EPA-600/2-77-117
June 1977

Environmental Protection Technology Series

CONTINUOUS SUBSURFACE INJECTION OF LIQUID DAIRY MANURE

Robert S. Kerr Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Ada, Oklahoma 74820

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CONTINUOUS SUBSURFACE INJECTION OF LIQUID DAIRY MANURE

by

J. L. Smith
D. B. McWhorter
R. C. Ward
Colorado State University
Fort Collins, Colorado 80523

Grant No. S-802940

Project Officer

S. C. Yin
Source Management Branch
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
ADA, OKLAHOMA 74820

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows; (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries; and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American public.

William C. Galegar
Director
Robert S. Kerr Environmental Research
Laboratory

ABSTRACT

The research has involved the development and evaluation of an efficient, economical, continuous subsurface injection machine. The application site was instrumented so the quality of water percolating beneath the injection zone could be measured. Wells located around the sites were used to monitor groundwater quality. Soil samples were taken periodically to determine nutrients, salts, heavy metal concentrations, and bacteria movement and survival.

Major environmental problems were increased soil salinity and movement of fecal coliform to the groundwater. Both of these problems can be eliminated by proper management and site selection.

Subsurface injection is economically feasible when compared with other methods of land application. Although capital costs are greater for subsurface injection, labor costs are significantly reduced. Other advantages of subsurface injection are elimination of odors, insects and visual pollution and minimization of runoff pollution.

This report was submitted in fulfillment of Grant No. S-802940 by Colorado State University under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers a period from January 21, 1974, to December 1, 1976, and work was completed as of September 30, 1976.

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ACKNOWLEDGEMENTS

The authors wish to thank Sherm Worthington, Larry Wyatt, James Honn, and Steve Smith for their assistance during the term of this project. They willingly went to the site in all types of weather and often had to perform rather unglamorous tasks.

The assistance of Mr. S. C. Yin and Mr. L. R. Shuyler of the Robert S. Kerr Environmental Research Center is gratefully acknowledged. Their many suggestions and interest contributed significantly to the success of this project.

Chemical analysis of the plant, soil and water samples was conducted by the CSU Analytical Chemistry Facility under the direction of Dr. William S. Ferguson. Mr. Kirke Martin and Dr. S. M. Morrison performed the biological analysis. The authors wish to express their appreciation to these individuals for their assistance.

Finally, the authors wish to thank Mrs. Peggy Stumpf and Mrs. Phylis Sitzman for their excellent work in preparation of this report.

J. L. Smith
D. B. McWhorter
R. C. Ward

SECTION I

CONCLUSIONS

Continuous subsurface injection provides an efficient method for land application of liquid manure. Using the system, it is possible to apply at high rates (1,500-3,800 ℓ/min typically), and achieve relatively high loading rates (up to 748,000 ℓ/ha) per application. Applications can be repeated weekly or more often, depending upon the type of equipment used.

Odor, insect, runoff and visual pollution are eliminated with subsurface injection. Liquid manure is pumped from the holding facility through a combination of permanent and portable pipe and a 200-meter flexible hose to the injector. The injector applies the manure in a broad, shallow cavity, approximately 12 cm below the ground surface, and thoroughly mixes it with soil. The manure is completely covered with soil and is never exposed. A modified injection system was used for frozen ground. In this case, approximately 70% of the injected area was covered.

A 0.49 ha site was adequate for application of 95,000 liters of 1.2% solids manure each month from September 1974 through March 1975. The maximum total application was 3.5×10^6 ℓ/ha or 42,000 dry kg/ha. This area should be adequate for an unlimited time period, provided precautions are taken to control soil salinity.

Soil salinity and fecal coliform contamination of the groundwater were major environmental problems. Natural precipitation may be adequate for control of soil salinity in some regions; however, natural precipitation may not be adequate in semiarid regions. In this case, it may be necessary to irrigate areas to leach salts out of surface soils.

Contamination of groundwater by fecal coliform appears to be related to the specific site. The groundwater was within 0.5 m of the ground surface during the irrigation season. This did not provide adequate filtration for the fecal coliforms. Also, the groundwater passed through home sewage disposal systems in the vicinity of the site, thereby increasing the fecal coliform concentration. The groundwater should be more than 1 m below the surface of sandy loam soils to prevent fecal coliform contamination.

The manure applied to the site provided adequate crop nutrients to produce silage corn yields similar to those produced by normal cultivation and fertilization. Chemical analysis of leaf and grain samples indicated that heavy metals were not concentrated in plant tissues.

Subsurface injection is an economical method for land application of liquid manure. Although capital costs are relatively high, operating costs are significantly reduced. For example, direct surface spreading of the manure from a 100-cow free-stall dairy in solid form required 504 hours per year. Subsurface injection of liquid manure from the same dairy required only 324 hours per year.

SECTION II

RECOMMENDATIONS

The subsurface injector was successful in applying the relatively small quantity of manure generated by the dairy described in this report. The injection system should now be studied in a much larger system, i.e., one which generates approximately 30,000 liters per day. This would better define the system's limitations and enable a more thorough study of the environmental impact.

Soil salinity was a major problem in this research. The movement and control of salts in the soil above the water table should be studied. Methods of controlling the movement of salts to the groundwater may be required if land application of liquid manure is to be economically successful. In other words, salts must be removed from surface soil for crop growth. However, it may also be necessary to limit their movement into the groundwater. Thus, a method of controlling movement of salts would be desirable.

Movement of nitrates to the groundwater may also be a limiting environmental factor for land application of manure. The mineralization of nitrogen from manure and movement of nitrates in the soil should be studied. This should generate a series of recommendations with regard to suitable application sites and loading rates. Most of the current recommendations appear to be very conservative.

SECTION III

INTRODUCTION

Modern methods of animal production involve intensive use of capital to reduce labor costs and increase production efficiency. This has resulted in the practice of feeding large numbers of animals in confined areas generally near population centers. Advantages of this system are that it permits mechanization of feeding, use of controlled environments, and the production of large numbers of animals near processing plants or markets. The major problem with confinement feeding is the disposal of large quantities of manure produced by the animals.

Liquid manure systems are popular in confinement feeding operations. Liquid manure systems utilize pumps, tanks, pipelines, etc., rather than the normal inefficient bulk handling equipment used with dry or semisolid manure. In addition, water can be used for flushing and cleaning feeding areas. However, manure must still be disposed of, regardless of the handling system or its efficiency.

Yeck and Schleusener (1971) discussed processing of manure for refeeding and other uses. While this should represent the most desirable method of recycling, developmental work is still required. Also, the acceptability of refeeding manure has not been resolved. Until these problems are solved, processing and refeeding of manure cannot be regarded as an acceptable disposal method.

Methods ranging from lagoons and oxidation ditches to municipal treatment plants have been studied, used, or proposed for treatment of animal wastes. Success of treatment operations has varied with location and management. Full treatment is expensive because of the large quantity of material involved and the relatively high solids concentration. Other treatment processes require good management and strict supervision to avoid nuisance and other pollution hazards. All forms of treatment produce sludges which require safe methods of ultimate disposal or recycle.

A subsurface injection system was developed by Colorado State University (Gold et al., 1973). With this system, it is possible to recycle large quantities of material on relatively small land areas and avoid nuisance pollution. The system eliminates the need for treatment and is highly efficient, inexpensive, and particularly suited for recycle of material near populated areas. Development of the technology for injection of manure would provide an acceptable method of recycling manure until more sophisticated processing methods are developed.

OBJECTIVES

The overall objective of the research is to evaluate environmental problems and costs associated with recycling of liquid livestock manure on agricultural land through subsurface injection. This includes determination of the following:

1. The potential for contamination of ground and surface water.

2. The land requirements for disposal.

3. The minimum depth of injection required to keep material covered and prevent it from being washed away with rainfall and/or irrigation waters.

4. Any odors and/or insect problems.

5. The availability of plant nutrients, soil contamination by salts and fecal coliforms, and the effect on crop yield.

ON-LAND DISPOSAL

Land spreading has been used to dispose of manure for centuries. Although manure has limited value as a source of plant nutrients, it does produce some benefit in terms of improved soil tilth and/or as a soil conditioner. The normal practice of land disposal involves bulk collection of manure, transport to a disposal area and surface spreading. The manure is then incorporated into the soil during normal tillage operations at some later time.

Surface spreading of manure can result in a serious deterioration in the quality of runoff (Bernard et al., 1971; U.S. EPA, 1971a). Further surface application near populated areas often results in problems of aesthetics and various forms of nuisance pollution, such as odors and insects. Because of these problems, future use of surface spreading appears to be limited to situations where conditions can be carefully controlled.

Injection of waste material beneath the ground surface eliminates many of the difficulties associated with surface spreading. Subsurface injection has the following distinct advantages:

1. Eliminates odor and insect problems.

2. Minimizes contamination of runoff waters for effective pollution control.

3. Adds organic matter to the soil and thus acts as a soil conditioner and source of plant nutrients.

4. Eliminates viewing by the public and is thus aesthetically more acceptable.

5. Is economical.

The unique feature of the injection system developed at Colorado State University is that material is discharged uniformly and at shallow depths under the wings of wide sweeps, while the tilling action of the sweeps mixes it with soil. Experience gained in current research has indicated that this procedure is desirable for the following reasons:

1. Thorough mixing produces a large interface area between the material and soil. Because of the capillary attraction of the soil, water moves into the soil and the injected material dries rapidly. The soil then dries, primarily by movement of water to the soil surface. This decreases the possibility of groundwater contamination and permits injections at greater frequency.

2. The material is maintained in an aerobic environment, thus eliminating the possibility of mummification.

3. Less tractor drawbar power is required to pull the injector through the soil, thereby reducing disposal costs.

The injectors can be operated at depths ranging from 7.5 to 25 cm. Liquid waste having 5% solids is fully covered at an operating depth of 7.5 to 12.5 cm, with up to 5,300 ℓ/min discharge and ground speed within the range of 0.8 to 2.4 km/hr (187,000 to 748,000 ℓ/ha).

The current machine has been used with sewage sludge having a solids content up to 10%. However, 5-6% solids is considered optimum because of difficulties in pumping thicker material through the machine and because lower solids contents significantly increase the volume of liquid that must be handled.

DESIGN OF THE SUBSURFACE INJECTION EQUIPMENT

A series of laboratory tests (Gold et al., 1973) was conducted to study various methods of injecting liquid, organic wastes with up to 6% solids into the soil. The optimal procedure was determined to be one where the material was thoroughly mixed with the top 10 cm of soil. This procedure resulted in the most rapid drying of the liquid portion of the material and also facilitated repeated applications in the shortest time interval. Deep injections dried slowly and resulted in near mummification of the injected material.

The first subsurface injector system, shown in Figure 1, consisted of a 2,840 liter portable tank and the injector pulled behind the tank. The major accomplishment of this phase of the research was the development of the injector units. These consisted of commercially available spring-loaded chisel plow shanks with 40 cm wide, high-lift sweeps. The liquid waste is discharged under the wings of the sweep through a deflector mounted on the rear of the shank, as shown in Figure 2.

Figure 1. Original subsurface injector.

Figure 2. Subsurface injector sweep and deflector.

As the sweep passes through the soil, it creates a broad, shallow cavity into which the liquid waste is injected. Soil falls over the wings of the sweep, filling the cavity and mixing with the waste. The covering soil also fills the vertical slot formed by the shank, leaving the soil surface relatively undisturbed. Normally, liquid waste is injected at a depth of 10 to 16 cm. Injection within this range provides an aerated environment for the waste and insures rapid drying. Major benefits of rapid drying are decreased potential for transport of contaminants from the sludge to groundwater and the ability to make repeated passes over the same area at shorter time intervals.

The deflector outlet area opening can be changed by bolting plates of various lengths across the rear of the deflector. In clayey soils with thicker waste materials (5% solids or more), the plate is left off. However, the plate must cover the entire back of the deflector when injecting thin waste materials in sandy soils. Deflector plugging is not a problem when the material is pumped to the deflectors under a small pressure (34 kPa), using a trash pump (pass 3.8 cm diameter solids).

Two major problems were observed in testing the first machine: (a) it was impossible to pull the portable tank through the field except under nearly ideal conditions, and (b) the "turn around" time was too long and only 2% of the total operating time was spent injecting.

Major modifications of the above system were incorporated into subsurface injectors used to dispose municipal sewage sludge (Boulder machine) and liquid dairy manure (Fort Collins machine). The units are shown in Figures 3 and 4.

Material is supplied continuously through an underground pipeline which is connected to a 200-meter flexible hose which, in turn, is connected to the injector. A pump, located at the source or storage facility, delivers the material to the injector. This eliminates the need to pull heavy portable tanks through the field and provides continuous operation of the injector until the supply is exhausted.

The Fort Collins machine has five injector sweeps with a 7.6 cm supply hose. It is capable of injecting at rates up to 1,500 liters per minute over a 230 cm width. The 34 kW wheel-type tractor is capable of pulling the unit and hose in good weather at 2.4 km/hr. In moderately severe weather, the speed must be increased due to the torque characteristics of the tractor engine.

The Boulder machine consists of seven injector sweeps with a 11.4 cm supply hose. It is capable of injecting at rates up to 3,000 liters per minute over 305 cm width. A 31 kW crawler tractor has sufficient power to pull the unit at approximately 1.6 km/hr. Speeds as low as 0.8 km/hr can be used in good soil conditions. The tractor is equipped with wide tracks (84 cm) to provide flotation in adverse weather. This unit is used regularly in mud and snow; however, it will not operate when the frost depth is greater than 5 cm.

Figure 3. Boulder subsurface injector.

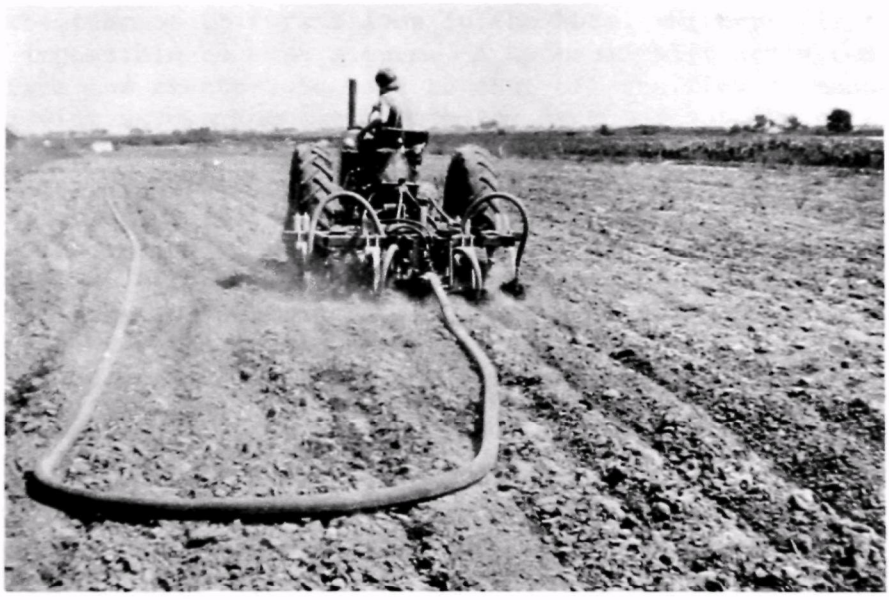

Figure 4. Fort Collins subsurface injector.

Specifications and approximate sizes for the equipment are given in Tables 1 and 2.

TABLE 1. SEVEN SWEEP INJECTOR SPECIFICATIONS

Operating speed	0.8 to 2.4 km/hr
Capacity per sweep	230 to 450 liters/min
Operating depth	7.6 to 20 cm
Field efficiency	87 percent
Tractor power required	
Wheel type	34 to 90 kW
Crawler type	30 to 45 kW
Capacity	187,000 to 748,000 liters/hectare
Maximum area covered per hose attachment	7.49 hectares
Pressure required at hose attachment	400 kPa
Solids content	6 percent (nominal)
Frequency of injection	2 to 7 days

TABLE 2. INJECTOR SIZE RANGE

Hose diameter, cm	Flow, liter/min	Full hose weight, kg/m	Number of sweeps	Width, m
7.6	1,500	4.6	5	2.27
10.1	3,000	8.0	7	3.20
11.4	3,800	10.3	9 or 11	5.03
12.7	5,300	12.8	13	5.94

Sweeps on the Fort Collins machine were replaced with chisel points for use in frozen ground. The revised machine is shown in Figure 5 and an injector is shown in Figure 6. Note that the deflector was replaced by a straight tube. With changes, it was possible to inject with the ground frozen to a depth of 10 cm. However, the waste material was not completely covered (it was estimated that between 60 and 70% coverage was achieved) and only two passes could be made on a given area. The surface was left in a rough condition with large pieces of frozen soil in random positions. This surface condition should decrease the potential for runoff pollution.

The modified injector was also evaluated for use with septic tank wastes in a high-mountain community (Summit County, Colorado). In these tests, the coverage was essentially 100%; however, there were operational problems due to large rocks in the injection field. Replacement of the chisel points with narrow (8 cm wide) high-lift sweeps eliminated most of these problems. Sweeps have a tendency to move or slide over and around rocks, whereas chisel points tend to catch on them.

The injector is hitched to the crawler tractor by a parallel bar linkage. This hitch holds the injector level with respect to the tractor at all operating depths and as the injector is raised and lowered, During normal operation, the injection depth is controlled by gauge wheels. However, in adverse weather or field conditions, it is sometimes necessary to support the injector from the tractor. Both modes of operation are possible, using hydraulic controls on the tractor. The standard agricultural three-point hitch is used for attaching the injector to wheel-type tractors.

Turning the machine around while pulling the hose requires some operator skill. An experienced operator can turn in 30 to 45 seconds and can inject over 95% of the time the injector is in the field. The major difficulty in turning is that the operator must perform a series of relatively precise movements with the tractor to form a loop in the hose. Without first forming a loop, it is impossible to make a turn. A hydraulically activated plug valve, controlled from the tractor, is used to shut off the flow of manure when turning or moving across the field with the injector out of the ground.

Maintenance of the injection system is relatively simple. Experience indicates that the injector sweeps may have to be replaced twice during the first year of operation at a new site. Annual replacement thereafter is usually sufficient. It is necessary to relocate the hose coupling at the machine every three to four months. This is accomplished by cutting off about 18 inches of the hose and reinstalling the coupling. In more than three years of operations, this is the only service required on the hose. No wear has been detected.

During cold weather, precautions must be taken to prevent liquid from freezing in the hose. The normal procedures are to purge the delivery system and hose with air or to drain the hose by gravity. A three-inch hose can be emptied by loading it on a transport reel. Reel units are commercially available and are also convenient for transporting the hose or for storage. Reel units for hoses larger than three inches in diameter can be equipped with air pumps for purging the hose.

Figure 5. Fort Collins subsurface injector adapted for use in frozen ground.

Figure 6. Injector for frozen ground.

SECTION IV

SITE DESCRIPTION AND EXPERIMENTAL PROCEDURES

APPLICATION SITE DESCRIPTION

The manure injection site was located on the Duane Fisher farm, approximately 1/2 mile north of Timnath, Colorado, and 5 miles east of Fort Collins, Colorado. Soils at the 1.05 ha site consist of approximately 45 cm of loam and sandy loam overlaying alluvial sands and gravels. The soil pH is 7.6.

The normal water table depth ranges from 1.5 to 2 m during the period from September to May or early June. However, during the irrigation season (June through September), the water table depth ranges from 0.5 to 1 m below the soil surface.

The site layout is shown in Figure 7. Plots 1 and 2, (0.19 ha) were operated together as were plots 3 and 4 (0.3 ha). The remainder of the site was used as a control and received no manure. Groundwater equielevation lines (March 1975) are also shown in Figure 7.

Manure was pumped from a 34,000-liter holding tank to the application site through 90 m of buried 10 cm PVC pipe. The 200-meter flexible hose was attached at the pipe outlet indicated in Figure 7. A 10 cm portable centrifugal pump, located near the holding tank, was used to move the manure through the underground pipe, flexible hose and subsurface injector. Valves at the pump were arranged to recirculate manure back to the tank to agitate the liquid manure.

Silage corn and sugar beets were raised on the site prior to its use for this research. Both liquid and feedlot manure were applied to the site but no accurate records were available.

MANURE APPLICATION

Manure was injected on all plots, starting in September 1974. Approximately 95,000 liters were applied each month, in three applications per month. Through April 1975, plots 1 and 2 received a total dry solids loading of 19,800 kg/ha and plots 3 and 4 received 10,200 kg/ha.

For six weeks during January and February 1975, manure was spread on the ground surface, due to frozen ground, rather than being injected. The following year manure was injected on a regular basis and throughout the winter using the modified injector described previously. No surface runoff was observed in either case.

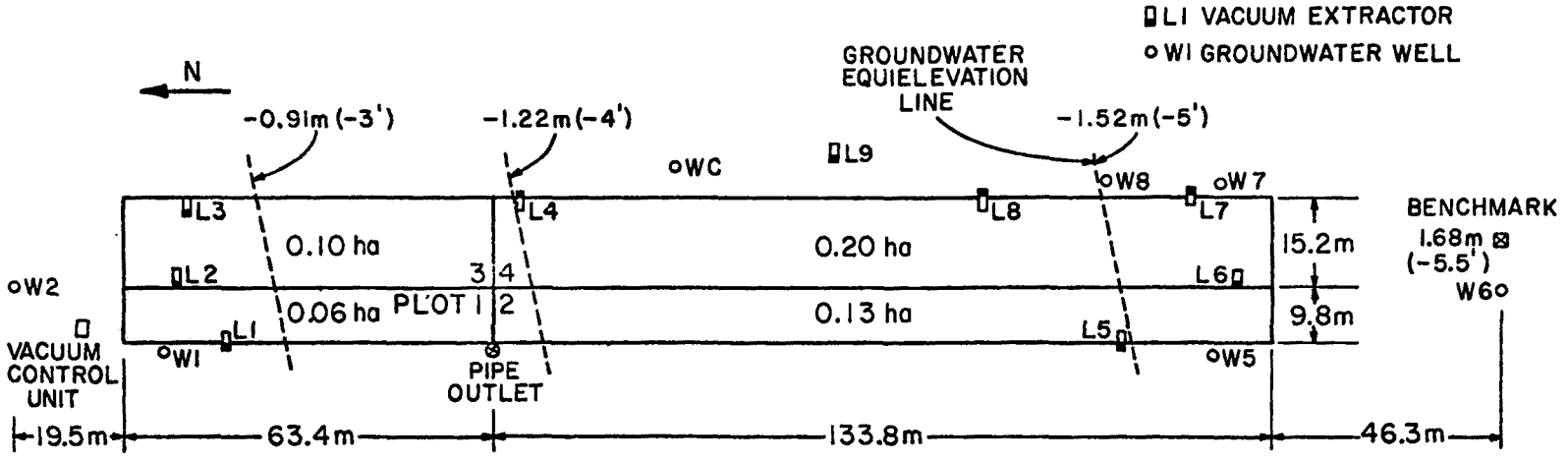

Figure 7. Manure injection site.

Corn was grown on plots 1 and 2 from June through September 1975. From May through September, manure was injected in plots 3 and 4, increasing the total dry solids applied by 18,000 kg/ha to a total of 28,200 kg/ha. After the corn was removed in September, manure was injected on all plots through March 1976, increasing the total dry solids loading by 13,800 kg/ha. The loadings are summarized in Table 3.

SOIL AND GROUNDWATER SAMPLING

Soil samples were collected with a manual soil probe or a Giddings Rig Core Sampler. Seven to 10 cores were collected from each plot, the cores were divided by depth, and each set of depth samples were composited.

Well locations are indicated in Figure 7. Well 2 was regarded as being least affected by the manure application and well 7 was regarded as the most likely affected. Groundwater samples were collected from the wells with a portable pump. The bottom 60 cm of the 10 cm PVC well lining pipe was perforated to allow entry of water.

VACUUM EXTRACTORS

Soil water leaching from the manure application site is diluted when it reaches the groundwater. The degree of dilution depends upon the thickness of the aquifer, groundwater flow rate, and rate of percolation. Therefore, it is difficult to measure leachate quality and nearly impossible to estimate the amounts of contaminants leached by sampling groundwater.

Consequently, percolating leachate should be sampled before it reaches the groundwater. Also, it would be advantageous to collect quantitative samples of the leachate in order to determine total amounts of pollutants entering the groundwater system.

Soil water above the groundwater table normally exists at less than atmospheric pressures. Precipitation or leachate from sludge will percolate downward through the soil at negative gauge pressures ranging up to 25 cm of mercury. Thus, ordinary piezometers and observation wells used to sample groundwater are useless above the water table because the pressure in the soil is less than the pressure in the well (atmospheric) and water will not flow into the well. A sampling device which can collect percolating soil water under negative pressures (to 25 cm Hg) must be used.

Such a leachate vacuum extraction system was developed by Duke and Haise (1973). In the system (Figure 8), hollow, saturated, porous, ceramic tubes (30 cm long and 1.27 cm diameter) were placed near the bottom of a stainless steel trough (152 cm long, 15 cm wide, and 18 cm deep). The ceramic tubes had a bubbling pressure (vacuum at which desaturation begins) of one atmosphere. When a vacuum, larger than the negative pressure of the soil water but smaller than the vacuum at which the ceramic desaturates, is applied to the ceramic tubes, water will pass through the tube walls without allowing the air to pass. Two rows of four tubes each, connected end-to-end with plastic tubing, were placed on 2 cm of soil in the soil-filled trough.

TABLE 3. SUMMARY OF MANURE LOADING.

Time Interval	Total Loading, ℓ/ha		Dry Solids Loading, kg/ha	
	Plots 1 and 2	Plots 3 and 4	Plots 1 and 2	Plots 3 and 4
September 1974-April 1975	1.65×10^6	0.85×10^6	19,800	10,200
May 1975-September 1975		1.50×10^6		18,000
September 1975-March 1976	1.15×10^6	1.15×10^6	13,800	13,800
Total applied	2.80×10^6	3.50×10^6	33,600	42,000

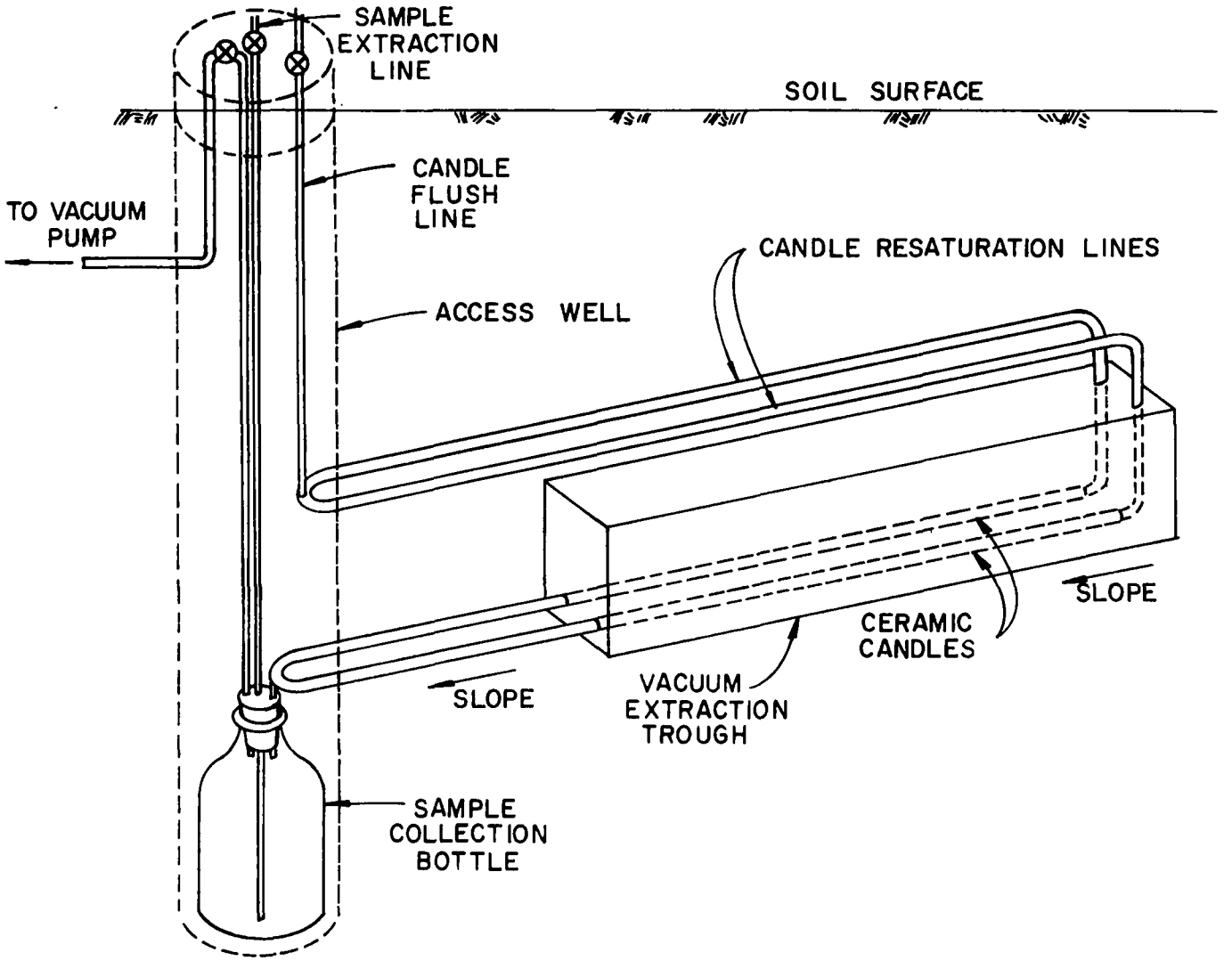

Figure 8. Vacuum extractors.

The depth of the trough was selected, based on a theoretical analysis (Corey, 1974), so that the soil-water pressure would adjust approximately to the ambient soil-water pressure at the top of the trough. Thus, the extractor should not interfere significantly with normal soil-water flow and a quantitative sample of leachate should be collected. The variation of soil-water pressure upward from the ceramic tubes depends upon the soil properties and flow rate. For the extraction troughs and vacuums used in this study and the soil at the manure application site, the negative pressure at the top of the trough should vary less than 10% from the ambient soil-water pressure. This variation is smaller at higher soil-water percolation rates.

The extractor troughs and access wells were installed in a trench about 1 m below the soil surface. Plastic tubing was used to connect the ceramic tubes to a sample collection bottle located in the bottom of a 30 cm diameter lined access well. The trough and plastic tubing were sloped toward the well so leachate would flow to the bottle by gravity. The trench was backfilled with soil in about the same order as it was removed. Errors introduced by this installation procedure may result in a small overestimate of the volume of water leaching from the site (Trout et al., 1975).

Vacuum from the control system was applied to the sample collection bottle and to the ceramic tubes through 0.64 cm polyflow tubing. The vacuum control system consisted of a vacuum pump, tank pressure switch, and a mercury manometer. The pressure switch regulated the vacuum in the tank between 38 and 50 cm Hg. This vacuum was reduced about 12 cm Hg at the extractors. Three extractors were connected to each vacuum control unit.

The sample collection bottles were emptied through the polyflow extraction line at regular intervals, depending on precipitation and manure application. Location of the vacuum extractors on the application site is indicated in Figure 7.

ANALYSIS OF WATER AND PLANT TISSUE SAMPLES

Sample Preparation

Water samples were collected and stored in polyethlylene bottles. To maximize stability in storage, samples were usually placed in bottles which had previously been used for the same type of sample.

Aqueous samples were processed on the day received, when possible. Groundwater samples were filtered through a membrane having 0.45 micron pores. All samples were divided into two fractions. One fraction, preserved with 1 mℓ of concentrated sulfuric acid added to each liter of sample, was used for nitrogen and boron determinations. The second fraction, preserved with 12 mℓ of 0.5 molar nitric acid added to each liter of sample, was normally used for metal determinations. Sometimes metal determinations were performed on the sulfuric acid preserved fraction. Phosphorus and chloride were determined on either fraction, according to availability.

Plant tissue samples were oven-dried for storage. Aliquots for analysis were handpicked from the bulk sample because pulverization in a Wiley mill was found to introduce metal contamination.

Digestion of manure and plant tissues were accomplished with nitric-perchloric mixed acids. Dry ashing was carried out in a muffle furnace. "Plasma" ashing (oxygen excited in a low pressure plasma discharge) was applied when neither wet digestion nor dry ashing was acceptable for trace metal analysis by atomic absorption.

Validation of the chemical analysis results produced was assured by interspersing control among the unknown runs. The overall amount of control approximated 5 to 10% of all runs. Examples of control runs are blanks, blind duplicate determinations on unknowns, addition of known amounts of the sought constituent to an unknown sample and then observing what percentage of the known added material was recovered. Laboratory standards whose composition is known were also included as control. All procedures comply with or are equivalent to recommendations published by the U.S. EPA (1972).

Determination Methods

Metals--

Metals were determined by atomic absorption, using excitation either by flame or, when higher sensitivity was required, by carbon rod atomization.

Chloride--

Chloride was determined by titration with silver nitrate, using either potassium chromate indicator or a silver-silver chloride indicator electrode.

Nitrogen--

Nitrogen determinations in all cases were based on final measurement as ammonia, either by titration with sulfuric acid or by potentiometry, using an ammonia-sensitive electrode. Samples were reduced, using Devarda alloy in the presence of excess magnesium oxide while concurrently steam distilling the reaction mixture to remove ammonia continuously. For ammonium nitrogen determinations, ammonia either was separated by the same procedure, omitting the Devarda alloy, or measured directly in a sample aliquot, using the ammonia-sensitive electrode. Total Kjeldahl nitrogen determinations on manure suspensions were carried out conventionally after establishing that pretreatment with salicyclic acid and sodium thiosulfate was unnecessary.

Phosphorus--

Phosphorus was determined colorimetrically as orthophosphate by the vanadomolybdophosphoric acid method.

ANALYSIS OF SOIL SAMPLES

Determination Methods

Texture--

Texture was estimated by feel.

pH--

pH was measured on a saturated soil paste with a glass electrode pH meter.

Electroconductivity--

Electroconductivity was measured with a Solu-Bridge RD-26 and conductivity cell on a saturation extract.

Organic Matter--

Organic matter was determined colorimetrically on a sample prepared by wet oxidation with potassium dichromate and concentrated sulfuric acid with spontaneous heat of reaction.

Nitrate--

Nitrogen samples were prepared by the phenoldisulfonic acid method and levels were determined colorimetrically.

Available Phosphorus--

Available phosphorus was extracted by the Olsen Bicarbonate Method and determined by the ascorbic acid determination method.

Available Potassium--

Available potassium was extracted with 1N neutral ammonium acetate. Levels were determined by flame photometry.

Total Nitrogen--

Total nitrogen was determined by a regular Macro-Kjeldahl method.

MICROBIOLOGICAL AND OXYGEN DEMAND ANALYSIS METHODS

Determination Methods

All procedures used are described in Standard Methods for the Examination of Waters and Wastewaters (AOHA, 1971)

Fecal Coliforms--

Fecal coliforms in water samples were determined by the membrane filter procedure. In soil samples, fecal coliforms and total coliforms were determined by the Most Probable Number test.

BOD and COD--

BOD and COD were determined by methods 219 and 220 of the above listed source.

SECTION V

ENVIRONMENTAL MONITORING

INTRODUCTION

Evaluation of the effect of using the subsurface injection system described previously for liquid manure requires measurement of changes which occur at the application site. In this research, this involved measuring the quantity and quality of manure applied and its effect on the soil, crops, groundwater and leachate. Both biological and chemical analyses were used in the evaluation.

Odors, insects and runoff were never observed at the application site. This was due to the fact that the manure was thoroughly covered and mixed with the soil. In general, the regular injection of manure from the holding tank decreased odors and insects around the milking parlor and enhanced the farmstead environment.

MANURE CHARACTERISTICS

Composition of the manure used in this research is shown in Table 4. The manure consisted of flush water from the floor of a milking parlor retention pen and wash water from the milking parlor itself. The manure was collected in a holding tank, located under the retention pen floor, for a period of approximately 10 days before it was injected.

Manure samples were normally analyzed on a monthly basis; however, not all determinations listed in Table 4 were made each time. The complete list, except for the heavy metals, was made every three months. Due to the relatively low heavy metals content of the manure, no further heavy metal measurements were made and no heavy metals were monitored in the soils, leachate, or groundwater at the application site.

PATHOGENS

Fecal coliforms (*E. coli*) were used as an indication of the presence of other enteric bacteria and pathogens because of their large numbers and ease of measurement. The fecal coliform level in the liquid dairy manure was approximately 2.8×10^6 per 100 mℓ, or approximately 2.8×10^7 fecal coliforms were added to the soil with each dry kilogram of manure.

Well samples were evaluated for presence of Salmonella and Pseudomonas. Neither of these organisms was observed.

TABLE 4. DAIRY MANURE ANALYSIS

Determination	Average Value	Range
Total Kjeldahl N	765 mg/ℓ	570 - 880 mg/ℓ
NH_3 - N	618 mg/ℓ	490 - 740 mg/ℓ
Total P	92 mg/ℓ	70 - 140 mg/ℓ
K	1,076 mg/ℓ	820 - 1,500 mg/ℓ
Cl	161 mg/ℓ	60 - 235 mg/ℓ
Solids	1.2%	0.9 - 1.3%
TDS	6,700 mg/ℓ	5,700 - 8,700 mg/ℓ
Conductivity	5,700 μmhos/cm	4,600 - 6,400 μmhos/cm
Cd*	0.8 ppm	
Cu*	33 ppm	
Ni*	<4.17 ppm	
Zn*	167 ppm	

*One determination

Results of soil core analysis, shown in Table 5, indicated that fecal coliforms did not move readily through the soil when the water table was at a depth greater than 1 m below the manure injection zone. This result agrees with more extensive data reported by Trout et al. (1975) involving municipal sewage sludge.

TABLE 5. COLIFORM ANALYSIS IN SOIL SAMPLES*

Sample Depth, m	Total Coliforms/100 gm	Fecal Coliforms/100 gm
0.3	160,000	4,900
0.6	22,000	<200
1.0	1,700	<200
1.3	230	<30

*Sampled April 1975

Well water samples contained few fecal coliforms during the non-irrigation season. As shown in Table 6, groundwater fecal coliform levels in January and April were normally less than 10 per 100 mℓ. During this period, the water table depth was from 1.5 to 2 m below the manure injection zone.

TABLE 6. BOD, COD AND FECAL COLIFORM IN WATER AND MANURE SAMPLES

Date	Sample	BOD, mg/ℓ	COD, mg/ℓ	Fecal Coliforms/100 gm
September 1974	W-2	2.8	68.7	3,000
	W-3	2.8	204.2	2,400
	W-7	--	312.9	>30,000
	W-9	5.6	61.0	<10
	Manure	6,200	9,100	2,800,000
January 1975	W-2	--	--	8
	W-5	--	--	30
	W-7	--	--	<4
April 1975	W-2	--	--	8
	W-5	--	--	24
	W-7	--	--	<4
	L-3	1.4	129.1	--
	Manure	--	--	2,500,000
June 1975	W-2	24.9	6.1	12,000
	W-5	42.8	7.2	--
	W-7	5.6	40.9	30,000
	L-3	4.8	148.8	--
	L-8	3.6	231.4	--
September 1975	W-2	3.4	--	6,000
	W-7	7.4	--	2,400
January 1976	W-2	--	--	6
	W-7	--	--	4
	Manure	6,900	9,600	2,800,000
September 1976	W-2	--	--	26,000
	W-7	--	--	42,000

Fecal coliform levels in the groundwater were considerably higher during the irrigation season. Referring to Table 6, fecal coliform levels in wells 2 and 7 were both increased and the level in well 7 was normally greater than the level in well 2 in June and September. There are two apparent reasons

for this. First, the water table was often within 0.5 m of the ground surface during this time and thus there was not sufficient unsaturated soil to remove the fecal coliform prior to their reaching the groundwater. Second, there were several home sewage disposal systems near the application site. During the irrigation season, the groundwater may have picked up fecal coliform as it passed through these systems. Based on these results, it appears that the water table must be at a depth of 1 m or more below the manure injection zone to prevent contamination of the groundwater with fecal coliforms.

OXYGEN DEMAND

The oxygen demand in a liquid sample, an indication of unstable organic matter, is measured by the biochemical oxygen demand, BOD. The chemical oxygen demand, COD, is a measure of the oxygen consuming capacity of inorganic and organic matter present in the liquid.

Approximately 0.06 kg of BOD and 0.09 kg of COD were added to the soil with each dry kilogram of manure. Referring to Table 6, virtually all of the BOD and COD were removed in the soil. Also, comparison of September 1974 results with June 1975, indicated no increase in groundwater BOD or COD as a result of manure application.

SALINITY

The electroconductivity of soil saturated extract is an indirect measurement of total dissolved solids (TDS) or soluble salts. When the value of 4.0 mmhos/cm is reached, TDS can be harmful to some plants (Richards, 1969). This high TDS condition can be created in arid climates when most of the manure solution evaporates, leaving an accumulation of soluble salt ions in the surface soil.

The soil electroconductivity is shown in Figure 9 for plots 1 and 2 and Figure 10 for plots 3 and 4. This soil has a relatively high electroconductivity at all times, probably due to the shallow water table.

Also, the groundwater has a high TDS, particularly in September at the end of the irrigation season (refer to Tables 7, 8, and 9). The electroconductivity on non-injected plots ranged between 3.5 and 4.2.

Manure application increased the soil electroconductivity on all plots. A heavy rain (approximately 2.5 inches) during the first week in June 1975, reduced the electroconductivity on all plots and it was further reduced on plots 1 and 2 by irrigation. After the irrigation season, the electroconductivity increased until crops were planted and irrigation waters were applied the following year.

Leachate TDS was always very high, as shown in Table 7. However, very little of the applied water (less than 5%) reached the extractor level during the non-irrigation season. Thus, it had little effect on the groundwater.

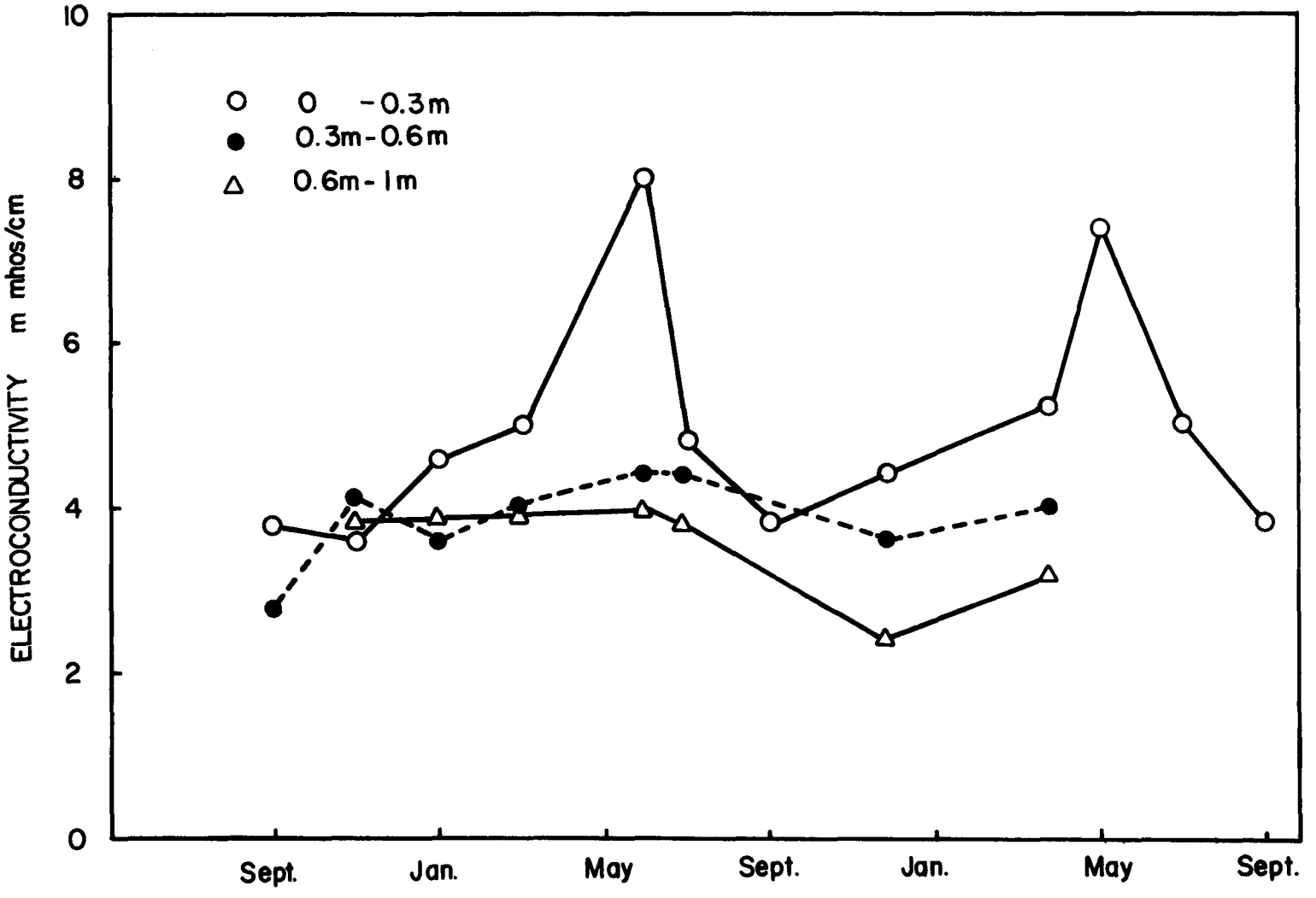

Figure 9. Soil electroconductivity on plots 1 and 2.

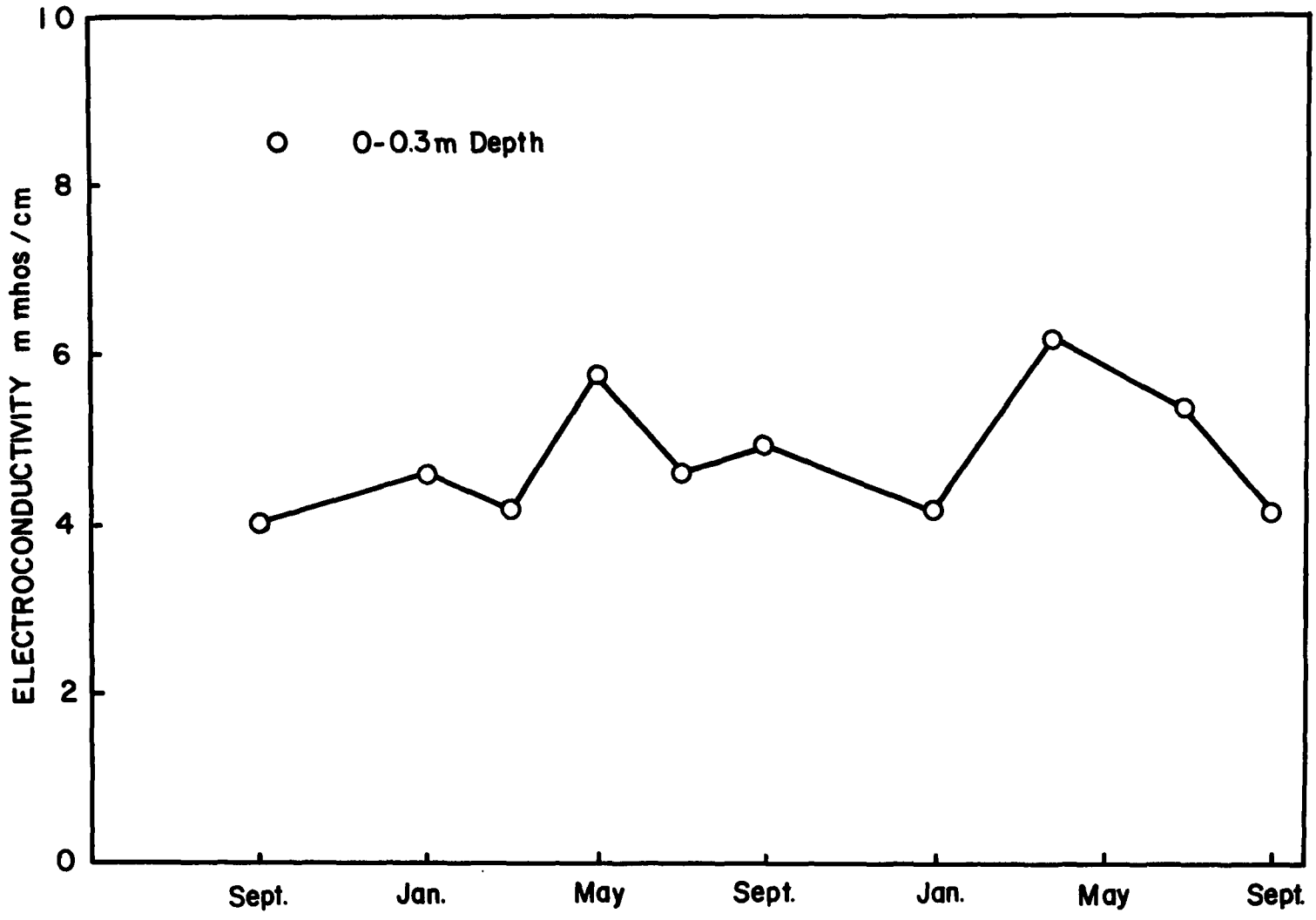

Figure 10. Soil electroconductivity on plots 3 and 4.

TABLE 7. VACUUM EXTRACTOR SAMPLE ANALYSIS

Date	Sample	TKN mg/ℓ	NO_3-N mg/ℓ	PO_4-P mg/ℓ	K mg/ℓ	Cl mg/ℓ	TDS mg/ℓ
Oct. 1974	L1	2	1.8	1.2	4.7	145	7,300
	L2	5	--	0.78	7.7	130	8,000
	L3	11	--	0.63	7.2	205	8,200
	L4	4	--	0.07	2.9	65	6,500
	L5	5	--	0.09	2.5	110	5,200
	L6	10	--	--	5.3	65	5,500
	L7	11	--	0.34	3.7	120	8,400
	L8	11	--	0.20	5.9	45	--
	L9	2	--	0.12	3.6	95	5,100
Jan. 1975	L1	4	--	--	--	84	6,400
	L5	8	--	--	--	63	7,600
	L9	3	--	--	--	91	6,000
Mar. 1975	L3	--	1.9	--	25	125	7,000
	L3	--	--	--	--	--	7,500
	L5	--	3.6	--	39	75	3,900
	L7	4.6	2.6	--	56	190	7,000
May 1975	L1	11	10.7	--	45	155	5,300
	L3	29	28.7	--	63	245	7,300
	L5	28	27.8	--	24	90	--
	L5	28	27.9	--	27	90	3,900
	L6	37	31.2	--	49	155	4,200
	L6	30	22.4	--	47	150	--
	L7	42	41.7	--	29	185	7,000
	L7	22	21.8	--	32	180	--
	L9	14	13.6	--	37	330	6,900
Sept. 1975	L1	1.2	1.0	0.38	41	155	--
	L4	12	11.4	0.24	30	175	--
	L8	9.1	9.1	1.1	35	295	--
	L9	8.0	7.9	0.11	25	170	--
Oct. 1975	L1	3.4	3.3	1.0	46	155	4,900
	L4	14	13.7	0.2	32	175	5,100
	L5	--	--	1.0	40	290	6,300
Jan. 1976	L1	0.69	0.47	0.76	45	150	--
	L3	2.9	2.6	1.5	53	270	--
	L9	0.82	0.54	0.6	49	130	--

(continued)

TABLE 7 (continued).

Date	Sample	TKN mg/ℓ	NO_3-N mg/ℓ	PO_4-P mg/ℓ	K mg/ℓ	Cl mg/ℓ	TDS mg/ℓ
Apr. 1976	L1	14	--	--	--	135	5,300
	L3	23	--	--	--	185	7,300
	L5	9	--	--	--	230	3,900
	L9	17	--	--	--	--	6,900
Sept. 1976	L1	4.5	--	--	--	165	6,100
	L2	8	--	--	--	192	--
	L3	6.7	--	--	--	--	--
	L5	9.4	--	--	--	163	3,800
	L9	4.6	--	--	--	126	6,800

TABLE 8. INITIAL GROUNDWATER QUALITY (Sept. 1974)

Determination	Average Value*	Range
Total Kjeldahl N	10 mg/ℓ	6 - 16 mg/ℓ
NO_3-N	8.6 mg/ℓ	0.1 - 5.7 mg/ℓ
PO_4-P	3.5 mg/ℓ	1 - 7 mg/ℓ
K	12 mg/ℓ	2.4 - 31 mg/ℓ
Cl	46 mg/ℓ	30 - 80 mg/ℓ
TDS	4,800 mg/ℓ	3,900 - 6,500 mg/ℓ

*Average of samples taken from all nine wells.

Groundwater TDS, as shown in Tables 8 and 9, tended to vary with irrigation. TDS values were higher in August and September and lower from January through June. Note, however, that the groundwater TDS was always greater than 2,000 mg/ℓ, which probably accounts for the high soil electroconductivity at the site. It was not possible to determine the rate of movement of leachate from the site to the groundwater during the irrigation season, due to the high groundwater table. However, comparison of TDS values for wells 2 and 7 indicates that manure application had little effect on the groundwater TDS.

TABLE 9. ANALYSIS OF GROUNDWATER SAMPLES

Date	Sample	TKN mg/ℓ	NO_3-N mg/ℓ	PO_4-P mg/ℓ	K mg/ℓ	Cl mg/ℓ	TDS mg/ℓ
Jan. 1975	W-2	6.9	6.6	0.2	5	--	2,000
	W-7	10	9.8	0.6	9	--	2,100
Mar. 1975	W-2	8	7.6	0.04	7	25	2,200
	W-7	7.3	7.1	--	4	30	2,000
Apr. 1975	W-2	9.6	8.4	0.05	5	25	2,000
	W-5	12	11.9	0.05	10	30	2,400
	W-7	9.4	9.3	0.06	5	25	2,100
May 1975	W-2	11	--	0.04	4	30	2,200
	W-5	8	--	0.05	8	25	2,200
	W-7	8	--	0.03	4	30	2,200
June 1975	W-2	12	--	0.03	4	30	2,200
	W-5	8.6	--	0.02	8	30	2,200
	W-7	8.8	--	0.03	4	30	2,100
July 1975	W-2	11	--	--	--	--	2,200
	W-7	11	--	--	--	--	2,200
Aug. 1975	W-2	5.6	--	0.1	3	90	4,100
	W-5	19	--	0.1	8	150	4,900
	W-7	7.9	--	0.35	8	60	4,600
Oct. 1975	W-2	15	--	--	6	--	4,700
	W-7	6.9	--	--	7	--	3,400
Jan. 1976	W-2	7.7	6	0.07	4	--	2,100
	W-7	7.8	7	0.06	6	--	1,700
Apr. 1976	W-2	8.7	--	--	--	--	1,900
	W-7	9.4	--	--	--	--	2,000
Sept. 1976	W-2	9.1	8.8	--	5	45	4,300
	W-7	7.4	7.4	--	4	30	4,100

It is possible to create harmful salt accumulations in manure-amended soils under semiarid conditions which would require addition of water to leach the salts to lower levels. Such procedures may require good management and close observation of the nitrate concentration in the leachate to prevent contamination of the groundwater.

LEACHATE AND GROUNDWATER ANALYSIS

Results of chemical analysis of soil leachate and groundwater samples are shown in Tables 7, 8 and 9. Note that most of the total nitrogen is in the nitrate form at the extractor level (1 m) and in the groundwater. TDS values are high in the leachate as expected, due to the soil salinity and high TDS of the manure.

It was not possible to reliably estimate the average rate of leachate movement from the injection zone, due to the small quantity of water which moved down. On the basis of the available data, less than 5% of the total applied water (manure and precipitation) became deep seepage during the period from September to May. During the irrigation season when more water was applied, the groundwater was above the extractors, which prevented their use except for groundwater sampling.

The nitrogen (and nitrate) concentration in the leachate tended to increase in May. This was probably due to a small amount of precipitation received in early April.

Comparison of values listed in Tables 8 and 9 indicates that the groundwater moving under the site was not degraded by leachate from the site.

Smith et al. (1977) proposed use of the following equation for predicting the eventual well mixed groundwater contaminant concentration due to land application of waste materials:

$$C_g = \frac{Q_L}{Q_i} (C_L - C_o) + C_o$$

where: C_g = groundwater concentration after complete mixing

C_o = background concentration of groundwater

C_L = leachate concentration

Q_i = rate of flow of groundwater

Q_L = rate of flow of leachate into the groundwater

Assuming Q_L/Q_i is 0.01, a typical value for a similar application site, the difference between the initial groundwater contaminant concentration and leachate concentration would have to be greater than 100 mg/ℓ. Because of the variation in background concentrations, as shown in Table 8, a difference as small as 1 mg/ℓ would be difficult to detect. Thus, the application of manure to this site had little or no effect on groundwater quality, except as noted elsewhere in this report.

Most of the total applied nitrogen is either used in plant growth, denitrified, or remains in the upper soil layer. Since most of the applied nitrogen was in the ammonia form, it was probably held in the soil and mineralized slowly. However, this required further study because, although nitrogen is an asset to agricultural lands, it can also be a dangerous contaminant in drinking water. The maximum level of nitrate nitrogen recommended in drinking water is 10 mg/ℓ (U.S. EPA, 1971b). Organic and ammonium nitrogen in the soil, unless volatilized or used by plants, will be mineralized and nitrified to nitrate nitrogen. Nitrate ions are highly mobile in the soil, and unless denitrified or taken up by plants, will move with percolating water to the groundwater. As discussed by Hinesly et al. (1971), nitrogen is the first limiting factor when municipal sludge is applied to agricultural lands.

SOIL ANALYSIS AND CROP YIELDS

Effects of applying liquid manure to the site soils are illustrated in Table 10. Organic matter, nitrate, phosphorus and potassium were increased in the top 0.3 cm of the soil, due to the application of liquid manure.

Based on the average manure composition, a total of 57 kg of K was placed on the site. Assuming all of this remained in the top 0.3 cm of soil, the K level should have been increased by approximately 600 ppm. The K level was increased by approximately 400 ppm, a reasonable comparison, in view of the increased K concentration in the leachate, as shown in Table 10. A similar calculation indicates that the increased organic matter content of the soil compares favorably with the measured value. The P level should have increased by approximately 60 ppm. In this case, some results listed in Table 10 indicate an increase but they are generally inconclusive. Recall that the P concentration in the leachate was very low. However, it appears that most of the organic matter, P and K added to the soil were retained in the upper 0.3 m.

Most of the nitrogen in the manure is in the form of NH_3 (see Table 4). Ammonia is mineralized to nitrate, NO_3, which is more readily utilized by plants. A mass balance for nitrogen is difficult because many values must be assumed (Trout et al., 1975). Results in Table 10 show that more nitrate was available for plant growth after manure application. This is also reflected in the increased yields for 1976 shown in Table 11, and increased nitrogen in plant leaves and grain shown in Table 12.

The greater yield in 1976 as compared to 1975 was also due in part to improved germination. Planting was delayed in 1975, due to the high soil salinity. When the corn was planted in June, germination was reduced, as compared to the untreated area. In 1976, the same germination rate was observed in all areas. No manure was applied after March 1976. The corn was planted earlier and was irrigated prior to emerging. All of these factors probably contributed to the increased germination and yield in 1976.

TABLE 10. SOIL ANALYSIS

Date	Plot	Depth (m)	pH	O.M. (%)	NO_3-N (ppm)	P (ppm)	K (ppm)	Texture
Sept. 1974	Composite	0.3	7.6	1.8	20	65	313	sandy loam
	1, 2, 3	0.6	7.6	0.9	6	18	220	sandy clay loam
	& 4	1.0	7.6	0.5	5	10	170	clay loam
Apr. 1975	Composite	0.3	7.8	2.0	61	50	610	sandy loam
	1 & 2	0.6	7.9	1.2	39	14	245	sandy clay loam
		1.0	8.0	0.6	18	3	88	clay loam
Sept. 1975	Composite	0.3	--	2.1	46	59	680	loam
	1 & 2	0.6	--	1.0	27	31	342	clay loam
		1.0	--	0.7	12	8	136	clay loam
Apr. 1976	1	0.3	--	2.5	120	110	690	sandy loam
		0.6	--	1.4	45	32	300	sandy clay loam
		1.0	--	0.7	16	13	273	clay loam
	2	0.3	--	2.4	152	125	750	sandy loam
		0.6	--	1.5	58	43	311	sandy clay loam
		1.0	--	0.6	52	14	299	sandy loam
	3	0.3	--	2.0	98	58	716	sandy loam
		0.6	--	0.8	30	7	154	sandy clay loam
		1.0	--	0.6	28	5	97	sandy loam
	4	0.3	--	2.0	81	48	514	sandy loam
		0.6	--	0.8	26	4	118	sandy loam
		1.0	--	0.5	8	2	66	loamy sand

TABLE 11. SILAGE CORN YIELD* AND GERMINATION DATA

Year	Plots 1 & 2		Plots 3 & 4		Untreated	
	Germination %	Yield kg/ha	Germination %	Yield kg/ha	Germination %	Yield kg/ha
1975	96.7	40,600	--	--	99.9	44,400
1976	99.8	45,300	99.8	45,300	98.8	45,000

*Typical yield: 43,700 kg/ha (Source: 1974 Colorado Agricultural Statistics, Colorado Department of Agriculture, Denver, Colorado)

Sweet corn was planted on a small area in plot 2 in 1975. Although it was not used directly for research purposes, it had excellent flavor and was a good morale booster for project personnel.

Heavy metals contents of the silage corn grown on the plots are shown in Table 12. Values are all within normal ranges.

TABLE 12. ANALYSIS OF CORN LEAF AND GRAIN SAMPLES

Sample	Date	Cd (ppm)	Cu (ppm)	Ni (ppm)	Zn (ppm)	B (ppm)	TKN % dry weight
Typical values -- leaf		0.0 - 5.0	6 - 20	0 - 5.5	20 - 70		
Typical values -- grain		0.1 - 1.0	4 - 10	0 - 5.0	20 - 100		
Leaf	July 1975	0.2	8	<1	48	0.16	1.6
Leaf	Sept. 1975	0.2	8	1	56	--	1.6
Grain	Sept. 1975	0.3	12	1	68	--	1.8
Leaf	July 1976	--	--	--	--	--	2.1
Leaf	Sept. 1976	--	--	--	--	--	2.4
Grain	Sept. 1976	0.3	9	1	54	--	2.6

SECTION VI

ECONOMIC COMPARISONS

In order to compare economics of continuous subsurface injection with other land application systems, a comparison developed by the North Carolina Agricultural Extension Service in Circular 568 (Kriz et al., 1973) will serve as a basis. In this circular, six different dairy waste management systems were compared. The information was based on handling manure from a 100-cow herd with each animal weighing 640 kg (1,400 lbs).

One of the systems analyzed by Kriz et al. (1973) utilized storage and spreading of dairy manure in liquid form. This particular system will be modified to incorporate the continuous subsurface injector, thus creating a seventh system for comparative purposes.

The liquid manure system described by Kriz et al. (1973) had a storage capacity which represented a 30-day clean-out interval. Also, a retention pond was incorporated into the dairy layout to collect the milkhouse wastewater and the storm runoff from a 152.4-mm (6-in.) rainfall (24-hour, 10-year storm). The estimated initial investment and annual costs of disposal for the liquid manure system, as given in Circular 568, are presented in Table 13.

In Table 14, the items and costs are listed for a continuous subsurface injection system under the same conditions used in Table 13 [100 cows at 640 kg (1,400 lbs) each]. The scraper, its required tractor use, storage tank, agitator pump, and retention pond cost the same for both systems, but are not necessarily the same equipment. A high efficiency pump would be required for the injection system; however, this would not be as critical for the spreader system.

With the continuous subsurface injector, it becomes feasible to inject the runoff water from the retention pond rather than irrigating. For the volumes being considered in this comparison (859 kℓ or 226,000 gallons of runoff), 9.4 hours of injector time is required for disposal. The same pump used to empty the pit can be used for the retention pond, thus the need for an electric pump, irrigation equipment, and electricity is eliminated when the continuous subsurface injection system is used.

In this particular comparison, 171 kℓ (45,000 gallons) per month are being disposed, since the storage tank for the spreader system contains this volume. Apparently, no provision has been made for dilution water. In this case, only 22.5 hours are needed to continuously inject the 2,052 kℓ (540,000 gallons) of waste produced during the year. The total annual hours

TABLE 13. ESTIMATED INITIAL INVESTMENT AND ANNUAL COSTS OF DISPOSAL FOR A LIQUID MANURE STORAGE AND TANK SPREADING SYSTEM FOR A 100-COW, FREE-STALL DAIRY WITH A 30-DAY STORAGE PERIOD (from Circular 568, North Carolina Agricultural Extension Service)

Item	Estimated Cost				
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual
Scraper, rear mounted	$ 300	0.18*			$ 54
Tractor, 37-44 kW for scraping			280	$ 2.26	633
Storage tank	3,900	0.12†			468
Agitator pump	1,900	0.27‡			513
Tractor, 45-59 kW for agitating and pumping			45	2.90	131
Spreader, liquid manure	2,100	0.23**			438
Tractor, 67-74 kW for hauling and spreading			105	3.52	370
Retention pond	150	0.12†			18
Pump, 1.5 kW, 76 liters/min (20 gpm)	500	0.27‡			135
Irrigation equipment	1,215	0.19††			231
Electricity			188	0.06	11
Labor			440	2.50	1,100
Total	$ 10,065				$ 4,147

*8 years of life; 7% interest on ½ initial cost; repairs, 1% of initial cost; taxes and insurance, 1% of initial cost

†15 years of life, 7% interest on ½ initial cost; repairs, 0.5% of initial cost; taxes and insurance, 1% of inital cost

‡6 years of life; 7% interest on ½ initial cost; repairs, 6% of initial cost; taxes and insurance, 1% of initial cost

**6 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

††8 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

TABLE 14. ESTIMATED INITIAL INVESTMENT AND ANNUAL COSTS OF DISPOSAL FOR A LIQUID MANURE STORAGE AND CONTINUOUS SUBSURFACE INJECTION SYSTEM FOR A 100-COW, FREE-STALL DAIRY WITH A 30-DAY STORAGE PERIOD

Item	Estimated Cost				
	Initial Investment	Ownership Cost Factor	Hours	Hourly Rate	Annual
Scraper, rear mounted	$ 300	0.18*			$ 54
Tractor, 37-44 kW for scraping			280	$2.26	633
Storage tank	3,900	0.12†			468
Agitator pump	1,900	0.27‡			513
Tractor, 45-59 kW for agitating, pumping, and injection (pit and pond)			44	2.90	128
Installation of piping	2,480	0.12†			298
Flexible hose	1,300	0.27‡			351
Subsurface injector	1,000	0.23**			230
Tractor, 67-74 kW for injecting			32	3.52	113
Retention pond	150	0.12†			18
Labor			324	2.50	810
Total	$11,030				$3,616

*8 years of life; 7% interest on ½ initial cost; repairs, 1% of initial cost; taxes and insurance, 1% of initial cost

†15 years of life; 7% interest on ½ initial cost; repairs, 0.5% of initial cost; taxes and insurance, 1% of initial cost

‡6 years of life; 7% interest on ½ initial cost; repairs, 6% of initial cost; taxes and insurance, 1% of initial cost

**6 years of life; 7% interest on ½ initial cost; repairs, 2% of initial cost; taxes and insurance, 1% of initial cost

of injection for both the pit and pond is approximately 32 hours, compared to 150 hours for liquid spreading and 188 hours of pumping the retention pond in the liquid spreading system. The estimated costs shown in Table 14 included 12 hours of agitation.

The major cost for the continuous subsurface injection system is the piping. The cost was computed for 488 m (1,600 ft) of PVC pipe. Also, since the subsurface injector being considered here is not currently available on the market, a cost of $1,000 was estimated. Flexible hose for the system would cost approximately $1,300.

The total initial investment for the continuous system is almost $1,000 higher than the spreader system. The major difference is reflected in the annual costs where there is a $531 savings with the continuous subsurface injector over the liquid spreader system. Since the initial cost of the continuous system is higher, the major annual cost savings result from the reduced time needed to dispose of the wastes.

The comparisons presented in Tables 13 and 14 illustrate a liquid manure system where a scraper is used to deposit the manure in a storage tank. The major difference between the systems is the means of getting the manure to the field and incorporation into the soil. How do these systems compare economically to other means of collection and disposal? Returning to the North Carolina Agricultural Extension Service Circular 568 and using the results presented there (Table 15), it can be seen that the liquid spreader system has the highest annual cost. The continuous subsurface injector system has been inserted into Table 15 to illustrate how it compares economically. Rather than the liquid manure, 30-day storage system having the highest annual cost with the batch spreader, the continuous injector method of disposal lowers the cost of the liquid system and makes it more competitive.

The continuous subsurface injector may make the last three systems presented in Table 15 more economical if the irrigation component was replaced with the injection system. Since the irrigation system is continuous, the injector would not have as dramatic economic effects as it had with the liquid spreader. However, it may have dramatic effects on the environmental conditions of the disposal operation. Since the effluent is underground, many problems associated with surface irrigation of wastewater would be eliminated.

Along this same line, those methods that use surface disposal may require an additional field operation in order to "plow down" the manure. No attempt has been made to include this cost into the above economic comparison. This cost would not be necessary with the continuous injection system. Also, no attempt has been made to account for inflation between the time when Kris et al. (1973) made their calculations and the time when the calculations were done for this paper. Summer of 1974 estimates were used for the subsurface injector. If inflation had been accounted for, the liquid manure system with continuous subsurface injection would be even more competitive economically.

TABLE 15. ESTIMATED INITIAL INVESTMENT, ANNUAL COSTS AND LABOR REQUIREMENTS FOR ALTERNATIVE WASTE MANAGEMENT SYSTEMS FOR A 100-COW, FREE-STALL DAIRY*

Waste Management System	Initial Investment	Annual† Ownership Costs	Annual Labor Requirements (hrs)	Total Annual Cost
Direct spreading in solid form	$ 4,415	$1,873	504	$3,206
Storage and spreading in solid form	5,165	1,963	504	3,326
Storage and spreading in liquid form (30-day storage and liquid spreader)	10,065	1,902	440	4,147
Storage and injection in liquid form (30-day storage and continuous injection)	11,030	1,932	324	3,616
Lagoon and irrigation	7,680	1,391	325	2,924
Flush, storage tank, and irrigation	12,945	2,475	223	3,501
Flush, lagoon, and irrigation	17,095	2,898	213	3,982

*Data for all systems except the continuous injection system taken from Circular 568 of the North Carolina Agricultural Extension Service.

†Does not include tractor ownership costs.

Thus, not only is the continuous subsurface injection system economically competitive and a tremendous labor saving concept, it also provides a much better means of disposal from an environmental standpoint. Odors and insects normally associated with manure disposal on land are greatly reduced since the manure is covered by the soil at such a depth that rapid drying occurs and aerobic conditions prevail. As a result, the environment is greatly improved for the dairy farmer and his neighbors, and becomes much more pleasing aesthetically.

SECTION VII

APPLICATION EXAMPLE

Many dairies along the "Front Range" of Colorado and in other urbanizing areas of the country are facing a difficult situation. The perishability of milk and the need for market necessitate a location near cities, while the environmental conflicts seem to be forcing them further away. A specific example is the Colorado State University (CSU) Dairy located in Fort Collins. The dairy was located in the late 1950's. Its location was assumed to be far enough from the city to cause few problems. Figure 11 very clearly illustrates the situation today. The dairy is surrounded by urbanization and is facing a critical situation with regard to waste disposal.

Figure 11 illustrates how the continuous subsurface injection system could be installed at the CSU Dairy. Manure from the dairy would be stored in the manure pit. Before beginning the disposal operation, the slurry would be prepared for pumping by developing a 5 to 8% solids content. This may or may not require the addition of water, depending upon the collection system (scraper or flush). From the pit, the manure would be pumped via an underground pipe to a point in the center of a nearby field. At this point, a flexible hose would be attached. The dairyman then injects the manure with a continuous operation. The fields are rotated and when not used for injection, are used for pasture, crops, etc.

From one hose connection, approximately 7.5 hectares (18.4 acres) can be injected. Assuming a dairy herd of 100 cows at 640 kg (1,400 lbs) each, results in a yield of approximately 260 dry Mg (287 dry tons) of manure each year (105 lbs of manure/cow/day x 15% dry matter x 100 cows x 365 days/year ÷ 2,000 lbs/ton). If only one connection is used, the loading on the site is 35 dry Mg/ha/yr (15.6 dry tons/acre/year). If two hose connections are installed, only 17.5 dry Mg/ha/yr (7.8 dry tons/acre/year) are applied. Recommended rates for crop growth vary widely [22 Mg/ha/yr-66 Mg/ha/yr (10-30 tons/acre/year)], but around 22 Mg/ha/yr (10 dry tons/acre/year) is currently accepted as a safe figure (Reed, 1969; Miner, 1971). Rates of 98 Mg/ha/yr (48 dry tons/acre/year) have been used by Kansas State University to obtain maximum corn yields (Shuyler et al., 1973). Salt accumulations become critical with some manures in this situation. However, with the 100-cow dairy herd, one or two hose connections are easily within the safe range. (Two connections may be more desirable so crops can be grown on the field not being used for disposal.)

The continuous nature of the injection system shows its advantages when the time and cost of disposal are computed. For the assumed herd above, 0.057 cubic meter (2 cubic feet) of manure at 85% water will be generated

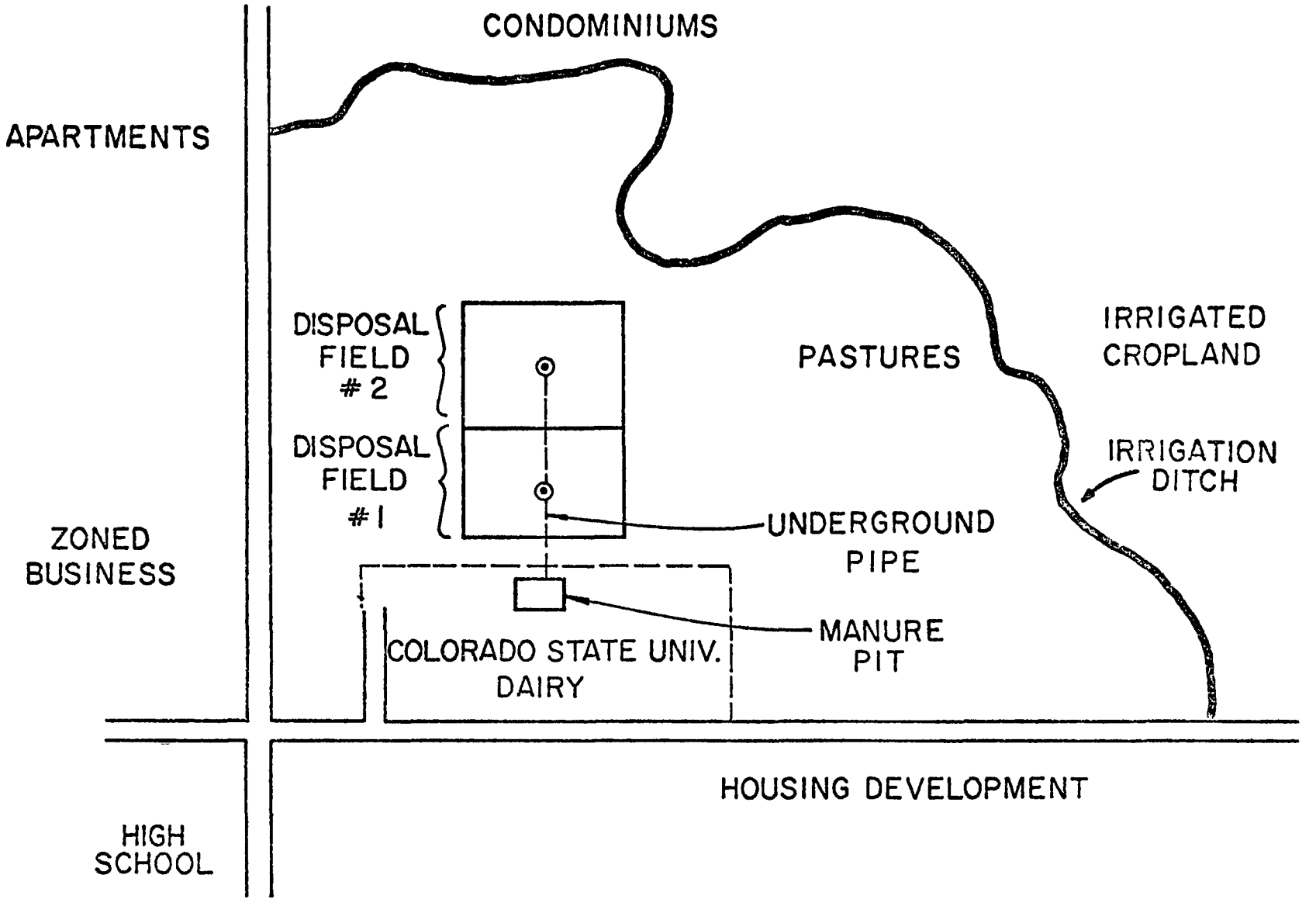

Figure 11. Colorado State University's Dairy location illustrating urbanizing nature of surroundings and proposed layout of a continuous subsurface injection system.

per cow per day (ASAE Standard No. R 345). To achieve a pumpable consistency (95%), an additional 0.057 cubic meter (2 cubic feet) of water must be added for a total of 0.114 cubic meter (4 cubic feet) per cow per day. This amounts to 114 liters (30 gallons) of liquid manure per cow per day or 11.4 kℓ (3,000 gallons) per day for the herd. For the year this totals 4.16 Mℓ (1.095×10^6 gallons) which must be injected. For the one hose connection, 555 kℓ/ha/yr (59,500 gallons/acre/year) need to be injected, while for the two hose connections, 278 kℓ/ha/yr (29,6000 gallons/acre/year) must be injected.

Assuming a pumping rate of 1,420 ℓ/min (400 gal/min) and an application rate of 266 kℓ/hr/pass (28,000 gallons/acre/pass), the one hose connection system would require a little over two passes per year. The two hose connections would involve slightly over one pass per year. Pumping 1,420 ℓ/min (400 gal/min) and having 4.16 Mℓ (1.095×10^6 gallons) to be pumped and injected at the same time, requires 45 hours per year. No time is involved in transportation or filling a portable tank. Using a 3,040 liter (800 gallon) capacity liquid spreader would require approximately 1,360 trips in one year or an average of 3.7 trips per day. The continuous injection system requires 7.5 minutes per day of actual injection. Assuming 30 minutes per trip for the liquid spreader, the savings are readily apparent.

SECTION VIII

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-117	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE CONTINUOUS SUBSURFACE INJECTION OF LIQUID DAIRY MANURE		5. REPORT DATE June 1977 issuing date 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. L. Smith, D. B. McWhorter, and R. C. Ward		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Colorado State University Fort Collins, Colorado 80523		10. PROGRAM ELEMENT NO. 1HB617 11. CONTRACT/GRANT NO. S-802940
12. SPONSORING AGENCY NAME AND ADDRESS Robert S. Kerr Environmental Research Lab. - Ada, OK Office of Research and Development U.S. Environmental Protection Agency Ada, Oklahoma 74820		13. TYPE OF REPORT AND PERIOD COVERED Final (1/74-12/76) 14. SPONSORING AGENCY CODE EPA/600/15
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

The research has involved the development and evaluation of an efficient, economical, continuous subsurface injection machine. The application site was instrumented so the quality of water percolating beneath the injection zone could be measured. Wells located around the sites were used to monitor groundwater quality. Soil samples were taken periodically to determine nutrients, salts, heavy metal concentrations, and bacteria movement and survival.

Major environmental problems were increased soil salinity and movement of fecal coliform to the groundwater. Both of these problems can be eliminated by proper management and site selection.

Subsurface injection is economically feasible when compared with other methods of land application. Although capital costs are greater for subsurface injection, labor costs are significantly reduced. Other advantages of subsurface injection are elimination of odors, insects, and visual pollution and minimization of runoff pollution.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Dairies; Fertilizers; Wastes; Injection; Pollution; Groundwater; Runoff; Salinity	Continuous subsurface injection machine; Groundwater quality monitoring; Soil nutrients; Fecal coliform	02/C

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 55
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U. S. GOVERNMENT PRINTING OFFICE: 1977-757-056/6457 Region No. 5-11