture content at depth were monitored by tensiometers and neutron probes. The rate of water leaching was continuously recorded by a rain gage and a recorder. Spray nozzles, an automatic timer, and a mixing storage tank were installed to spray wastewater in a way similar to field application of wastewater.

The total cost of a lysimeter is approximately $650. The lysimeters can be used at prototype test facilities to determine the optimum wastewater application rate and to schedule wastewater application to land under different environmental conditions.

SOIL LYSIMETERS FOR VALIDATING MODELS OF WASTEWATER RENOVATION BY LAND APPLICATION

Construction, Operation and Performance

I.K. Iskandar and Y. Nakano

Introduction

At the present time, one of the major problems facing government agencies in implementing land treatment of municipal wastewater is public acceptance of the concept. One method of gaining public acceptance is to build a series of demonstration sites in each state to assure the public that the consequences of land treatment are within acceptable sanitation limits. This can be done by the development and validation of a computer simulation model to predict the quality of the leachate. However, this method is expensive and time consuming. Another method, which has been developed in recent years, is to use several models for simulating nutrient transformations or moisture flow in soils (Boast 1973, Dutt et al. 1972, Hagin and Amberger 1974, Beek and Frissel 1973). But, while each model is more or less concerned with one or more land treatment aspects, no literature has been published on the overall biophysical-chemical aspects of wastewater interaction with soils and plants in land treatment. One advantage of using lysimeters in research is that, with this method, climatic and other environmental factors involved in soil and water interaction can be controlled. This not only saves time and money, but allows the same investigator to perform several desired tests.

Although land application of wastewater has been practiced since at least the sixteenth century and in the United States since the nineteenth century (Iskandar 1978), very little information is available on the maximum amounts of wastewater that can be applied to land without reaching a certain concentration of NO_3-N in groundwater. This is mainly due to the complicated biological processes in soils and the lack of a validated model for nitrogen transformations.

This report describes the construction, operation and performance of large-scale, thoroughly instrumented lysimeters to be used in verifying the developed land treatment model. The lysimeters could also be used as pilot systems to demonstrate the feasibility of land treatment under various environmental conditions [a less expensive method than outdoor prototype test cells (see Iskandar et al. 1976)].

Detailed blueprints of the lysimeters are kept at CRREL and are available on request.

System overview

The four large-scale lysimeters at CRREL were designed to investigate the physical, chemical and biological changes that occur in wastewater as it percolates through the soil in the slow infiltration mode. Each lysimeter is 90 cm in inside diameter and 185 cm in height and is manufactured by Kaiser Aluminum and Chemical Corp., Windsor, Vermont. The lysimeters are made of corrugated aluminum culverts (Fig. 1) to minimize possible water channeling.

To avoid contamination of the soil solution from possible release of metals from the culvert wall, the insides of the lysimeters were coated with Polane, an inert material (purchased from the Sherwin Williams Corp., Product No. V79V26F). Before coating the aluminum, the surface was cleaned (etched) with a brush and organic solvent (Roller cleaner, Product No. K20K2) to remove oil and grease. The Polane was applied in a well ventilated room in a small quantity to form a uniformly thin layer and was allowed to dry for 48 hours. The bottom of each lysimeter was filled with a 15-cm layer of concrete sealed with epoxy and shaped to form a gentle slope towards a hole in the center of the layer. The leachate was collected and metered
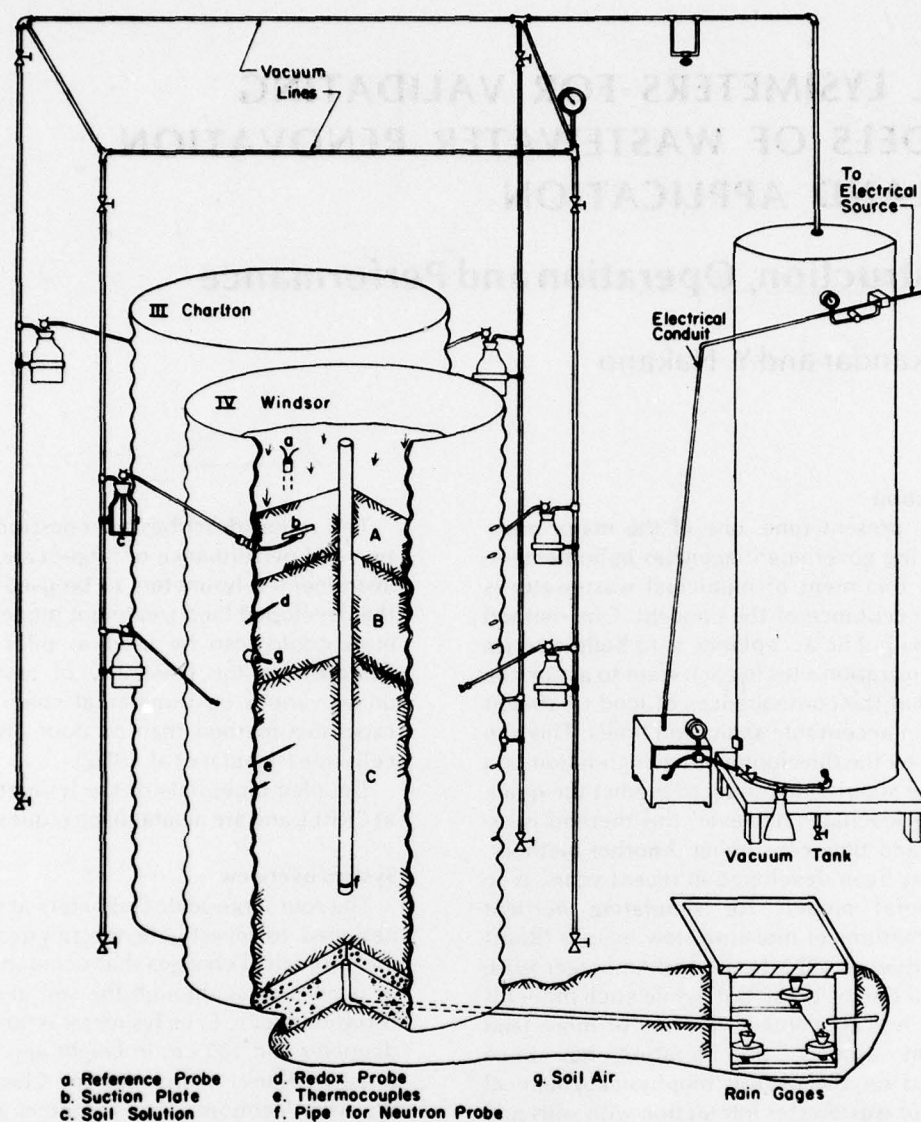
Figure 1. Isometric view of lysimeter.

Labels within figure:
- III Charlton
- IV Windsor
- Vacuum Lines
- To Electrical Source
- Electrical Conduit
- Vacuum Tank
- Rain Gages

a. Reference Probe   d. Redox Probe   g. Soil Air
b. Suction Plate   e. Thermocouples
c. Soil Solution   f. Pipe for Neutron Probe

by a rain gage device [Remote Recording Rain Gage, Model P-501, Weather Measure Corp., Sacramento, California (Fig. 2)].

Access holes of proper size and location were drilled through the flat surface of the corrugated culverts nearest the desired level. All metal chips were removed by placing the inlet hose of a vacuum cleaner directly behind the drilled holes while they were being drilled. Each lysimeter was equipped for collection of soil water and soil air samples at depth. Thermocouples and platinum electrodes were also installed to enable measurements to be made of temperature and redox potential at depth. The locations of the sampling devices or probes are shown in the blueprint at CRREL and are summarized in Table I.

More than one sampling or measurement site at the same depth was used to ensure statistical validity and to overcome the heterogeneity of the soils. Since this is especially problematic in the redox measurements, three probes were used at each depth.

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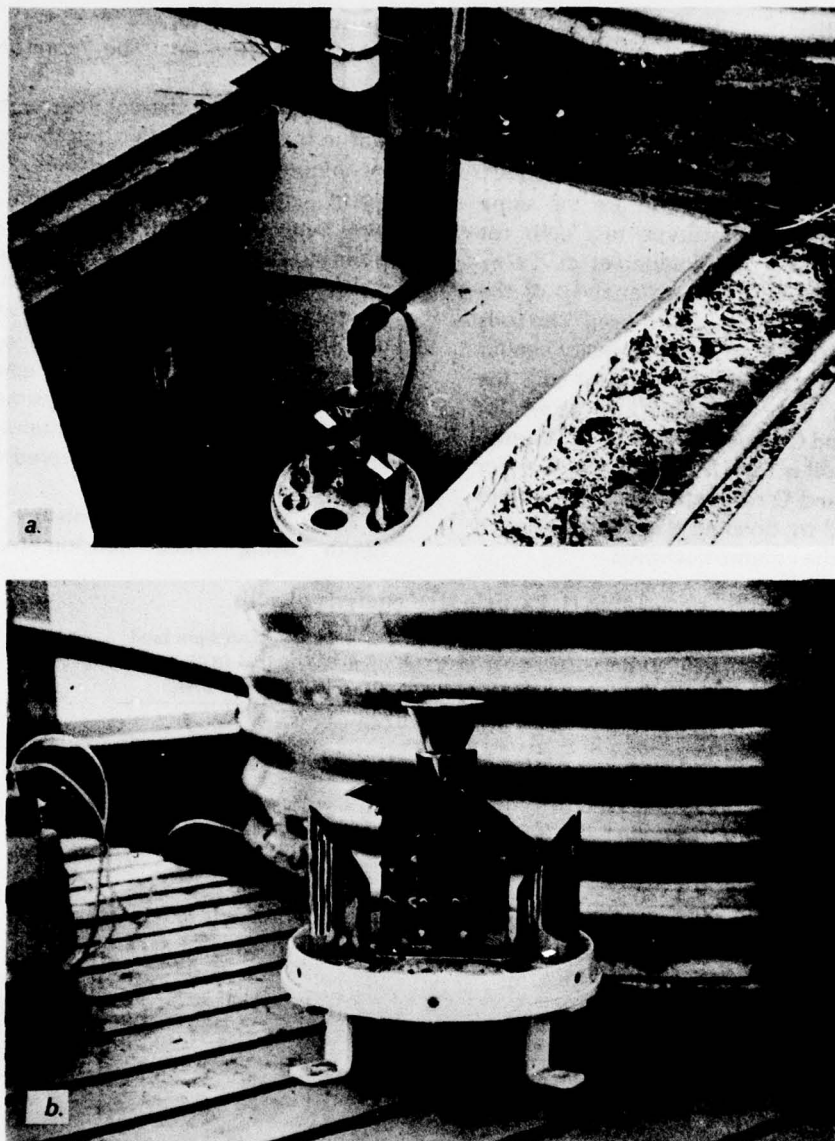
Figure 2. Rain gage for monitoring rate of leachate.

Table I. Locations and numbers of sampling devices or probes and parameters measured.

Soil horizon	Soil solution Depth (cm)	No.*	Redox probes Depth (cm)	No.	Soil temp Depth (cm)	No.	Soil air Depth (cm)	No.	Tensiometer Depth (cm)	No.
A	7.5	2	7.5	3	5	2	7.5	2	7.5	1
	15	2					15	2		
B	30	2	30	3	28	2	30	2	38	1
	45	2	45	3	43	2	45	2	75	1
C	97	2	97	3	95	2	98	2		
	135	1					135	2		
	Leachate									

* Number of samplers.

3

Soils characteristics

Two lysimeters were filled with Charlton silt loam soil and the other two were filled with a Windsor sandy loam. Both soils were obtained from local fields in New Hampshire, transferred to the laboratory, and sieved. The fraction <1 mm was used for sieving. These are the same soils used in outdoor prototype test cells for land treatment research (Iskandar et al. 1976). Table II shows the particle size analysis of the different horizons of the two soils used. The soils were packed carefully to a bulk density similar to that found in the field. In Windsor soil, the bulk density is 1.41, 1.59 and 1.55 g/cm³ for horizons A, B and C respectively. The bulk density of Charlton soil is 1.64, 1.57 and 1.69 g/cm³ for horizons A, B and C respectively. These values were calculated by dividing the weight of each soil horizon by the volume occupied.

Moisture movement

Moisture flow may be monitored in three ways:

1) By measuring the volumetric moisture content in the soil at depth using the neutron probe technique (Troxler Laboratories, Inc., Raleigh, North Carolina). For this method, a stainless steel pipe (4.1-cm outside diameter, 0.089-cm wall thickness) was installed in the center of the soil column down to 122-cm depth (Fig. 3). The lower end of the pipe was sealed with a welded disk from the same material. The outside of the pipe was coated with Polane, using the same procedure described for the lysimeter. Approximately 15 cm of the pipe remained above the soil surface. The pipe was covered with a rubber stopper while not in use.

2) By monitoring the moisture tension with depth using three tensiometers in each

Table II. Particle size analysis of soils.

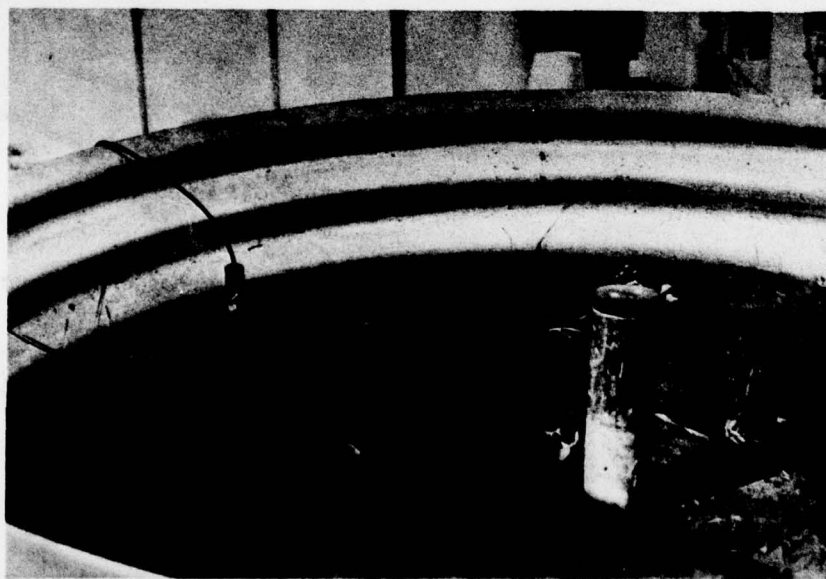| Soil horizon	Depth (cm)	Clay (<0.001-0.01) (mm)	Silt (0.01-0.075) (mm)	Fine sand (0.075-0.05) (mm)	Medium sand (0.05-2.0) (mm)
			Windsor soil (%)		
A	0-25	2	11	57	30
B	25-45	2	36	46	36
C	45-150	2	31	50	17
			Charlton soil (%)		
A	0-25	14	34	32	20
B	25-45	13	34	29	24
C	45-150	11	32	31	26

Figure 3. Neutron probe tube.

lysimeter, one in each soil horizon. The exact location of each tensiometer is described in Table I. The tensiometers were inserted approximately 15 cm from the wall into the soil. A tensiometer-manometer system was used (Fig. 4).

3) By recording the rate of leachate using a tip bucket and recording device. Figure 5 shows the interface circuit* of the rain gage utilized. Each bucket tipping represents 7 ml of water. The interface is connected to a Hewlett-Packard 7100B Strip Chart dual channel recorder. Typical settings of the recorder are: chart speed 2.5 cm/hr; channel 1 Range-CAL 1V, 20 V; channel 2 Range-CAL 0.5 V, 20 V. From the recorder data, information concerning the amounts of water percolated per unit of time can be obtained.
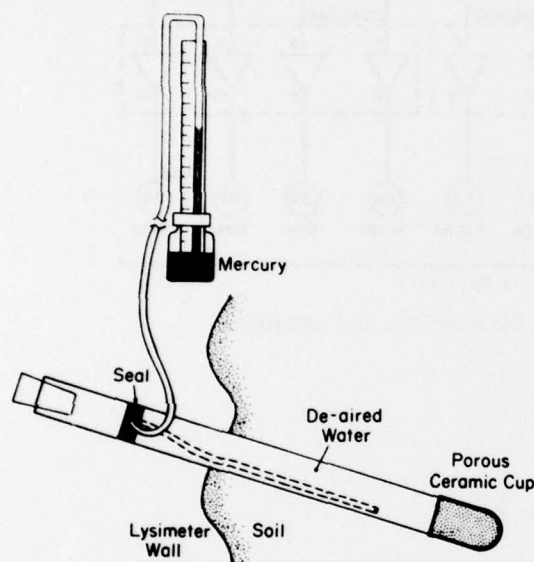

Figure 4. Tensiometer-Manometer and soil air sampler.

Soil solution sampling

Soil solution sampling has always been an important factor in interpreting soil chemistry data. Collection of soil solution by suction lysimeters is probably the best sampling method for studies concerning soil solution chemistry. However, several factors affect the integrity of samples obtained in this way, including rate of sample intake, lysimeter clogging, sampler depth, and type of vacuum system. Hansen and Harris (1975) studied the effects of these factors on the quality of soil solution collected by porous ceramic cups. They concluded that sample variability can be reduced by shortening the sampling intervals, by using uniform sampler lengths, and by using the same initial vacuum for

* This circuit was designed and built by the Engineering Services Branch of the Technical Services Division of CRREL.

all samples. But England (1974) questioned the validity of soil solution samples collected by suction cups for chemical analysis. His argument was based mainly on the heterogeneous nature of soils. The porous cups represent point sources of suction which drain different sized pores. Wood (1973), however, found that ion exchange and ion filtration do not constitute a significant problem in the use of ceramic cups if the cups are washed with acid and then washed with water.

To determine the rate and extent of P and N (as NO_3) sorption on ceramic plates, two plates were soaked in a standard solution of P and NO_3, and the solution concentrations of both P and NO_3 were determined each day for 7 days (Fig. 6). Mercuric chloride was added to eliminate the algal growth. The data indicated no appreciable sorption of either P or NO_3 on the plates.

Severson and Grigal (1976) studied the effect of extraction time on soil solution concentration using porous ceramic cups. They found that solution concentrations, especially of P, Ca and K, changed with the length of extraction time. As time to extract a sample increases, the sample probably represents solution held by soil at tensions approaching those applied to the ceramic cup. It is expected that the effect of extraction time on the soil solution chemistry would be much lower in using suction plates than in using porous cups. This is mainly due to the presence of a larger volume of solution in the plates before any suction has been applied. In the present study, suction plates were used rather than ceramic cups.

For each lysimeter, ten 10.2-cm-diameter plates were placed at various depths (Table I), and one 25.4-cm plate was placed near the bottom of the lysimeter. These plates are available from Pacific Lysimeter, Seattle, Washington. The plates were cleaned by placing them in 0.1 N HCl for 24 hours and then rinsing them carefully with distilled water. The plates were kept in water until they were installed.

Figure 7a shows a soil solution collection bottle. The purpose of the reservoir tube in the bottle is to prevent drying of the suction plates. As the solution in the suction plates is released, solution from the reservoir replaces it. The vacuum system (Fig. 8) being used is designed to ensure that the vacuum used to collect the soil solution samples does not exceed a certain level. The system essentially consists of a 120-gal galvanized reservoir tank with an automatic
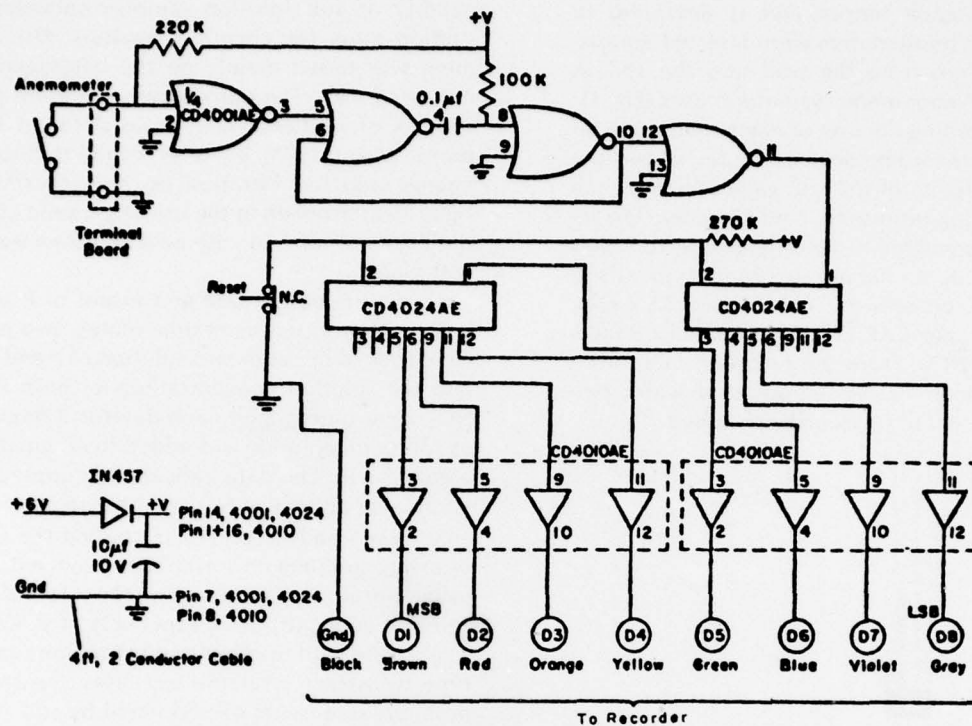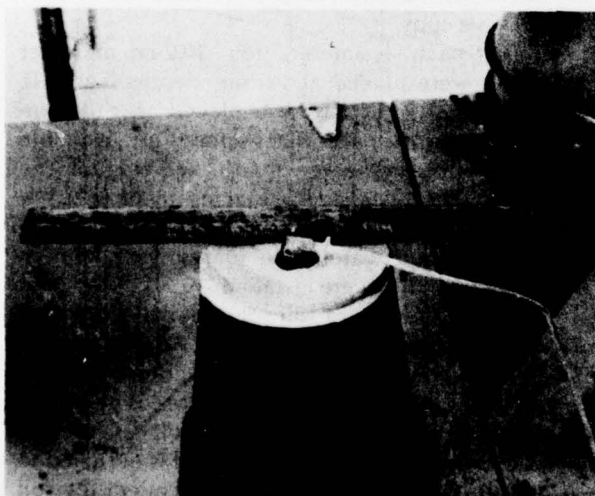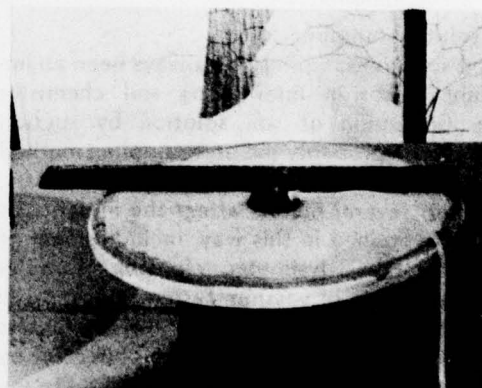
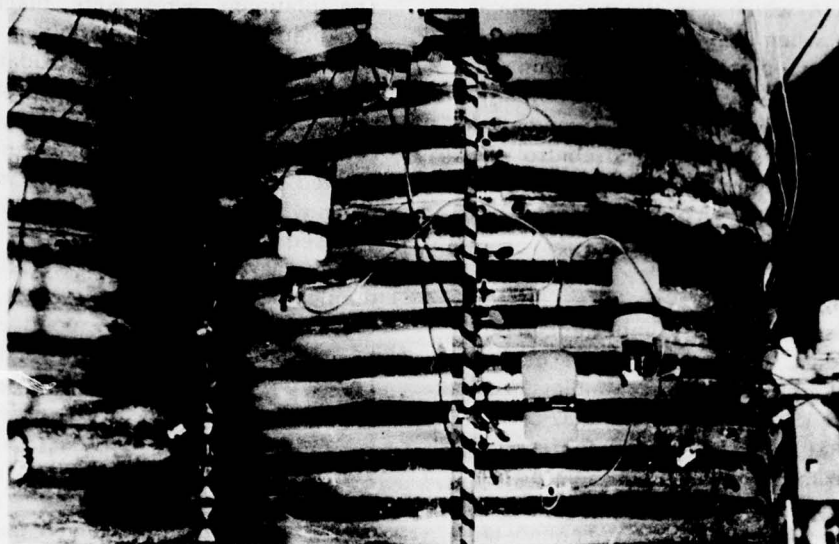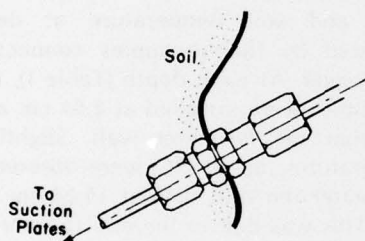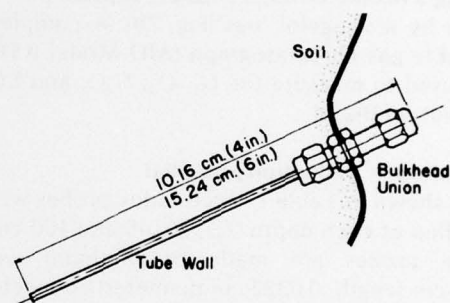Figure 5. Flow diagram of interface circuit between rain and recorders.

a.

b.

Figure 6. Suction plates used in soils solution collection.

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a. Soil solution collection bottles.

b. Soil solution connection.

c. Soil air sampling diagram.
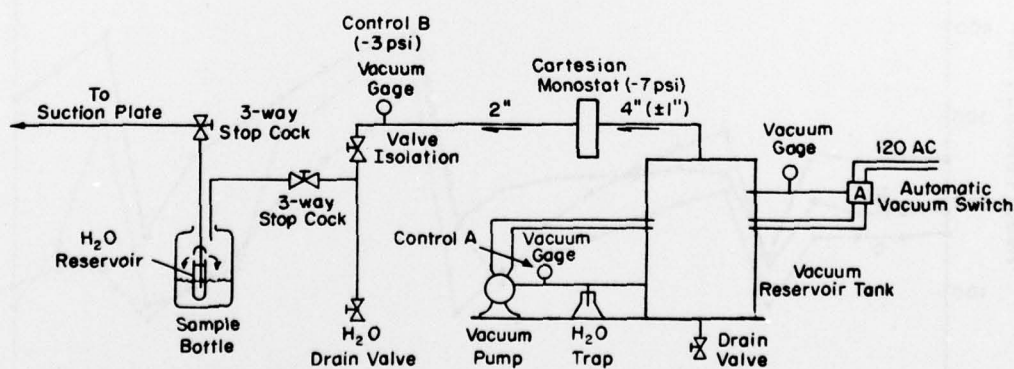
Figure 7. Soil solution collection.

Figure 8. Flow diagram of vacuum system.

vacuum switch (A) which activates a mechanical vacuum pump when the vaccum in the tank becomes less than a preset value. The pump was purchased from Tower Equipment Company, 7609 S.E. 27th Massen, Washington. Two control switches (manometers) are used to control the vaccum on the solution containers. Control A is usually at $-48,300$ Pa (-7 psi) and Control B is at $-20,700$ Pa (-3 psi).

Soil air sampling

Analysis of soil air is very important in soil chemistry studies, particularly those dealing with biological transformations. Stainless steel tubes (10.2 and 15.2-cm length and 0.32-cm ID) were inserted at depths (Table I) to form an angle of approximately 20° with the soil surface. This was mainly to eliminate soil solution from entering the gas tube. The tubes were connected to a swagelok union mounted on the wall of the lysimeter. Soil air samples were collected by inserting a needle through a rubber septum held in place by a swagelok nut (Fig. 7b). A complete portable gas chromatograph (AID Model A512) was used to measure the N_2, O_2, N_2O, and CO_2 contents of the air.

Oxidation — Reduction potential

As shown in Table I, three redox probes were installed at each depth (7.5, 30, 45 and 100 cm). These probes are made of platinum wire (2.54-cm length, 0.0322-cm diameter) connected with a copper wire to a data acquisition system.

The platinum wires were blacked using a Beckman model PK-1A platinizing kit to prevent probes from pointing. The oxidation potential (Eh) of hydroquinone for each probe in a buffer solution at pH 4 and 7 was measured using a calomel reference electrode. Any probe that showed more than 10-mV deviation from the mean was cleaned with 1 N HCl, reblacked and checked again.

Figure 9 shows the changes in soil Eh at 7.5 cm during three weeks of wastewater application to Charlton soil. There is a good agreement between the three probes in the relative change of Eh. It is interesting that, after application of wastewater, there is a sharp increase in Eh followed by a gradual decrease. While the gradual decrease in soil Eh is expected, the reason for the sharp increase is not known: It might be due to dissolved oxygen in the wastewater. Similar trends of Eh cycles have been reported in soil columns by Whisler et al. (1974) using sandy soils and wastewater.

Temperature

Air and soil temperature at depth are measured by thermocouples connected to a data logger. At each depth (Table I), two thermocouples were installed at 2.54 cm and 15.24 cm from the lysimeter wall. Slightly higher temperatures (up to 1°C) were observed in the soil nearer the wall than at 15.24 cm from the wall. This was due to thermal flux through the side of the lysimeter. To better simulate field
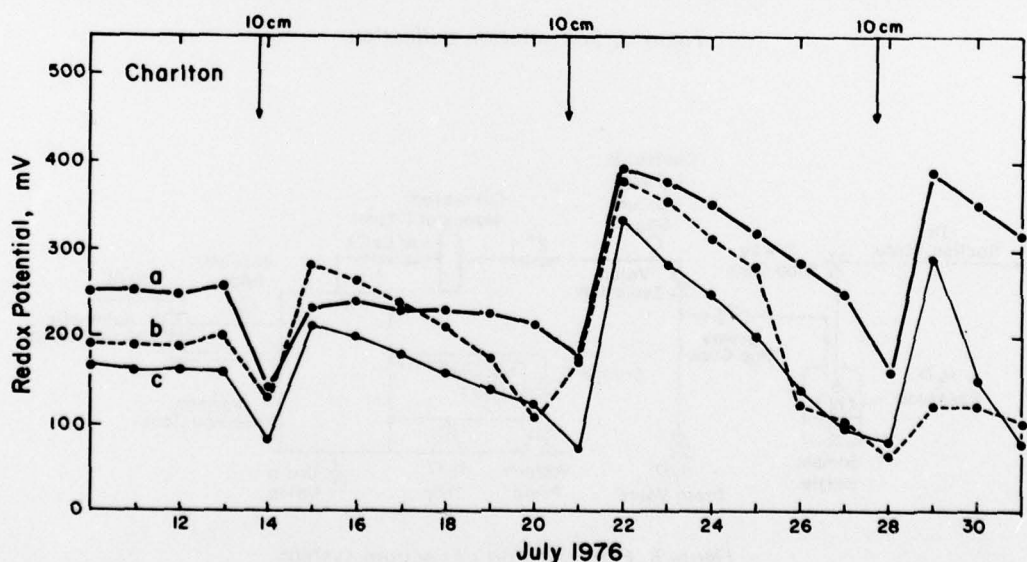

Figure 9. Changes in soil oxidation potential during a cycle of wastewater application.

conditions where heat is input only from the soil surface, the lysimeter walls were insulated with Styrofoam.

Data acquisition

Temperature and Eh status can be monitored at any desired interval from minutes to 24 hours. An 800 Kay Data Acquisition System (Kay Instruments, Bedford, Massachusetts) with a printer and a paper tape puncher was used in this program. A computer program was developed to store the information from the paper tape.

Spray system

Physical simulation of a large-scale spray operation in the field by small-scale operation in the greenhouse is empirically known to be difficult. Before the development of the automatic spray system (Fig. 10), wastewater was applied to the lysimeter in several equal portions. Each portion was flooded manually onto the soil surface
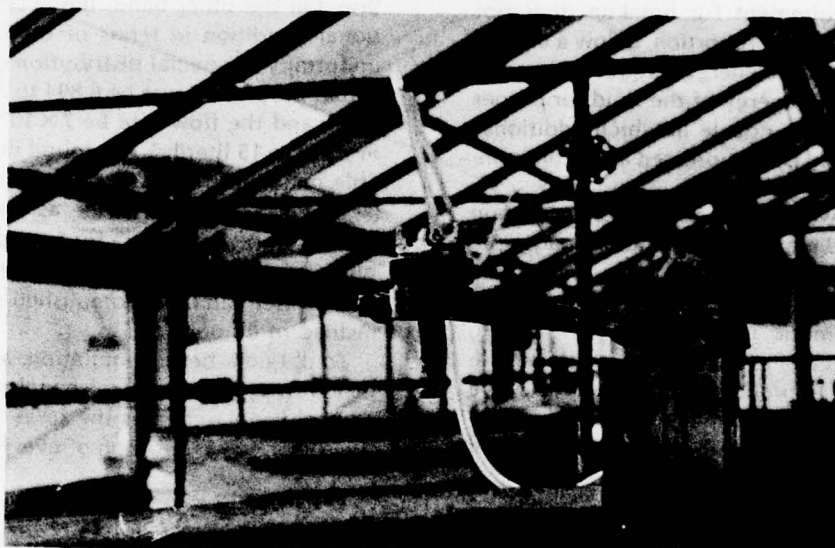
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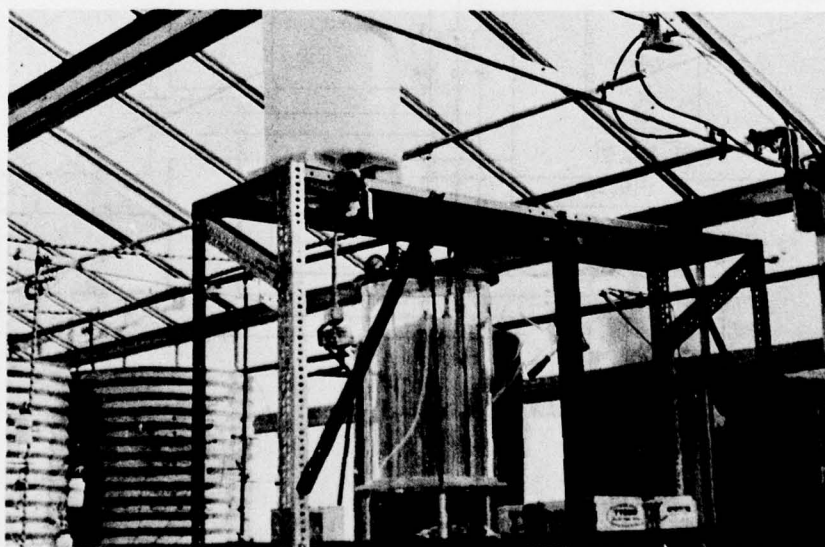
b.

Figure 10. Spray nozzle (a) and storage tank (b).

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within equal time intervals. Because this manual operation was costly, and did not accurately simulate field operation, an alternative method was sought.

A spray application using a spray nozzle was found to be feasible. The breakup mechanism of liquid in such a nozzle includes: I) the initial breakup of a liquid jet due to hydrodynamic instability and (2) the further breakup of a liquid drop while the drop is moving in the air. The flow rate through the nozzle decreases proportionally as the area of application decreases. Because the energy requirement for breakup does not decrease in the same proportion, below a certain critical size of nozzle energy is required in addition to the kinetic energy of the fluid for proper spray. A pneumatic nozzle in which additional energy is supplied by compressed air is commonly used.

Since the wastewater contains a certain amount of solid matter, the diameter of a simple nozzle cannot be very small, so the kinetic energy cannot be increased as much. Several types of pneumatic nozzles were considered, and a commerically available pneumatic nozzle was obtained. It produced droplets that were too small under the normal operational conditions, and a significant portion of the wastewater

was lost in the form of mist during the application. After a series of experiments, a Model 686C SPRACO pneumatic nozzle made by the Spray Engineering Company, Burlington, Massachusetts, was chosen. The normal operational requirements of this nozzle are that the air pressure be 68,900 to 275,600 Pa (10-40 psi) and the flow rate be 2×10^{-2} to 5×10^{-2} m³/hr (20 to 50 liter/hr).

The required average flow rates of wastewater are about 4 liter/hr for 2 in. per 8 hours application and 8 liter/hr for 4 in. per 8 hours application. On the other hand, the acceptable operational condition in terms of the drop size and uniformity of special distribution of wastewater is that the air pressure be 6,894 to 20,700 Pa (1 to 3 psi) and the flow rate be 7×10^{-3} to 1.5×10^{-2} m³/hr (7 to 15 liter/hr). It is found that the acceptable minimum flow rate of about 7×10^{-3} m³/hr (7 liter/hr) is almost twice as large as the required average flow rate for 5 cm per 8 hours application. In this case, the spraying of 5 cm of wastewater can be accomplished within 4 hours instead of 8 hours.

To obtain a better simulation, a solenoid ON-OFF valve with a control panel was used. The control panel activates the spray system during the specified first portion of every 30-minute cy-
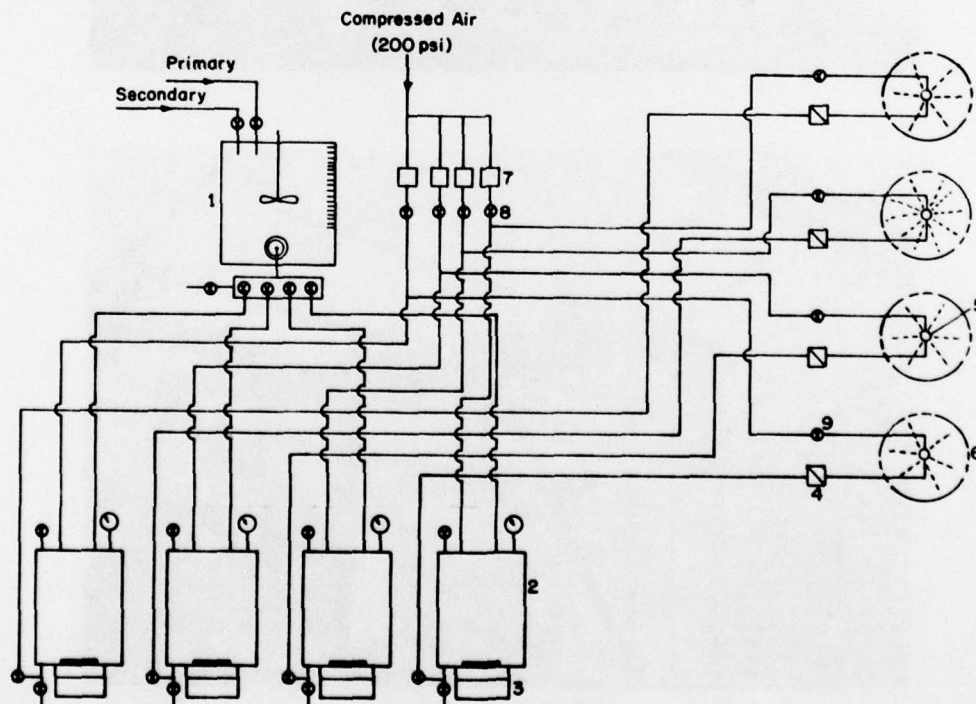

Figure 11. Flow diagram of spray system.

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cle and idles it during the remainder of the cycle. In this way, the wastewater is more evenly distributed within a certain period of time. The flow diagram of the spray system is shown in Figure 11. The mixing tank, 1 (Fig. 11), is suitable to longer storages of wastewater that has received either primary or secondary treatment. Every applicaton day the specified quality and quantity of wastewater for each lysimeter are transferred from mixing tank 1 to each of 4 storage tanks, 2. The wastewater in the storage tanks is then stirred by a magnetic stirrer to ensure that the wastewater is homogeneous.

At the time of application, the starting switch of the control panel is set ON. The panel opens a solenoid valve for a specified period and closes. The cycle takes 30 minutes. When the solenoid valve is open, regulated compressed air [approximately 20,700 Pa (3.0 psi)] is introduced into the closed storage tank, 2 (Fig. 11), as well as into a spray nozzle, 5. The wastewater in the storage tank flows into the spray nozzle through a filter, 4. Spraying continues until the solenoid valve is closed. The filter is designed to prevent clogging of the nozzle by the relatively large-size suspended matter. At the end of application, the filter is washed with a small amount of water.

Cost

Table III shows the construction cost estimates of CRREL's lysimeters. These are 1975 estimates. Some of the items listed may be used to serve several lysimeters. Total cost per lysimeter is approximately $650.

Table III. Construction cost estimate of CRREL lysimeters, 1975 (not including labor).

	Cost estimate
Lysimeter	$152.00
Cleaner product	1.00
Concrete etch	1.00
Polane coating	5.50
Catalyst for Polane coating	1.00
Reduce solvent	.50
Soil suction plates	100.00
Nozzle (each)	10.00
Automatic timer	18.00
Storage tank	50.00
Mixing tank	50.00
Dual setting vacuum	45.00
120-gal tank, range boiler	135.00
Gage, vacuum, Bourdon dial type (in. of Hg HS-39706)	9.00
Cartesian diver type absolute pressure control C 2200	55.00

Discussion

The lysimeters were used in several experiments in connection with land treatment of wastewater. The first experiment was conducted to determine the moisture flow in the Windsor sandy loam and the Charlton loam soils using the neutron probe technique. The second experiment was conducted to determine the residence time of Cl^- as a conservation element in soils and to correlate the rate of Cl^- movement with the rate of water movement. The third experiment was conducted to investigate the influence of wastewater application schedule on the water Cl^- and nitrate movement in soils. The lysimeters are now being used to study the nitrogen transformation in land treatment using the stable isotope ^{15}N as a tracer. The results obtained will be used for the validation of a land treatment model. Reports on each experiment are being prepared for publication.

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