6-1983

Effects of Surface Application of Dairy Manure on the Infiltration Rate and Quality of Surface Runoff

Digital Object Identifier: https://doi.org/10.13023/kwrri.rr.138

Joseph L. Taraba
University of Kentucky, joseph.taraba@uky.edu

I. J. Ross
University of Kentucky

John D. Bottom
University of Kentucky

Bill J. Barfield
University of Kentucky

Repository Citation

Taraba, Joseph L.; Ross, I. J.; Bottom, John D.; and Barfield, Bill J., "Effects of Surface Application of Dairy Manure on the Infiltration Rate and Quality of Surface Runoff" (1983). *KWRRI Research Reports*. 65.
https://uknowledge.uky.edu/kwrri_reports/65

Research Report No. 138

EFFECTS OF SURFACE APPLICATION OF DAIRY MANURE ON THE INFILTRATION RATE AND QUALITY OF SURFACE RUNOFF

By

Joseph L. Taraba
Associate Extension Professor

I. J. Ross
Professor

Principal Investigators

John D. Bottom
Research Associate

Bill J. Barfield
Professor

Project Number: A-081-KY (Completion Report)

Ageement Numbers: 14-34-0001-0119 (FY-1980)
14-34-0001-1119 (FY-1981)

Period of Project: October 1979 to May 1983

Water Resources Research Institute
University of Kentucky
Lexington, Kentucky

The work upon which this report is based was supported in part by funds provided by the U.S. Department of the Interior, Washington, D.C., as authorized by the Water Research and Development Act of 1978. Public Law 95-467.

June 1983

DISCLAIMER

ABSTRACT

Title: Effects of Surface Application of Dairy Manure on the Infiltration Rate and Quality of Surface Runoff

Dairy manure was surface spread on 12 ft x 12 ft plots on an established fescue pasture in the summer and fall of 1981 and 1982. The soil was a Maury silt loam. A simulated rainfall was applied to plots to test the effects of nitrogen loading rate (75, 150, and 300 #N/acre) time delay between manure application and the simulated rainfall events (0, 3, 6, 24, 48, 96 hours and a 120 hour test repeated on 0 hr plot with 300 #N/acre), and type manure (semi-solid - 1981 and liquid - 1982) on the concentrations of pollutants in the surface runoff. The pollutants measured were COD, TSS, FSS, VSS, TS, FS, VS, NO_3, NH_4, N, P, and K. The simulated rainfall rates were 3.42 in/hr for 1981 and 4.02 in hr for 1982. The average field infiltration rate for the non-manured test plots were 3.40 in/hr in 1981 and 4.42 in/hr in 1982.

The infiltration rates of the manured plots were reduced by 5.8 to 15 percent for semi-solid manure and 23 to 31 percent for liquid manure for zero hour time delay plots. The infiltration rates increased to within 92 percent of the control plots after 120 hour time delay. The pollutant yields increased with nitrogen loading rate except for FSS yield which remained below the control plot yields. The NO_3 yields was below the control plot except for 300 #N/acre plots. The reduction in pollutant yields with increased time delay was found to average 46 and 76 percent for the 24 and 48 hour time delays for semi-solid manure and 75 and 94 percent for liquid manure. The yields for TSS, FSS and VSS for liquid manured plots did not exceed the control plot yields until after the 48 hour time delay.

Descriptors: Agricultural runoff,* animal wastes*, manure non-point pollution sources*, pollution load, soil treatment.

ACKNOWLEDGEMENTS

This project could not have been completed without the help of a large group of people:

Joe Redwine and his assistants Becky Bingner and Connie Deetz in the Agricultural Engineering Waste Analysis Laboratory; Agricultural Engineering summer students, Sam Hale, Ron Bunn, Robert Henson, Steve McManus and Marc Reid; Jim Crutchfield and his assistants Movella Jones and Maewanna Dye in the Department of Agronomy Plant Analysis Laboratory; Frank Button and his assistant Clyde Enlow at the Coldstream Dairy; and finally Coldstream farm managers Dave Smith, Robert Herrin and Darrel Campbell.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Application of animal manure to the land has long been an accepted means of waste disposal. However, the advent of close confinement livestock feeding operations with increased concentrations of manure have raised concerns in Kentucky about the environmental degradation of surface and ground waters in the handling and disposal of animal wastes that are produced. Approximately 38 million tons (3.5×10^{10} kg) of manure are being produced annually by domestic animals in Kentucky with 2 billion tons (1.8×10^{12} kg) produced nationally.

Presently animal waste from daily operations in Kentucky is stored and disposed of primarily in the solid and semisolid forms. High solids liquid manure application methods continue to increase in popularity on dairy farms as well as most swine operations. These alternative forms of manure handling allow management flexibility in utilization of manure as a fertilizer substitute. However, the applications of manure on land can increase the potential for pollution of surface waterways and groundwater if the site is inadequate to handle the manure application rate or if proper management methods are not followed.

Transport of potential pollutants from a manured field during a precipitation runoff event is by either attachment to suspended sediment particles or is in the soluble form in the runoff water. It is well known that clay soils and organic fractions of sediments have active surfaces that can react with an array of chemicals. The pollutants that are absorbed than have the potential to be carried in the runoff. Also, chemicals can go into solution without being attached to particles and can then be transported in the runoff water. Walter et al. (1979) states that eroded soil and soluble chemicals in the runoff are the principle sources of potential stream water pollutants. Wadleigh (1968) reports that approximately 4.4 billion tons (4×10^{12} kg) of sediment per year are deposited in U.S. streams. He also estimated that about 2.7 million tons (1.6 x 10^{10} kg) of phosphorus as soluble forms in the runoff water or as absorbed or attached fractions of sediment are washed into surface waters annually. Recently, the EPA has estimated that in eight southeastern states, which included Kentucky, the daily load to streams from nonpoint agricultural sources may include 1400 tons (1.24 x 10^7 kg) of total organic carbon, 160 tons (1.42 x 10^6 kg) of nitrogen, and 60 tons (5.33 x 10^5 kg) of phosphate (PO_4) from fertilizer and organic wastes. Therefore, it is reasonable to assume that with increased surface application of manure, the potential for higher concentration of pollutants in the runoff will also increase.

Passage of the 1972 Federal Water Pollution Control Act Ammendments, Public Law (PL) 92-500, mandated the control of nonpoint source pollution. Agricultural practices are a major contributor to both surface and subsurface water pollution. To understand why most agricultural practices are considered nonpoint sources of pollution it will be helpful to define what is meant by point and nonpoint sources. The term nonpoint source is descriptive of the manner in which pollution enters water, a source lacking a high degree of discreteness. On the other hand, a point source is any discernable confined conveyance, including but not limited to any pipe, ditch, conduit, well, container, concentrated animal feeding operation, or floating craft from which pollutants are or may be directly discharged into the receiving waters. Under section 304(e) of PL 92-500, runoff, from cropland and pasture on which manure is spread, is considered a nonpoint source of pollution which is required to be controlled. For this to be accomplished, section 208 and section 101(a) of the Act established a means for development of long term management plans to control potential nonpoint pollution sources.

The major constituents in runoff waters which are considered for pollution analysis are biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen (inorganic and organic forms), dissolved oxygen

(DO), total solids (TS), suspended solids (SS), dissolved solids (DS), and fecal coliforms, If levels of one or more of these pollutants in water analyzed near an agricultural source exceed regulatory limits, the Environmental Protection Agency (EPA) must, by law, either investigate the situation and determine possible solutions or eliminate the source by shutting down the operation. Therefore, it is imperative that farmers become aware of pollution potential from their lands.

Several research projects have dealt directly with the pollutant runoff problem. McCaskey, et al. (1971) and Overcash (1976) noted that different application rates of manure yield varying degrees of pollutant runoff concentration. More specifically, they found that plots receiving low rates of applied dairy wastes did not contaminate surface water as much as plots receiving higher rates of application. Further, it has been shown that varying waste management schemes can alter pollutant yield in runoff water. Observations, made by Timmons and Holt (1973), indicated that nutrient losses from cropland were highest when there was no incorporation of applied fertilizer, intermediate with fertilizer broadcast on plowed ground and then disked, and least when the applied fertilizer was plowed under and disked before simulated rainfall events. Wendt and Corey (1980) hypothesized that management practices which reduce soil erosion and runoff, such as conservation tillage, would reduce the pollution potential of runoff from cropland and therefore would reduce the overall environmental impact of agriculture on water quality.

A project completed by the Agricultural Engineering Department of the University of Kentucky, (Ross et al. (1978)), has shown that injection of manure into the soil essentially eliminates pollutants in the runoff from test plots when compared to surface application of liquid dairy manure on 3 to 6% slopes. For example, the concentration of COD in the first liter of runoff from sodded 9 ft. x 9 ft. plots receiving a surface application of liquid dairy manure, followed immediately by simulated rainfall, was 72-fold greater than the COD in the first liter of runoff from plots on which the manure was injected into the soil to a depth of 6 inches. Likewise, the total COD yeild in the first 100 liters of runoff from the 9 foot square plots was 17 times greater for surface applied plots than for 6 inch injected plots. These results show that injection is extremely effective in improving the quality of surface runoff. The same study indicated that runoff from plots receiving surface applications of liquid dairy manure was affected by the time delay between the manure application and the simulated rainfall. The first liter of runoff during a simulated rainfall immediately following application of manure to sodded plots contained approximately 7200 PPM of COD, 450 PPM of N, 7300 PPM of TS, 6×10^5 colonies of fecal coliform per 100 ml. A 24 hour delay between the time of liquid manure application on the rainfall event reduced the concentration of these water quality indicators by 80% to 97%. These results show the effectiveness of reducing pollutants in runoff by applying manure to soils at time when rainfall is not expected for one or more days. A regression analysis of the data in this study indicated that pollutant concentrations of COD, total N, and total solids; taken as a percentage of the total pollutant applied, in the runoff, from plots receiving surface application of liquid manure and was a function of the total quantity of runoff from the plots. More specifically they found the following relationships with corresponding regression coefficients (r^2).

$$\begin{aligned} COD &= 0.4958\, R^{-0.6838} & r^2 &= 0.95 \qquad (1)\\ N &= 0.5788\, R^{-0.6726} & r^2 &= 0.97\\ TS &= 0.5177\, R^{-7962} & r^2 &= 0.91 \end{aligned}$$

where,

COD = Percent of COD applied/liter of runoff
N = Percent of N applied/liter of runoff
TS = Percent of TS applied/liter of runoff
R = Liters of runoff.

Sharpley, et al. (1981a, b, c), Chien and Clayton (1980), and

Westerman and Overcash (1979, 1980) observed and predicted similar results. Sharpley and his colleagues found an inverse linear relationship between soluble P concentrations and the log of the sediment concentration in the runoff from several cropped and grassed watersheds. This relationship existed over a wide range of sediment concentrations. Similar results were found in different watersheds with the same soil type. Chien and Clayton used a modified Elovich equation to describe phosphate released from and sorption to soils. The equation consisted of two first-order kinetic reactions that successfully described data as a straight line for the entire reaction time involved. Westerman and Overcash developed regression fits of a simple power function to establish total nutrient loss during a rainfall event from plots with surface applied waste. The equation was of the form $M = BQ^A$ where M is the average concentration of the pollutant under study, Q is the runoff volume collected, and A and B were fitted constants.

Research has also been conducted showing the effects of time delays from manure application to a rainfall event on the percentage of the applied pollutants found in the runoff. Reddy, et al. (1979a, b), Reddy, et al. (1980a, b), Khaleel, et al. (1979a, b, c), Reese, et al. (1981), Steenhuis, et al. (1979), Frere, 1975 and others have shown that manure decomposition by microbial action in the soil and weathering follows a first-order decay relationship as it applies to time from the initial manure application where the runoff pollutant concentrations are shown as a percentage of the total pollutant collected during the rainfall event which is a function of the amount of pollutant applied to the test area. It is reasonable to assume from the above observation, that if sufficient time is allowed to ellapse between manure application and a rainfall event, pollutant potential will be reduced in the runoff. Thus time delay can be considered a management practice useful in reducing agriculture as a pollutant contributor.

Therefore, the purpose of the research project for which results are presented in this report was to measure and to evalute quantitatively the pollutants' concentration in runoff generated by a simulated rainfall event as affected by the form of the dairy manure applied, the nitrogen loading rate and the time delay between manure application and the rainfall event. The plots are on an established pasture planted with fescue grass. The specific objective of this project are:

1. To assess the statistical relationship(s) between the total pollutant yield in the runoff and nitrogen loading of dairy manure on the plots, form of the dairy manure (semi-solid or liquid), and the time delay between manure application and the simulated rainfall event.

Also, presented in this report is an objective developed during the research phase:

2. To assess the saturated or steady state infiltration rate of the manured plots during a simulated rainfall event as affected by the same parameters cited in objective 1.

CHAPTER II

RESEARCH PROCEDURES

Introduction

The effects surface application of dairy manure that have on runoff water quality and infiltration rates of an established pasture were tested using a series of experiments described in this chapter. Runoff was collected from a 12 foot square (13.378 m^2) field plot on which dairy manure had been surface applied. The variables that were tested to determine the effects manure application on runoff water quality were: form of manure, the nitrogen loading rate, and time delay to simulated rainfall. A runoff hydrograph was developed during the simulated rainfall test and samples were taken for later analysis of pollutants. Also, experiments were conducted to obtain the soil moisture characteristics which were required inputs for infiltration analysis. Finally, the collected data was statistically analyzed using techniques found in SAS (Statistical Analysis System) (1979).

Plot Design and Location

The runoff test plots were enclosed with sheet metal borders on three sides to form 12 foot square plots as illustrated in Figure 1. These plots were set on an established pasture hillside located on the University of Kentucky Coldstream Farm near Lexington. The grass was primarily fescue. Time delay plots corresponding to a given nitrogen loading rate and replication were grouped together in the test area. The placement of the plot groups for the various nitrogen loading rates and the replications were selected randomly on the slope. Plot locations for each test year are presented in Figure 2 (1981 plots, using semisolid manure) and Figure 3 (1982 plots, using liquid manure). Tables 1 and 2 identify the experimental conditions for plots shown in Figures 2 and 3, respectively. Also shown in these Figures is a topographic

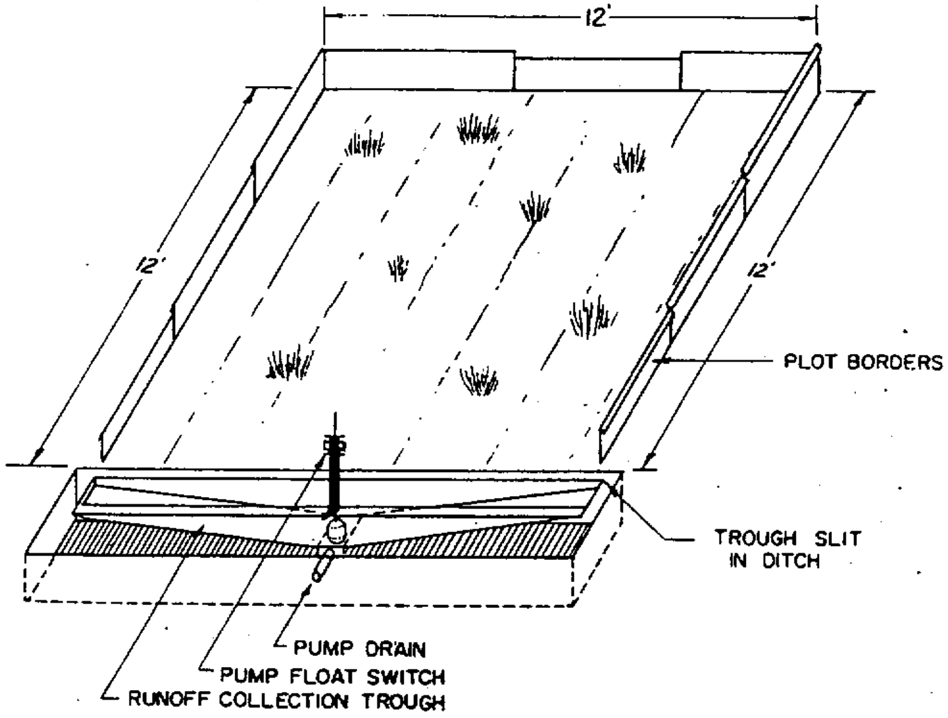

FIGURE 1: TEST PLOT BORDERS AND COLLECTION TROUGH

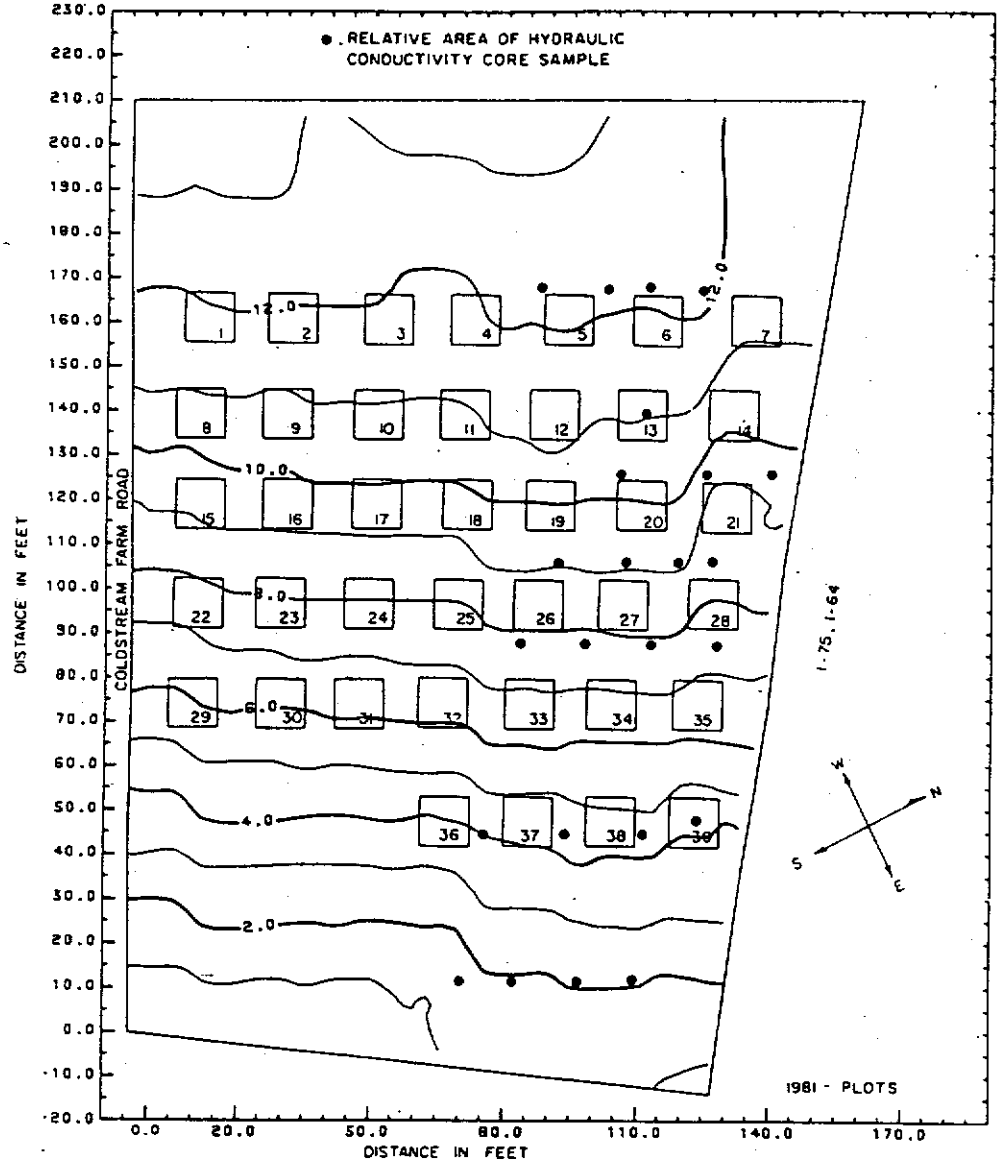

FIGURE 2: TEST PLOT MAP ON PASTURE-
1981

TABLE 1. 1981 PLOT IDENTIFICATION CORRESPONDING TO FIGURE 2

Plot Number	Date	Nitrogen Loading Rate (# N/acre)	Time Delay Before Rainfall (Hrs)	Replication
1	*	75	48	1
2	7/10/81	75	24	1
3	7/9/81	75	0	1
4	7/7/81	0	0	1
5	7/20/81	150	0	1
6	7/20/81	150	3	1
7	7/20/81	150	6	1
8	8/14/81	0	0	2
9	7/31/81	300	48	1
10	7/30/81	300	24	1
11	7/29/81	300	0	1
11	8/5/81	300	240	1
12	7/22/81	150	48	1
13	7/23/81	150	72	1
14	7/24/81	150	96	1
15	8/25/81	150	24	2
16	8/24/81	150	6	2
17	8/24/81	150	3	2
18	8/24/81	150	0	2
19	8/21/81	75	72	2
20	8/20/81	75	48	2
21	8/18/81	75	0	2
22	10/12/81	150	3	3
23	9/29/81	0	0	4
23	10/12/81	150	0	3
24	10/2/81	300	48	2
25	10/1/81	300	24	2
26	11/4/81	0	0	3
26	9/30/81	300	0	2
26	10/9/81	300	240	2
27	8/26/81	150	48	2
28	8/31/81	150	192	2
29	10/16/81	150	96	3
30	10/14/81	150	48	3
31	10/13/81	150	24	3
32	10/12/81	150	6	3
33	10/21/81	75	0	3
34	10/22/81	75	24	3
35	10/23/81	75	48	3
36	*			
37	10/30/81	300	48	3
38	10/29/81	300	24	3
39	10/28/81	300	0	3
39	11/6/81	300	240	3

---

*Plot identifications without a date specified were not run.

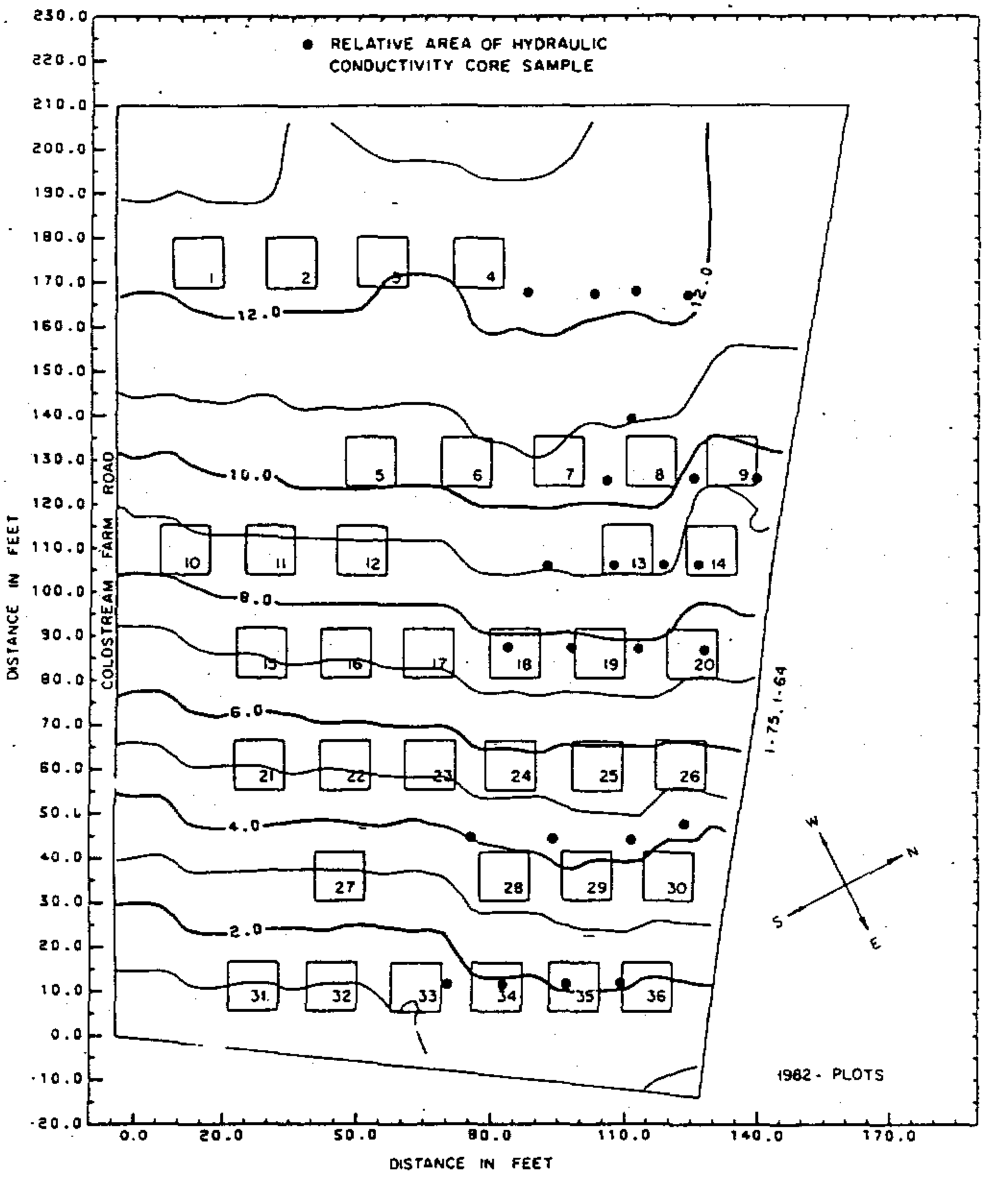

FIGURE 3: TEST PLOT MAP ON PASTURE-
1982

TABLE 2. 1982 PLOT IDENTIFICATION CORRESPONDING TO FIGURE 3

Plot Number	Date	Nitrogen Loading Rate (# N/acre)	Time Delay Before Rainfall (Hrs)	Replication
1	6/26/82	0	0	1
2	7/12/82	75	0	1
3	7/13/82	75	24	1
4	7/14/82	75	48	1
5	7/27/82	150	24	1
6	7/26/82	150	6	1
7	7/26/82	150	3	1
8	7/26/82	150	0	1
9	8/3/82	75	0	2
10	8/12/82	300	0	1
10	8/17/82	300	120	1
11	8/13/82	300	24	1
12	8/14/82	300	48	1
13	*			
14	8/4/82	75	24	2
15	9/9/82	75	48	3
16	9/8/82	75	24	3
17	9/7/82	75	0	3
18	8/18/82	300	0	2
18	8/23/82	300	120	2
19	8/19/82	300	24	2
20	8/20/82	300	48	2
21	9/20/82	150	6	2
22	9/20/82	150	3	2
23	9/3/82	0	0	2
23	9/20/82	150	0	2
24	9/21/82	150	24	2
25	9/22/82	150	48	2
26	9/23/82	150	72	2
27	10/21/82	0	0	3
28	9/29/82	300	0	3
28	10/4/82	300	120	3
29	9/30/82	300	24	3
30	10/1/82	300	38	3
31	10/5/82	150	0	3
32	10/5/82	150	3	3
33	10/5/82	150	6	3
34	10/6/82	150	24	3
35	10/7/82	150	48	3
36	*	150	96	3

*Plot identifications without a date specified were not run.

representation of the natural contours of the test area. This representation indicates a variation of the slope in the range of 4 to 8 percent on the test field.

Borders were driven at least 3 inches into slits cut into the sod to divert runoff water from manured plots during naturally occurring natural rainfall events and runoff from the simulated rainfall falling outside the plot borders. Also the borders served to retain simulated rainfall within the borders so that it could be collected.

A trough located on the downslope edge of the plot was used to collect runoff for pollutant analysis and runoff rate determination. A detailed description of the collection devices used in this process follows in a later section. Validation of the plot borders effectiveness was accomplished by flushing several barrels of water upslope from the plots. The borders proved effective in diverting runoff from the enclosed area using this procedure.

Runoff from test plots was collected in a covered trough which spanned the entire downhill end of the plot. A ditch was dug across the lower end of the plot to hold the trough. Care was taken to make a smooth, straight cut at the upper edge of the plot. A standard sod cutter was used to accomplish this task. The method used in preparing the ditch and trough set-up is shown in Figure 4. Sod was removed from a 1 foot by 14 foot section of ground parallel to the contour of the hill side. Soil was removed from this exposed area to form a 1 foot deep ditch. The upper edge of the ditch was made straight and smooth using a sod cutter. To enable the trough to be placed into the ditch, a slit was cut into the upslope smooth edge of the ditch approximately 2 inches below the soil's surface. The trough was placed in the ditch with the lip being slid into the slit as illustrated in Figure 1. This ensured that collection of runoff was limited to the surface layer above the troughs leading edge.

Manure Application

Manure for the experiments was obtained from the University of Kentucky's Coldstream Dairy Farm on which the experimental test plots

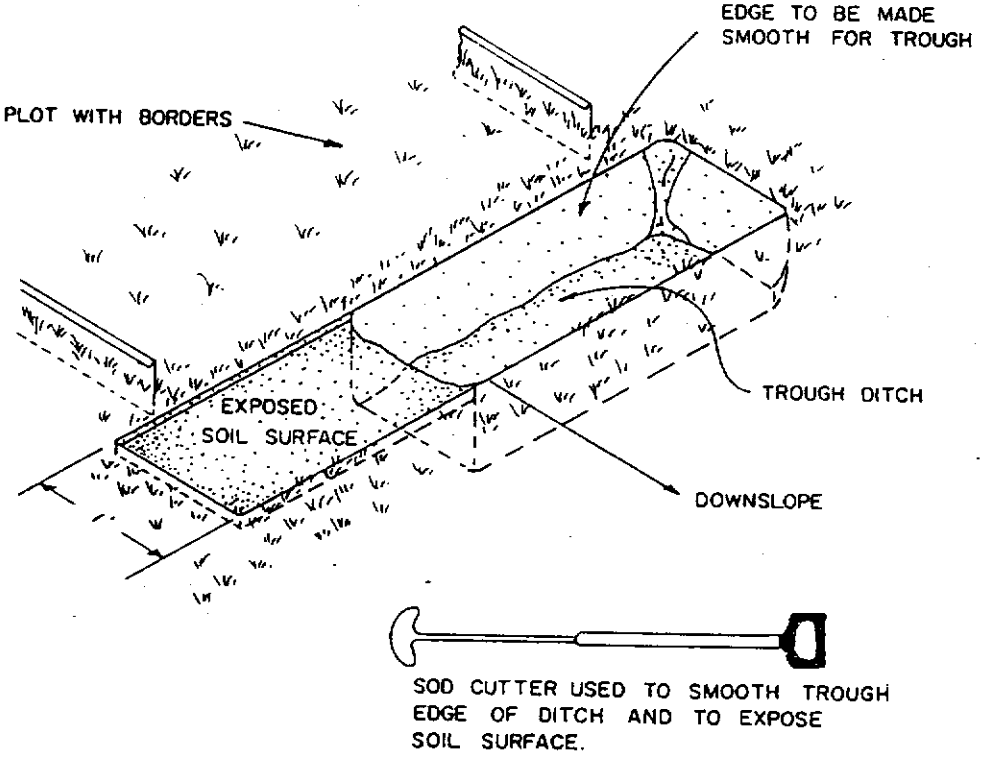

FIGURE 4: TROUGH DITCH CONSTRUCTION

were located. The dairy herd is made up of Holstein and Jersey cows and are fed a typical dairy ration on a concrete open lot. Manure was in two forms: semi-solid (15-25% solids) scraped from the concrete floor and liquid manure (4-7% solids) obtained from an above ground liquid manure tank. The plots with semi-solid manure were tested from July to October 1981 and the liquid manure plots were tested from July to October 1982. Well mixed grab samples of the dairy manure were taken to determine total Kjeldahl nitrogen (Standard Methods, 1975) to determine the amount of semi-solid of liquid dairy manure that was applied to a test plot to obtain a nitrogen loading rate of 75, 150, or 300 pounds per acre. The total nitrogen concentrations were found to be 3.55 pounds nitrogen per 1000 pounds (wet weight) for semi-solid manure and 2.13 pounds nitrogen per 1000 pounds (wet weight) of liquid dairy manure. The time delay between manure application to the plot and the simulated rainfall event varied with nitrogen loading. The time delays were 0, 24 and 48 hours for 75 pounds nitrogen per acre; and 0, 3, 6, 24, 48 and 96 hours for 150 pounds nitrogen per acre; and 0, 24, 48, 96 hours with a repeat rainfall simulation onto the 0 hour plot at 96 hours for the 300 pound nitrogen per acre plots. Three replications were run.

Manured plots onto which the delayed simulated rainfall was to be applied at 24 hours or later were covered with a 14 foot square wooden frame covered with 6 mil clear plastic, as illustrated in Figure 5. The covers were angled to prevent condensation falling on the plots and elevated to allow aeration of the manure and soil for natural drying.

Semi-solid Manure was collected directly from a feedlot floor located on the Coldstream Dairy using a front-end loader. The amount of manure needed for each test plot was determined for each nitrogen loading rate. From the tests of the nitrogen content of the manure. The collected manure was weighed for each application rate before it was spread onto the time delay plots for a given nitrogen loading and replication. The technique used in spreading the semi-solid manure consisted of manually applying the weighed manure samples to the surface of each plot making sure of a uniform coverage to simulate that obtained from a

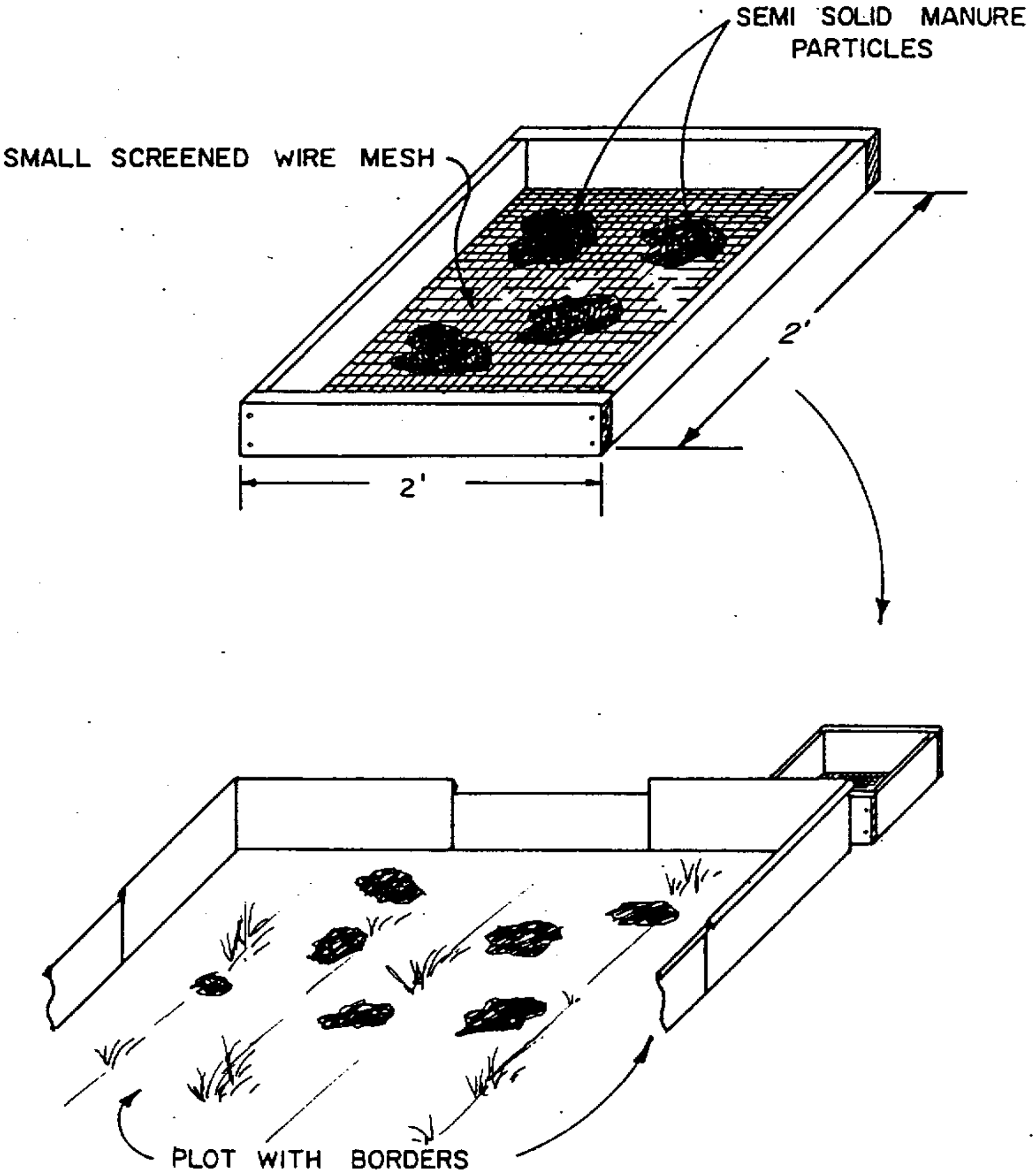

FIGURE 5: TEST PLOT COVERS

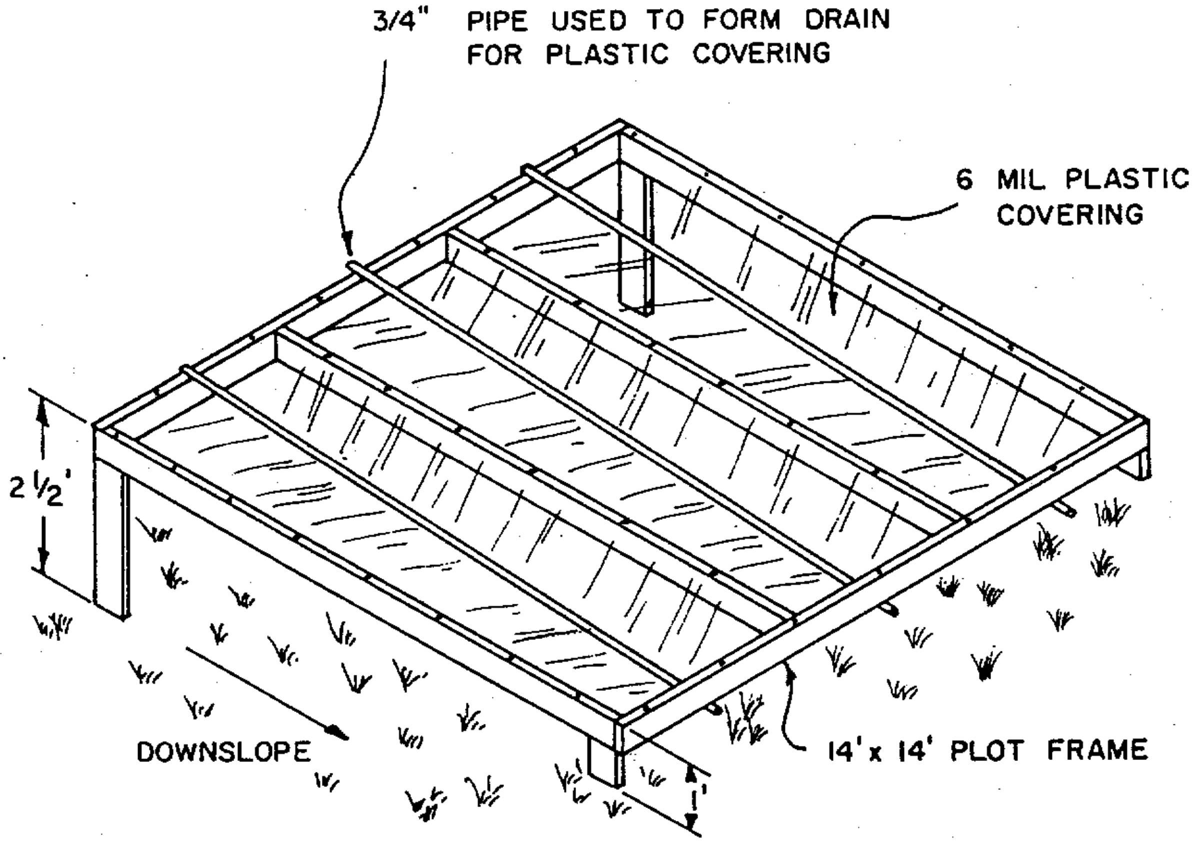

FIGURE 6: MANURE WEATHERING SAMPLES

standard manure spreader. After spreading was completed, an extra amount of manure was applied to a wire screen box located behind each test plot as illustrated in Figure 6. These samples were collected for analysis just prior to a simulated rainfall event for each time delay plot to determine the pollutant constituents in the manure as it existed on the plot at the beginning of the rainfall event.

Liquid Manure was obtained from one of two 82,000 gallon covered above ground storage tanks located on the Coldstream Dairy Farm. The manure and feed floor runoff were collected over a two month period prior to the testing period. The manure tank was agitated and manure was drained from this tank into a holding pit where it was thoroughly mixed by a chopper pump. The manure was screened through two screens (one inch and one-quarter inch) of hardware wire mesh to eliminate straw and large wood chips, which would clog the centrifugal pump used for spreading the manure. The liquid manure was weighed out for each plot for a given nitrogen loading rate based on a total nitrogen test. The weighed out manure was spread on the soil surface by the device illustrated in Figure 7. The splash plate on the outlet side simulated distribution from a liquid manure tank with a splash plate. Samples of the manure spread onto the plots were taken before distribtuion on the test plots to determine the actual nitrogen loading rates and to analyze the samples for all the pollutant constitutents. All of the time delay test plots were covered with the manure for a given nitrogen loading and replication before the runoff tests began.

Control Plots were set aside each year on which no manure was applied. Each year, three to four plots, distributed throughout the field were used to establish the background concentrations of the pollutants under study. On the average, one plot was tested each month.

Initial Soil Moisture of each test plot at the time of manure application was near field capacity. A city water source was utilized to saturate the plots for 10 to 24 hours prior to manure application. In addition, plots at field capacity would give a worst case condition of a precipitation runoff event since the time to surface ponding of the soil would be near the minimum and as a result, maximum pollutant concentrations

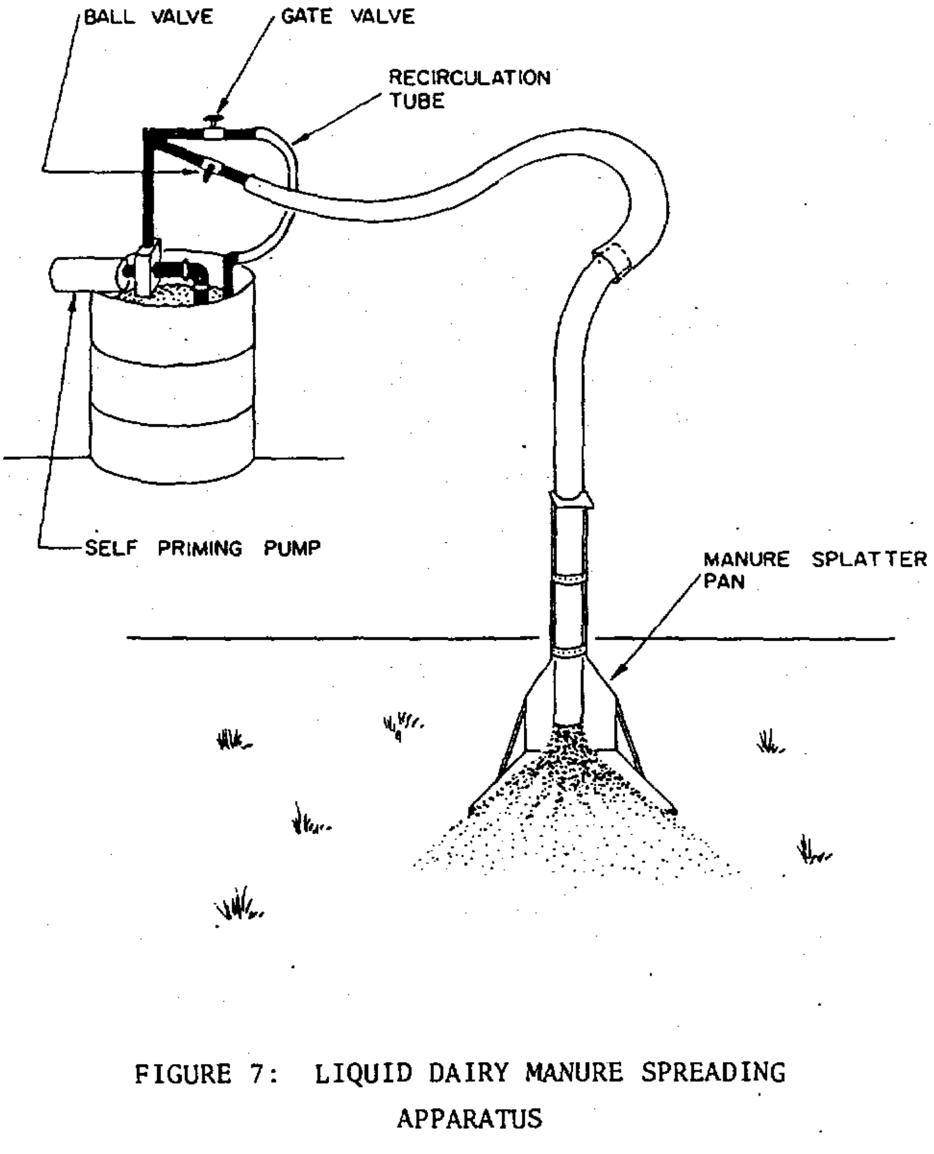

FIGURE 7: LIQUID DAIRY MANURE SPREADING APPARATUS

would likely be observed. Further, the earliest that a farmer can spread manure is when the fields are at or below field capacity.

Rainfall Simulation Apparatus and Calibration

The rainfall simulation apparatus used for these tests is similar to that presented by Hirschi, et al. (1981) and Williams, et al. (1978). The rainfall simulator provides the kinetic energy intensity, raindrop size, and raindrop fall velocity similar to natural rainfall events. The rainfall simulator used throughout the experiments is pictured in Figures 8 and 9. The rainfall pattern produced by this rainfall simulator is shown in Figure 8. Not shown in the diagrams is a screen material that completely enclosed the rainfall simulator to reduce wind drift of the simulated rainfall during testing.

Rainfall rates were determined using two methods. First, a relative rainfall rate was established from three standard rain gauges placed inside the plot during actual testing. Second, rainfall rates were obtained by noting the average number of pulses the rainfall simulator made per minute. A pulse was considered to be one sweep of the simulated rainfall over the plot area (Note: Hirschi, et al., 1981). Because pulse data was considered to be more reliable in determining rainfall rates, calibration of the field data was achieved by applying rainfall to a 12 foot square plastic plot cover (similar in design to Figure 5) for a given time period at several pulse rates covering a range of rainfall rates and pulse rates. The slope of the plot cover was sufficient to give zero storage of surface water so that all the water applied could be collected. The collected water volume per total time was determined. Several replications were used for the calibration to establish the inches of rainfall in an hour for various pulse rates.

The average simulated rainfall rate applied to the plots of semi-solid manure in 1982 was 3.42 inches/hour and a rate of 4.02 inches/hour was applied to liquid manure plots in 1982. The increased rainfall rate in 1982 was necessary because the average infiltration rate of the test field was found to increase from 2.08 inches/hour to 3.48 inches/hour.

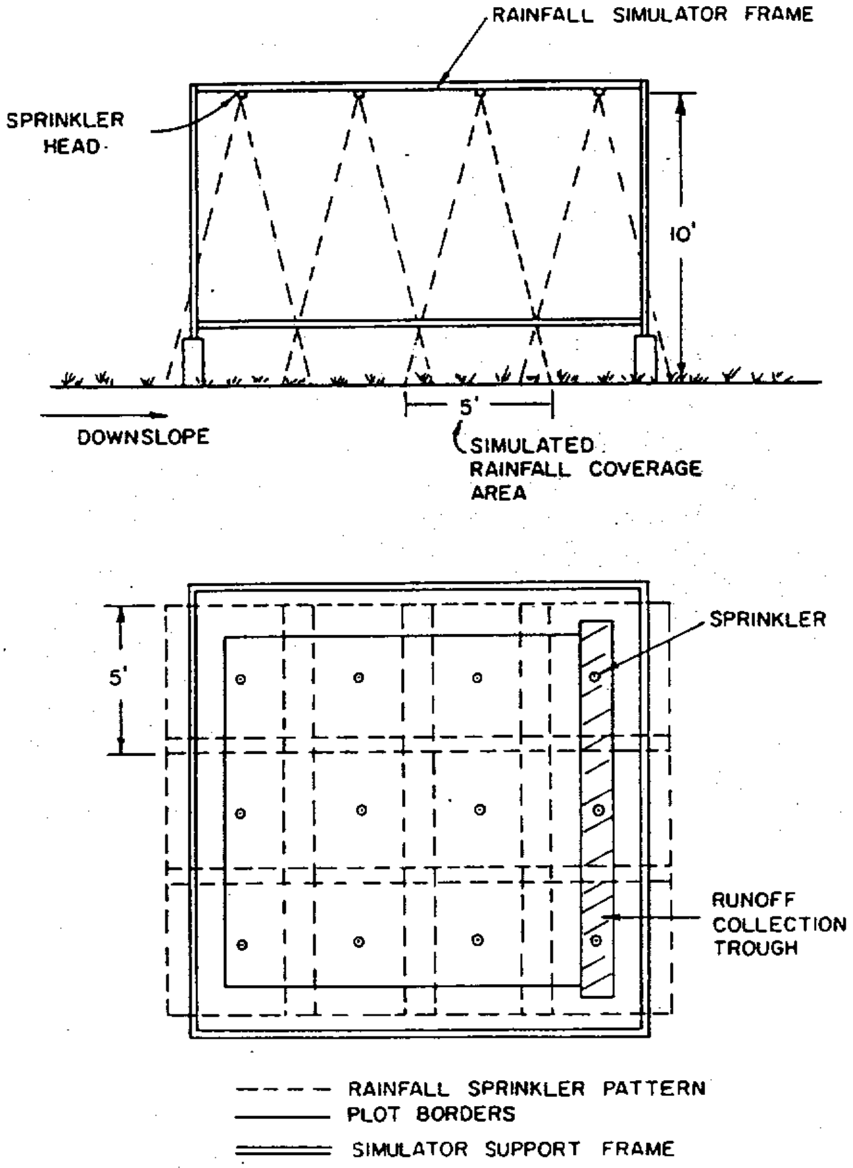

FIGURE 8: RAINFALL PATTERN OF RAINFALL SIMULATOR

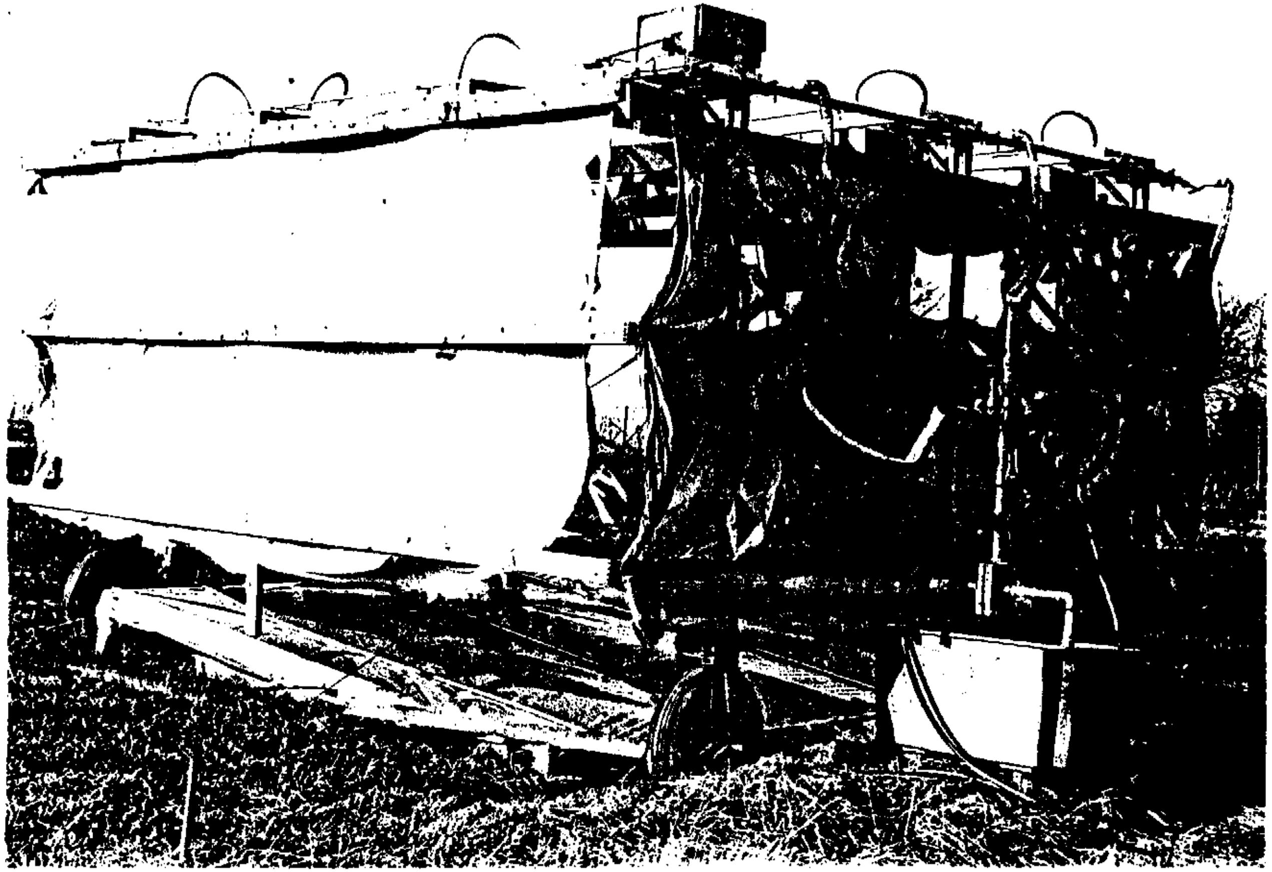

FIGURE 9: PHOTOGRAPH OF RAINFALL SIMULATOR

Since the longest duration of time for a simulated rainfall test on a plot is dictated by the shortest time between successive time delay plots (3 hours for the 150 lbs N/acre plots), the simulated rainfall rate had to be increased in 1982 so that all the plots were comparable. The details of the infiltration rates are noted in the Data and Results section.

Runoff Rate Determination and Pollutant Sample Collection

The runoff collection trough was designed to force collected runoff water from the bordered test plot in the trough, to the middle. At this point, a self priming marine utility pump was attached as indicated in Figure 1. The level of runoff water in the collection trough was maintained by a float and switch mechanism that activated the marine pump. When approximately one liter of runoff was collected in the trough, the float switch would activiate the pump. Runoff water was pumped from the trough into a sampling cylinder shown in Figure 10. Located inside the cylinder was a float switch mechanism similar to the one found in the collection trough. When 1 liter of runoff water was pumped into the sampling device the switch was activated which opened a solemoid valve to empty the cylinder and started a timer mechanism that was overriding the trough float switch controlling the pump. After the runoff water was drained passed the solemoid valve into either a sampling bottle or onto the gound for disposal, the time mechanism deactivated the solenoid valve and reactivated the trough float switch and marine pump of the sampling mechanism, thus completing one cycle which was equivalent to one liter of runoff from the test plot.

When the cylinder (sampling device) float switch activated an event counter was indexed to count the number of liters of runoff obtained. This made possible the collection of samples for chemical analysis after selected volumes of runoff. Usually one liter samples were collected at counts 1, 20, 40, 60, 100, and 150 liters. Depending upon the infiltration rate of the plot being tested, the time span between sampling varied. To establish runoff hydrograph data, time was usually recorded by a wrist

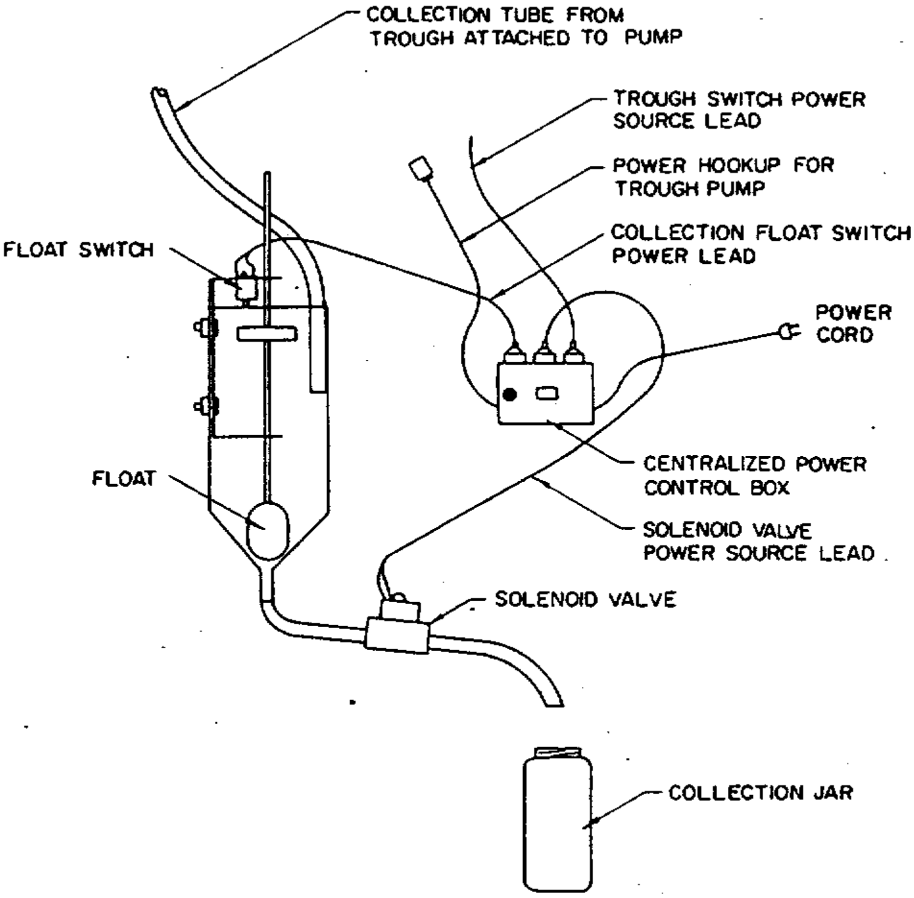

FIGURE 10: RUNOFF SAMPLING CYLINDER

watch with the second hand as each liter passed through the solenoid valve on the sampling device and at the beginning and end of the rainfall event. Once the samples had been collected they were transported in ice to the Department of Agriculatural Engineering Analytical Laboratory.

LABORATORY TEST PROCEDURES

Runoff water from the test plot was collected in one liter Nalgene plastic containers for chemical analysis. The containers were immediately sealed and placed into a sytrofoam cooler filled with crushed ice. Once the rainfall event ceased, the rainfall simulator was readied for the next test plot and soil moisture samples were collected in Nalgene plastic containers and placed in ice. This process took approximately fifteen minutes and once completed, samples were transported ten miles from the Coldstream Dairy Farm research facility to the Agricultural Engineering Analytical Laboratory on the University of Kentucky's main campus. In the waste laboratory samples were separated into two 500 ml Nalgene plastic containers for each collected runoff smaple. These separated samples were stored at just above freezing until analyzed.

Each runoff sample was analyzed for chemical oxygen demand (COD), nitrogen as nitrate (NO_3), nitrogen as ammonia (NH_3), total Kjeldahl nitrogen (TKN), total phosphorus (P), total potassium (K), total suspended solids (TSS), fixed suspended solids (FS), and volatile solids (VS). Samples to be analyzed for COD were extracted from containers filled with runoff waste water and acidified with concentrated sulfuric acid to eliminate further bacterial decomposition. Two methods were used in the analysis of COD during the test period. In 1981 samples were analyzed using procedures described by Standard Methods, (1975) modified for 20 ml samples. During 1982, COD was analyzed using the micro COD digestion procedures as described in the Hach Company Technical Information Series - Booklet Number 8 modified to use lab-filled Corning 9826-16 (16 x 100 mm) culture tubes with teflon lined screw caps and read on a Bausch and Lomb Spectronic 20. Potassium acid phythalate in distilled water at concentrations of 15, 30, 45, 60, 75, 100, 120, 150, 180, 240, 300, 480, 750, 1000, 1200 and 1500 ppm was regressed and used during 1982 to calibrate the procedure.

Nitrate and NH_3 were analyzed from the original runoff sample within three hours of their arrival at the waste laboratory. Eighty milligrams of runoff solution was weighed out and allowed to warm to room temperature before analysis. Nitrate was analyzed using the known addition method with an Orion Nitrate Ion Electrode, Model 92-07 and an Orion Digital Ionalyzer, Model 701A (Orion Manual, 1971). Standardization of the ion probe was made using dilluted Orion standards at 1, 10, and 100 ppm of NO_3 as N with phenyl mercuric acetate as a stabilizer for each set of runoff samples. Ammonia was determined using the standard curve method with an Orion Ammonia Electrode, Model 95-10 and Orion Digital Ionalyzer, Model 701A (Orion Manual, 1974). Standardization of the ion probe was made using dillutions of an Orion standard (1000 ppm NH_3 as N).

Samples to be analyzed for TKN, P, and K were stored at just above freezing for periods of 1 to 3 months before analysis was performed at the Agronomy Soils Laboratory located in the Agricultural Science Building North on the University of Kentucky's main campus. TKN was analyzed using the total Kjeldahl nitrogen method modified for aqueous solutions as described by Bradstreet (1965). Titration of the distilled samples used a 0.714 N sulfamic acid solution for the nitrogen determination. Deionized water was used as a blank for all runoff samples during the testing period. Phosphorus was analyzed using 35 ml samples taken from digested Kjeldahl nitrogen samples as described in Fiske and Subbarow (1925). Using a Technicon, Auto Analyzer I, samples were tested for P using the method in the Technicon Auto Analyzer I Manual (1965). Solutions of sodium phosphate, monobasic, diluted (Na_2HPO_4) in Kjeldahl.blank solution to give concentrations of 2, 4, 8, 12, 16 ppm of P was used for procedure calibration. K was obtained from the digested samples and the sample was filtered through number 1 and number 42 filter paper before analysis on a Varian AA-6 Atomic Adsorption which was interfaced with a

HP 981A calculator. The atomic adsorption apparatus was calibrated using dilutions of a standard 1000 ppm K stock solution from Fisher Scientific to cncentrations of 1, 2, 3, 4, 5 ppm K or 2, 4, 6, 7, 10 ppm K. Analysis for TSS, FSS, VSS, TS, FS, and VS used procedures described in Standared Methods (1975) for samples that had been stored at just above freezing for periods of 1 to 2 weeks. TSS was analyzed using methods 208 D modified for a single 24 hour drying period at 103 to 105°C. FSS and VSS were analyzed using method 208 G, 3, b, 3) and 4) modified to use blank corrections for non-ignited filter disks and a one hour residue ignition. TS was analyzed using method 208. A modified for a single 24 hour drying period at 103 to 105°C. Finally, FS and VS were analyzed using method 208 E, modified for a one hour ignition at 550°C.

Along with testing of the runoff sample, samples of manures taken from the plots and from the manure, were analyzed for all of the pollutants and solids content previously described. To ensure accuracy of results of the analyical procedures used for the runoff and manure samples, careful attention was taken to follow storage and analysis procedures of Standard Methods (1975).

FIELD AND LABORATORY SOIL ANALYSIS

The infiltration and runoff processes are directly related to soil physical properties determined from soil samples taken in situ and analyzed in the lab. To determine soil moisture from the testing plot area, soil samples were taken just before each simulated rainfall event started and during 1982 just after the rainfall event ended. Soil samples were taken 6 to 7 inches outside the bordered plot area being tested. The sample depth was approximately one inch below the soil surface. The samples were placed into 500 ml Nalgene plastic containers, sealed, and placed into a sytrofoam cooler filled with ice until transported to the University of Kentucky's Agricultural Engineering Waste Laboratory. Samples were stored for periods of one to three months just above freezing until analyzed for moisture content by weight using Methods of Soil Analysis (1965) (MSA).

Other parameters used in this evaluation of the infiltration and runoff rates of soils are the saturated hydraulic conductivity, bulk density, and saturated moisture content of the soil. Estimates of these parameters were determined by extracting undisturbed soil cores from the test plot field on the Coldstream Dairy Farm during 1982 (soil core locations shown in Figures 2 and 3) using a 3 inch high, 3 inch diameter aluminum pipe in a standard core sample. The extracted soil cores were placed in waxed cardboard containers and sealed for transport and storage. Saturated hydraulic conductivity was determined by setting the soil cores in a device similar to the classical device used by Darcy in his annlysis of water flow through a soil medium as illustrated in MSA (1965). The method included saturating the cores for 48 hours before water was forced through the soil by increasing the head of water to a constant level above the top of the core. Once a constant head was established, the volume of water collected from the water flow through the cores over a thirty minute period was determined. Three replications were completed for each core and the saturated hydraulic conductivity was estimated using Darcy's classical flow equation. Upon completion of saturated hydraulic conductivity tests, the cores were immediately weighed on a top loading scale and dried for 24 hours using procedures found in MSA (1965) for determination of moisture content by weight. Since the cores were at saturate before drying, the moisture content obtained is the saturation moisture content of the soil. Also, knowing the dimensions of the core being dried, bulk density was determined by dividing the volume of the core by the change in weight of the core before and after drying.

Disturbed soil was obtained from the test plot field and analyzed for soil moisture content and matric suction potential. Soil was placed in one inch diameter rings on a permeable pressure plate that could be saturated with water for a twenty-four hour period before pressure was applied. Tests were replicated using ten soil filled rings at pressures of 1, 2, 3, 5, 10, and 15 bars following procedures found in MSA (1965) for determination of water retentivity of soil at specifed values of matric potential. After pressure had been applied for forty-eight hours, it was released and the disturbed cores were taken from the pressure plate, weighed, and dried to determine moisture content at the various pressures. From the data obtained, a moisture-suction curve was established to determine the average suction of the soil profile and relative hydraulic conductivity for the soil at a known moisture content.

CHAPTER III

DATA AND RESULTS

INTRODUCTION

Research findings over the last few years has changed much of the basic considerations relating to the application of animal waste to agricultural land to reduce the pollutants in the surface runoff during a rainfall event. Typically, the research conducted used field trials on various types of wastes, crops, and land use conditions. Runoff pollutant data obtained in this manner was either directly reported in the literature, or an attempt was made to statistically analyze the data. The most frequent problem with these types of analysis are that an extensive data base was not created for a thorough analysis of process dynamics or process fundamentals of pollutants in the runoff water. As a means to eliminate this problem, extensive field trials were conducted under controlled experimental conditions and the results are reported in this report.

This chapter will deal with many of the soil parameters needed to evaluate the infiltration process as it is effected by the type of manure applied, the nitrogen loading on the test plots, and the time delay from the initial manure application until a simulated rainfall event is applied to the test plot. The soil parameters which are considered on each plot are the saturated moisture content, saturated hydraulic conductivity, bulk density, matric suction potential, and field saturated hydraulic conductivity. All data was statistically tested for significance using methods described is SAS (1979), and then utilized in evaluating the infiltration process.

A statistical evaluation of pollutant runoff data from test plots with surface applied dairy manure is presented. Runoff samples were collected and analyzed for various pollutants as previously described. This data was statistically fit to an exponential decay function to evaluate total pollutant carried in the runoff during a rainfall event as compared to the total amount of pollutant applied to the test plot. The total amount of pollutant carried in the runoff from each plot was then statistically analyzed for significant differences considering time delay, replication, manure loading, and manure type.

INFILTRATION ANALYSIS AND PARAMETER DETERMINATION

Saturated Hydraulic Conductivity

Twenty-four undisturbed soil cores 7.62 cm (3 in) diameter x 7.62 cm (3 in) long were extracted in-situ during 1982 and analyzed for saturated hydraulic conductivity. Three cores were discarded during the analysis because of insect damage during storage. The remaining twenty cores were tested using procedures similar to those followed by Darcy in his classical experiment of flow through a porous media. A modified version of the Darcy equation was used to determine saturated hydraulic conductivity of the three replications of each core as given in Equation 2.

$$K_s = C \frac{V}{\Delta t} \tag{2}$$

where,

K_s = saturated hydraulic conductivity of the soil

V = volume of water passed through the soil media over the testing period

Δt = time of the test

C = a constant equal to $\Delta L/A * \Delta H$ where ΔL is the length of the soil column, A is the surface area of the soil core determined from the area of a circle, and ΔH is the head of water above the soil core.

The head above the soil core was maintained at a constant value of 39.2 cm (15.4 in) for each core tested. Therefore, C was determined as having a constant magnitude of 4.26×10^{-3} cm^{-2} (2.75×10^{-2} in^{-2}).

Using the General Linear Model (GLM) of SAS (1979) and the Duncan's multiple range test, the saturated hydraulic conductivities were analyzed for statistical differences by taking into consideration the location of the cores in the test area, grouping of cores by row or column in the test area, and by replications of the test procedures in the laboratory. Analysis indicated that no significant differences existed between the infiltration rates and that a large standard deviation existed between the mean of the entire data set as shown in Table 3. This is an expected phenomenon as indicated by Biggerstaff and Moore (1982), Sharma, et al. (1980) and others and can be explained in several ways. First, the values of hydraulic conductivity for a tested core may be associated with surface sealing caused by the manner in which the cores were prepared for testing or from natural occurring phenomena. It has already been established that surface seals can reduce flow through a soil matrix. Second, large values of hydraulic conductivity may be associated with cores that have large macropores or cores that have poor contact with the walls enclosing the sample. Both of these phenomena will cause rapid flow of water through the sample causing an over estimation of the conductivity. Cores that had a high degree of variability between the replications were latter withdrawn based on the above phenomena. The results of these two analyses are presented in Table 3. This type of analysis indicated that a large number of cores are needed to evaluate the mean infiltration rate of saturated soil core samples and that a better estimate of matrix infiltration rate can be obtained by eliminating cores that have a large degree of variation.

Saturated Water Content and Bulk Density

Once the soil cores had been tested for saturated hydraulic conductivity, they were immediately taken from the test apparatus, weighed, and dried to obtain water content by weight. Since the soil cores were at saturation at the end of the hydraulic conductivity tests, the water content at this condition were the saturated water contents of the soil.

TABLE 3. MEASURED SOIL PROPERTIES OF THE COLDSTREAM DAIRY FARM TEST AREA.

Parameter	Mean	Standard Deviation	No. of Samples
Saturated Hydraulic Conductivity* (entire data set)	1.934 cm H_2O/hour (0.7613 in H_2O/hour)	1.6696	63
Saturated Hydraulic Conductivity (extreme highs and lows eliminated)	1.529 cm H_2O/hour (0.6019 in H_2O/hour)	1.1833	56
Saturated Hydraulic Conductivity (extreme highs and lows and cores with large variability in the replications eliminated)	1.2029 cm H_2O/hour (0.4736 in H_2O/hour)	0.8943	43
Saturated Water Content	44.12% cm^3/cm^3	1.5948	63
Bulk Density	1.3878 g/cm^3	0.0463	63

---

* 95% confidence limit interval of the entire data set was (1.5131 cm H_2O/hour to 2.3545 cm H_2O/hour).

Bulk density was also determined for each core by dividing the difference between the initial and final water contents of the soil by the volume of the core determined from the inside dimensions of the aluminum sleeves containing the sample. Using the relationship shown in Equation 3, the moisture content, determined on a weight basis, can be converted to moisture content on a volume basis.

$$\Theta_{vol} = \gamma_b * \Theta_{weight} \qquad (3)$$

where,

Θ_{vol} = moisture content volume basis

Θ_{weight} = moisture content weight basis

γ_b = bulk density, g/cm^3

All moisture contents were changed to a volume basis using Equation 3 for analysis. A statistical analysis was performed to establish significance of the data using SAS taking into consideration core location in the test field and replication. It was determined that no significant differences existed between the different values of saturate water content and the different values of bulk density at the 99 percent confidence interval. Therefore, it was concluded that the means of each of these parameters described the saturated water content and bulk density of the Coldstream Dairy Farm test area as shown in Table 3.

Parameter Determination

Several methods exist that can be used to evaluate the rate of infiltration into the soil. Some methods contain empirical equations that use parameters that must be determined from observed infiltration data. Horton's, Holtan's and SCS's equations are examples of emperical equations of infiltration. Horton (1939) proposed an infiltration equation that assumed infiltration will decrease with time because of swelling of the soil colloids and the closing of soil cracks, washing of fine particulates into the surface pores, and rain damage to the soil surface. Holtan (1961) proposed an infiltration relationship that assumed infiltration was function of the available water storage contained in a specified depth of soil. The Soil Conservation Service (1972) method predicts cumulative runoff as a function of cumulative rainfall by a curve number technique. Opposed to these emperical equations are physically based equations that are usually formulated from the equation of continunity and flow rate functions. Examples of these are the two-phase (water and air) flow equations (Brustkem and Morel-Seytoux, 1970 and Noblanc and Morel-Seytoux, 1972). Richard's equation was developed using continuity and Darcy's equation that considers the oil medium as a bundle of interconnected capillary tubes. Phillip's (1957) equation is based on an infinite series solution of the Richard's equation.

A simple equation was sought to relate infiltration rates to easily obtainable quantities because of the complexity of many of these solutions and the difficulty of measuring basic parameters appearing in others. The equation presented by Green and Ampt (1911) was a reasonable alternative. Their infiltration equations was physically based on Darcy's law using a capillary tube analogy for ponded surfaces. The method assumed an initial uniform moisture content in a homogenous soil (i.e., that piston flow occurs). Although their equation is an approximate equation, considerable research in recent years has shown it to have theorectical basis, as well as measurable parameters (Moore, 1981).

If the depth of ponding is considered negligible, the Green-Ampt equation can be written as

$$f = K\left(1 + \frac{S_w \Delta\Theta}{F}\right) \tag{4}$$

where,

f = the infiltration rate

F = the infiltration volume

$\Delta\Theta$ = the initial moisture deficit $(\Theta_s - \Theta)$

Θ_s = saturated moisture content

Θ = moisture content initially in the soil

S_w = the capillary drive at the wetting front, suction

K = the saturated hydraulic conductivity in the wetted zone

The use of Equation 4 will show that infiltration rate determined for each runoff plot are equal to the field saturated hydraulic conductivity of the soil for that plot considering steady state conditions. What follows are the results found using this analogy and the statistical difference of measured field saturated hydraulic conductivities associated with the application of manure to test plots.

The Infiltration Rate. Determination of the infiltration rate of a soil is made by subtracting the runoff rate determined for steady state conditions from the constant applied rainfall rate. As outlined in the procedures, rainfall rates were determined during each rainfall event by using three standard rain gages. Also, the number of pulses the rainfall simulator made during each event was recorded. This data was statistically regressed resulting in a relationship for determination of the rainfall simulator pulses needed to produce a given gage rainfall rate. The resulting equation was:

$$RRg = -0.707 + 0.0745\ P \qquad (5)$$

where,

RRg = rainfall rate determined from standard rain gages, in/hr

P = number of rainfall simulator pulses in one minute

A correlation of the regression showed that the data fit the predicted equation with an R^2 of .907. During 1982, calibration of the rainfall simulator resulted in a relationship between pulses the simulator made and the actual rainfall rate occuring over the plot. An $R^2 = .993$ of the data was obtained from the four rainfall events conducted for each of the seven pulse rates tested. The data covered the range of pulses used during actual rainfall events over manured plots for the two years and resulted in the equation:

$$P = 4.810 + 13.812\ RR_A \qquad (6)$$

where,

RR_A = actual rainfall rate for a given simulator pulse rate, in/hr

P = number of rainfall simulator pulses in one minute

Combining Equations 5 and 6 a relationship was obtained between the actual rainfall rate applied to the test pilot and the rainfall rate determined from rain gauges placed inside the test area. The resulting equation:

$$RR_A = 0.339 + -.972\ RR_g \qquad (7)$$

was used to establish rainfall rates for each plot. Runoff rates were also determined from runoff hydrograph curves established for each test plot. Runoff volume was plotted as a function of cumulative time, and steady state runoff rates were determined from the straight line portion of these curves. Infiltration rates were then established for each plot by subtracting the runoff rate from the rainfall rate as presented in Table 4 for 1981 and Table 5 for 1982.

Depth to the Wetting Front

A volume of water will move down through the soil profile as the infiltration process continues. The depth to which the water has penetrated into the soil can be established, given a time after the start of the rainfall event. This is the depth of the wetting front and can be mathematically represented as,

$$F = F/WR \qquad (8)$$

where,

TABLE 4. SOIL MOISTURE, RUNOFF AND INFILTRATION RATES FOR SEMI-SOLID MANURED PLOTS-1981

Nitrogen Loading Rate (# N/Acre)	Date	Time Delay Before Rainfall (HR)	Soil Moisture (% cm^3/cm^3)		Plot Number (See Figure 2)	Runoff Rate (IN/HR)	Infiltration Rate (IN/HR)
			Θ_f	Θ_i			
75	7/9/81	0	44.120	33.798	3	0.590	2.907
75	8/18/81	0	44.120	44.120	21	0.949	3.763
75	10/21/81	0	44.120	35.436	33	0.950	1.993
75	7/10/81	24	44.120	33.798	2	0.396	2.858
75	10/22/81	24	44.120	35.796	34	0.824	1.857
75	8/20/81	48	44.120	39.487	20	0.400	4.312
75	10/23/81	48	44.120	34.901	35	0.737	2.274
75	8/21/82	72	44.120	44.120	19	0.183	4.529
150	7/20/81	0	44.120	36.018	5	0.671	3.555
150	8/24/81	0	44.120	36.657	18	1.004	3.708
150	10/12/81	0	44.120	42.859	23	0.603	2.360
150	7/20/81	3	44.120	36.018	6	0.681	2.573
150	8/24/81	3	44.120	41.173	17	1.026	3.200
150	10/12/81	3	44.120	40.881	22	0.650	2.119
150	7/20/81	6	44.120	36.018	7	0.370	3.856
150	8/24/81	6	44.120	38.398	16	0.245	4.467
150	10/12/81	6	44.120	36.129	32	0.899	1.947
150	8/25/81	24	44.120	34.548	15	-	-
150	10/13/81	24	44.120	38.051	31	1.014	1.948
150	7/22/81	48	44.120	36.018	12	0.884	3.342
150	8/26/81	48	44.120	34.027	27	0.817	3.895
150	10/14/81	48	44.120	38.259	30	0.241	2.235
150	7/23/81	72	44.120	29.705	13	0.666	3.074
150	7/24/81	96	44.120	29.705	14	0.511	3.229
150	10/16/81	96	44.120	38.329	29	0.464	2.450
150	8/31/81	192	44.120	29.705	28	0.911	3.801
300	7/29/81	0	44.120	44.120	11	0.869	3.357
300	9/30/81	0	44.120	20.652	26	0.942	3.284

TABLE 4. (CONTINUED)

Nitrogen Loading Rate (# N/Acre)	Date	Time Delay Before Rainfall (HR)	Soil Moisture (% cm^3/cm^3)		Plot Number (See Figure 2)	Runoff Rate (IN/HR)	Infiltration Rate (IN/HR)
			Θ_f	Θ_i			
300	10/28/81	0	44.120	35.110	39	0.726	2.159
300	7/30/81	24	44.120	40.070	10	1.384	2.356
300	10/1/81	24	44.120	35.234	25	0.879	2.375
300	10/29/81	24	44.120	35.977	38	0.635	2.619
300	7/31/81	48	44.120	44.120	9	0.385	2.870
300	10/2/81	48	44.120	39.078	24	0.882	2.022
300	10/30/81	48	44.120	34.055	37	0.722	2.289
300	8/5/81	240	44.120	27.090	11	0.091	3.260
300	10/9/81	240	44.120	21.561	26	0.297	3.200
300	11/6/81	240	44.120	34.818	39	0.607	3.133
0	7/7/81	0	44.120	30.822	4	0.603	2.846
0	8/14/81	0	44.120	30.822	8	0.182	4.287
0	7/29/81	0	44.120	30.822	23	1.037	3.189
0	11/4/81	0	44.120	30.822	26	0.444	3.296

TABLE 5. SOIL MOISTURE, RUNOFF AND INFILTRATION RATES FOR LIQUID MANURED PLOTS-1982

Nitrogen Loading Rate (# N/Acre)	Date	Time Delay Before Rainfall (HR)	Soil Moisture (% cm^3/cm^3)		Plot Number (see Figure 3)	Runoff Rate (IN/HR)	Infiltration Rate (IN/HR)
			Θ_f	Θ_i			
75	7/12/82	0	44.120	35.340	2	0.434	3.549
75	8/3/82	0	36.499	21.906	9	1.009	2.177
75	9/7/82	0	44.120	38.532	17	0.455	3.402
75	7/13/82	24	44.120	33.057	3	0.354	4.115
75	8/4/82	24	40.781	18.853	14	0.237	3.960
75	9/8/82	24	41.780	39.025	16	0.672	3.535
75	7/14/82	48	40.683	31.961	4	0.264	4.205
75	9/9/82	48	44.120	36.117	15	0.130	4.416
150	7/26/82	0	44.120	27.71	8	0.820	3.221
150	9/20/82	0	44.120	44.12	23	0.903	3.167
150	10/5/82	0	43.001	40.468	31	0.330	3.808
150	7/26/82	3	41.183	24.967	7	0.994	2.707
150	9/20/82	3	44.120	36.041	22	0.995	2.978
150	10/5/82	3	39.462	36.569	32	0.949	3.296
150	7/26/82	6	44.120	26.660	6	0.874	2.633
150	9/20/82	6	42.286	34.653	23	0.987	4.211
150	10/5/82	6	44.120	37.151	33	0.402	3.989
150	7/27/82	24	42.189	33.800	5	0.403	3.657
150	9/21/82	24	44.120	35.285	24	1.030	3.691
150	10/6/82	24	44.120	38.733	34	0.951	4.130
150	7/28/82	48	42.224				
150	9/22/82	48	36.353	32.308	25	1.046	3.598
150	10/7/82	48	40.558	35.854	35	0.992	3.555
150	9/24/82	96	39.920	34.639	36	1.029	3.829
300	8/12/82	0	44.120	41.648	10	1.146	3.672
300	8/18/82	0	38.609	38.477	18	0.816	3.196
300	9/29/82	0	42.834	40.052	28	1.025	2.792

TABLE 5. (CONTINUED)

Nitrogen Loading Rate (# N/Acre)	Date	Time Delay Before Rainfall (HR)	Soil Moisture (% cm^3/cm^3)		Plot Number (See Figure 3)	Runoff Rate (IN/HR)	Infiltration Rate (IN/HR)
			Θ_f	Θ_i			
300	8/13/82	24	44.120	40.371	11	0.901	2.120
300	8/19/82	24	38.047	32.461	19	0.845	3.090
300	9/30/82	24	39.760	36.909	29	1.190	3.532
300	8/14/82	48	44.120	38.026	12	0.139	3.523
300	8/20/82	48	36.603	33.779	20	0.593	3.633
300	10/1/82	48	38.858	29.713	30	1.187	2.602
300	8/17/82	120	44.120	34.431	10	0.230	4.452
300	8/23/82	120	44.120	38.276	18	0.087	3.955
300	10/4/82	120	40.267	35.500	28	0.141	3.725
0	6/28/82	0	44.120	33.439	1	0.141	4.571
0	9/3/82	0	41.585	38.366	23	0.173	4.131
0	10/21/82	0	44.120	39.074	27	0.981	4.548

f = depth to the wetting front

F = infiltration volume at a given time

$\Delta\Theta$ = change in moisture between the initial moisture content of the soil (Θ_j) and the moisture content associated with the time at which the infiltration volume was established (Θ_f).

Infiltration volume was established by subtracting the runoff determined from runoff hydrograph data from the accumulated rainfall. Subtracting these two numbers resulted in the amount of water available for absorption into the soil.

Water contents on a weight basis were determined at the beginning and end of each rainfall event, since it is well known that soils very rarely reach full saturation. They were then converted to a volume basis using bulk density of the soil as determined earlier. Subtracting these two water contents gave the water change during the rainfall event which is needed in determining the depth of the wetting front given in Equation 4 and 8. The depth to the wetting front is determined by Equation 8.

The water contents used in determining the depth of the wetting front are presented in Tables 4 and 5. Infiltration volumes and change in water content are used directly in Equation 3.

Determination of the Average Soil Suction

The amount of water that can be absorbed into the soil profile during a rainfall event is greatly influenced by the ability of the soil to absorb water. Over the course of the rainfall event, the potential suction of the soil changes as the soil profile wets. Therefore, it is advantageous to define an average suction of the soil over the period of the rainfall event.

Moore, et al. (1980) established that the average suction during a rainfall event could be described by,

$$S_{av} = \frac{Yel\ (Kr(\Theta_f)^a - Kr(\Theta_i)^a)}{a\ (Kr(\Theta_f) - Kr(\Theta_i))} \qquad (9)$$

where,

S_{av} = average suction potential
Yel = air entry matric potential
a = $(b + 3)/(2b + 3)$, constant
b = slope of the log-log plot of water content versus suction curve
$Kr(\Theta)$ = relative hydraulic conductivity of the soil at a given water content.
Θ_i = initial soil moisture content
Θ_f = time assoicate with time at which infiltration volume was established

He further found that the air entry matric potential could be defined as,

$$Yel = e^x/\Theta_s^b \qquad (10)$$

where,

x = intercept of the log-log plot of water content versus suction curve
b = slope of the log-log plot of soil water content versus suction curve
Θ_s = saturated soil moisture content

Mein and Larson (1971), Bloomsburg and Corey (1964) and others have shown that the relative hydraulic conductivity can be designated as,

$$Kr(\Theta) = \frac{\Theta}{\Theta_s} \quad 2b + 3 \qquad (11)$$

Values for b (slope) and the intercept of the line were found from a log-log plot of desorption and water content obtained from pressure plot analysis. Regression analysis showed a $R^2 = .979$ for the data fit. The values of the slope b, and the intercept x, were 30.89 and 6.81 respectively. The air entry value was then established as 164.04 cm H_2O based on saturation moisture content of the soil established earlier. The constant a value was determined to be 0.59 for the soil and the relationship for relative hydraulic conductivity was formulated as:

$$Kr(\Theta) = \frac{\Theta}{44.12} \quad 16.62 \qquad (12)$$

taking into consideration saturation moisture content as previously defined.

Replacing all of the constants with measured values in the relationship for relative hydraulic conductivity in Equation 9. The following relationship for the average suction of the soil found on the Coldstream Dairy Farm test area is:

$$S_{av} = 277.92 \frac{Kr(\Theta_f)^{0.59} - Kr(\Theta_i)^{.59}}{Kr(\Theta_f) - Kr(\Theta_i)} \qquad (13)$$

Determination of Field Saturated Hydraulic Conductivity

Estimates of the field saturated hydraulic conductivity were formulated by replacing infiltration rates, depths to the wetting front and the equation for average suction of the soil in Equation 4 (Note: the initial and final moisture content of the field, determined for each plot, were used in establishing Kr(Θ)). Results showed, using a simple ratio, that the infiltration rate was equal to the field saturated hydraulic conductivity for each plot. Since these quantities are equal, the assumption of steady state condition existing at the 150 liter runoff volume is valid. Therefore, the trends and significant differences found for the infiltartion rate data as a result of the test variables can be assumed to parallel the effects on the field saturated hydraulic conductivity. Using this analogy, a statistical evaluation of the infiltration rates were conducted.

Field Saturated Hydraulic Conductivity on Manured Plots

Infiltration rates (or field saturated hydraulic conductivites) of each test plot were statistically analyzed using techniques found in SAS (1979). Significant differences between the data were determined by Duncan's multiple range test and the GLM module procedures of SAS. Testing considered type of manure applied to the plots, loading rate of the manure, replication of the plots, and time delay between initial manure application and simulated rainfall event. Time delay was considered to be nested within the manure loading rate and/or plot replication.

Field Saturated Hydraulic Conductivity of Control Plots

Several plots with no manure applied were used as controls and were tested to established background information for the field during each year. Results showed that mean infiltration rates of 1981 and 1982 test years were significantly different at the 95 percent confidence level as shown in Table 6. Weather conditions and/or soil structure during the two test years may have given rise to this difference. Therefore, the remaining analysis for manured plots was split into the year in which the plots were tested which also split the infiltration rates by form of the dairy manure applied--solid manure 1981 and liquid manure 1982.

Evaluation of Infiltration Rate (Field Saturated Hydraulic Conductivity Versus Saturated Hydraulic Conductivity Found in the Laboratory)

The previous data analysis has shown the variations and trends of field saturated hydraulic conductivities through various methods. But how does the field saturated conductivity compare to saturated hydraulic conductivities obtained through laboratory analysis? Using Duncan's multiple range test from the general linear model of SAS, hydraulic

TABLE 6. MEAN INFILTRATION RATES FOR CONTROL PLOTS

Test Year	Mean Infiltration Rate (in H_2O/hr)	Number of Observations
1981	3.405^A	4
1982	4.417^B	3

Means with different letters are significantly different at 95% confidence level.

TABLE 7. FIELD SATURATED HYDRAULIC CONDUCTIVITY (K_{FS}) COMPARED TO LABORATORY SATURATED HYDRAULIC CONDUCTIVITY (K_S)

Year	Parameter	Mean Saturated Hydraulic Conductivity (in H_2O/hr)	No. of Observations
LAB	K_S	0.7613^A	63
1981	K_{FS}	3.4045^B	4
1982	K_{FS}	4.4167^B	3

Means with the different letters are significantly different at 95% confidence level.

conductivities determined through laboratory analysis and from runoff data for 1981 and 1982 were tested. Results in Table 7 show that at the 95 percent confidence level, laboratory determined soil saturated hydraulic conductivites were 43 percent less than field saturated conductivites in 1981 and 56 percent less than 1982 data.

The difference between laboratory and field data that were determined can be attributed to many things. Bouma, et al. (1982) has shown that worm holes present in situ are not represented by soil cores for laboratory analysis, and can contribute significantly to differences in hydraulic conductivities of the soil matrix. Moore and Eigel (1981) have shown that surface sealing effects can greatly influence infiltration rates. In preparation of the soil core, sealing may be induced by smoothing the top and bottom of the core to the test cylinder. Also, Moore and Eigel (1981), Biggerstaff and Moore (1982), Schroeder, et al. (1982), McKeague, et al. (1982) and others have shown that infiltration rates obtained in the field may be greater because of inherent heterogeneity of the soil. Therefore, it is reasonable to expect that laboratory analysis of the saturated hydraulic conductivity of a soil will not describe the actual saturated conductivity of a soil matrix.

Infiltration Rates on Zero Delay Manured Plots

Zero hour time delay plots with manure applied were tested for significant differences in infiltration rates arising from the nitrogen loading rates. Semi-solid manure (1981) data showed no significant differences, but manured plots had lower infiltration rates of 5.8 to 15 percent. Liquid (1982) manure data, indicated at the 95 percent confidence level that plots with manure applied to the surface had significantly reduced the infiltration rate from 23 to 31 percent as compared to the control plots as shown in Table 8. Testing the significance of the replication for each manure type (by year) at the various nitrogen loading rates showed that the 1981 infiltration rates were significantly different at the 95 percent confidence level while there was no significance at this level found for the 1982 data. This data is shown in Table 9

TABLE 8. INFILTRATION RATES ON ZERO TIME DELAY PLOTS CONTAINING SEMI-SOLID AND LIQUID MANURE COMPARED TO PLOTS CONTAINING NO MANURE.

Nitrogen Loading (#N/acre)	Mean Infiltration Rate (in H_2O/hr)	No. of Observations
	Semi-Solid Manure 1981	
0	3.4045^{A}	4
75	2.8877^{A}	3
150	3.2077^{A}	3
300	2.9333^{A}	3
	Liquid Manure 1982	
0	4.4167^{A}	3
75	3.0427^{B}	3
150	3.3987^{B}	3
300	3.2200^{B}	3

Means with different letters are significantly different at 95 percent confidence level.

and indicated that either weather or changes in soil structure effected the infiltration process in 1981.

An attempt was made to explain the differences presented in Table 8 for the replications of the test data. Replication 1 was conducted in the early summer and replication 3 was run in early fall. Although not presented here in tabular form, a correlation was found when infiltration rates were compared to soil temperature data for the test months. At the 95 percent confidence level, 1981 data indicated that when soil temperature increased significantly over a range of twenty degrees farenheit, the infiltration rate of the soil was increased. In 1982, on the other hand test evaluation did not show significant differences in the data, primarily because a large fluctuation in soil temperature did not exist as it had in 1981. However a trend in the 1982 data did exist that followed the same pattern as the 1981 data. This increase in infiltration rate because of increased soil temperatures is caused by the change in the viscosity of the water flowing through the pore structures. As the fluid mixture increases in temperature it will flow more easily or faster as indicated by Streeter and Wylie (1971). Thus it would be expected that fluctations as shown in the infiltration data, would exist if soil temperature changed over the test period.

Infiltration Rates on Manured Plots as a Function of Time Delay to Rainfall Event

Zero, twenty-four, and forty-eight hour time delays for each manure nitrogen loading rate were compared. No significant differences (Tables 8 and 9) existed when time delay or nitrogen loading were considered for semi-solid manure in 1981. Liquid manure plots in 1982 showed no significant differences or trends in infiltration rate when considering time delay but did shown a significant difference when manure nitrogen loading rates decreased the infiltration rate as shown in Table 10.

TABLE 9. INFILTRATION RATES AFFECTED BY REPLICATIONS FOR 0, 75, 150, 300 POUNDS OF NITROGEN USING SEMI-SOLID AND LIQUID MANURE WITH ZERO TIME DELAY.

Replication	Mean Infiltration Rate (in H_2O/hr)	No. of Observations
	Semi-Solid Manure 1981	
1	$3.1662^{A,B}$	4
2	3.7605^{A}	4
3	2.4253^{B}	4
	Liquid Manure 1982	
1	3.7532^{A}	4
2	3.1678^{A}	4
3	3.6375^{A}	4

Means with different letters are significantly different at 95 percent confidence level.

TABLE 10. INFILTRATION RATES FOR THE VARIOUS MANURE LOADING RATES FOR SEMI-SOLID AND LIQUID MANURE AT 0, 24, AND 48 HOUR TIME DELAYS.

Manure Loading (#N/acre)	Mean Infiltration Rate (in H_2O/hr)	No. of Observations
	Semi-Solid Manure 1981	
75	2.8520^{A}	7
150	3.0061^{A}	7
300	2.5923^{A}	9
	Liquid Manure 1982	
75	3.7526^{A}	8
150	$3.6034^{A,B}$	8
300	3.1289^{B}	9

Means with different letters are significantly different at 95% confidence level.

TABLE 11. COMBINED TIME DELAYED PLOTS FOR THE VARIOUS MANURE APPLICATIONS FOR SEMI-SOLID AND LIQUID MANURE WHEN ONLY 0, 24, AND 48 HOUR DELAYED PLOTS CONSIDERED.

Time Delay (Hrs)	Mean Infiltration Rate (in H_2O/hr)	No. of Observations
	Semi-Solid Manure 1981	
0	3.0096^A	9
24	2.3355^A	6
48	2.9049^A	8
	Liquid Manure 1982	
0	3.4814^A	9
24	3.5973^A	9
48	3.3284^A	7

Means with different letters are significantly different at 95% confidence level.

Infiltration Rates as Affected by Long Term Time Delays

Each level of time delay for the semi-solid manure plots tested in 1981 showed significant differences resulting from time delay between manure application and rainfall event for the 150 pound nitrogen loading rate. Increased time delays on plots gave infiltration rates that increased and returned toward the background infiltration rate established for the test area. The liquid manure plots tested in 1982 had infiltrated rates that showed a similar pattern but no significance was found as shown in Table 12.

Significant trends were found for time delays for both manure forms for plots receiving the 300 pounds nitrogen loading rate. Infiltration rates on plots receiving semi-solid mnaure (1981) had no significant difference between the means for time delay although time delay did show a tendency to restore infiltration rates to the background level established for the field. The infiltration rates on plots receiving liquid manure (1982) also showed no significant difference between the means for time delay but did indicate that the mean for time delay plots (5 days), that had been rained on twice, were increasing toward the background infiltration rate level. These results are shown in Table 13.

Summary - Infiltration Studies

The general implication of the results presented above concerning the effect dairy manure has on the infiltration rate of the test plots is that rainfall events that occur within 96 hours of manure application have reduced infiltration rates thus increasing surface runoff of polluted water. Increasing manure loading rates also decrease the infiltration rate. But the longer the time delay, greater than 96 hours, and repeated rainfall events on the same plot show increases in the infiltration rates yielding reduced surface runoff and thus reduced pollutant discharge.

TABLE 12. TIME DELAY EFFECTS ON THE APPLICATION OF 150 POUNDS NITROGEN/ACRE AS DAIRY MANURE TO PASTURE

Time Delay (Hrs)	Mean Infiltration Rate (in H_2O/hr)	No. of Observations
	Semi-Solid Manure 1981	
0	$3.2077^{A,B}$	3
3	2.6306^{B}	3
6	3.4233^{A}	3
24	1.948^{B}	1
48	$3.1573^{A,B}$	3
96	$3.2290^{A,B}$	1
	Liquid Manure 1982	
0	3.3987^{A}	3
3	2.9937^{A}	3
6	3.6110^{A}	3
24	3.8260^{A}	3
48	3.5765^{A}	2
96	3.8290^{A}	1

Means with different letters are significantly different at the 95 percent confidence level.

TABLE 13. TIME DELAY EFFECTS ON THE APPLICATION OF 300 POUNDS OF NITROGEN/ACRE AS DAIRY MANURE TO PASTURE

Time Delay (Hrs)	No. of Times with Simulated Rainfall	Mean Infiltration Rate (in H_2O/hr)	No. of Observations
		Semi-Solid Manure 1981	
0	1	2.9333^A	3
24	1	2.4500^A	3
48	1	2.3937^A	3
5-day	2	3.1977^A	3
		Liquid Manure 1982	
0	1	3.2200^A	3
24	1	2.9140^A	3
48	1	3.2527^A	3
5-day	2	4.0440^A	3

Means with different letters are significantly different at the 95% confidence level.

POLLUTANT YIELD DURING RUNOFF EVENTS OF MANURED PLOTS

The estimate of the yield for each determined pollutant was made by the determination of the area under the curve of pollutant concentration versus the volume of runoff from a test plot. The pollutant yields were for the first 150 liters of runoff. The pollutant yields were tested for statistical significance using Duncan's multiple range test in GLM of SAS (1979).

Only a few of the pollutants yields that were statistically analyzed were found to have significant differences when considering the effects of the nitrogen loading rate and the time delay between the manure application to a test plot and the simulated rainfall event. The yield data had a high degree of variability which thus resulted in finding few significant differences among the effects. But further analysis of the data in the future should give better precision to the statistical testing. The effect of manure type was not tested because as previously mentioned, the increased simulated rainfall rate that was required in 1982 (liquid manure) over the rainfall rate in 1981 (semi-solid manure). The following discussion concerning the pollutant yields will stress trends found in the means of the pollutant yields as affected by the levels of each effect. Three comparisons were made for each pollutant yield for the semi-solid manured plots and the liquid manured plots: the effect of the nitrogen loading rate (0 (control plots), 75, 150 and 300 #N/Acre) for all time delay plots in Table 14, the effect of time delay (0, 24, 48, 120 hours (repeated rainfall on 0 hour plot), and the control plot) for the 300 #N/Acre plots in Table 15, and the effect of time delay (0, 24 and 48 hours) for all nitrogen loading rates (control values are shown) in Table 16.

Chemical Oxygen Demand (COD)

The effect of increasing the nitrogen loading rate was to increase the mean COD yield for both semi-solid and liquid dairy manure. The mean yields increased one order of magnitude between 75 #N/Acre and 300

TABLE 14. TOTAL POLLUTANT YIELD FROM TEST PLOTS AS AFFECTED BY NITROGEN LOADING RATE FOR SEMI-SOLID AND LIQUID MANURE

Nitrogen Loading (#N/Acre)	COD (GM)	OBS	TSS (GM)	OBS	FSS (GM)	OBS	VSS (GM)	OBS	TS (GM)	OBS	FS (GM)	OBS	VS (GM)	OBS	NH_3 (GM)	OBS	NH_4 (GM)	OBS	N (GM)	OBS	P (GM)	OBS	K (GM)	OBS
											SEMI-SOLID MANURE - 1981													
0 (Control)	5.92^A	3	38.7^A	2	295.5^A	2	6.4	3	15.5^A	4	--	--	1.01^A	2	0.45^A	4	--	--	0.15^A	4	0.96^A	2	0.59^A	4
75	126.5^A	8	84.9^A	7	131.4^A	4	23.8	7	94.6^A	8	29.9	8	35.2^A	8	0.10^A	8	4.7^A	4	12.4^A	8	2.4^A	6	30.3^A	8
150	704.9^A	14	155.8^A	12	66.0^A	11	--	--	557.0^A	14	169.8	13	$415.4^{A,B}$	14	0.15^A	12	8.58^A	5	39.5^A	14	12.9^A	7	70.0^A	14
300	1444.3^B	11	185.6^A	9	122.7^A	8	296.5	11	854.7^A	11	351.6	10	1005.0^B	11	0.38^A	12	35.4^A	4	80.4^B	11	20.3^A	10	93.8^A	10
											LIQUID MANURE - 1982													
0 (Control)	12.9^A	3	1900.0^A	2	1781.2^A	2	849.1^{AB}	2	4.8^A	3	3.8^A	3	1.0	3	0.15^A	3	--	--	0.2	3	1.0	3	16.2	3
75	218.9^A	7	178.1^A	4	76.6^A	4	95.4^B	5	94.1^A	8	49.8^A	8	129.1	8	0.18^A	5	3.2^A	1	12.5	3	11.3	7	17.0	7
150	757.4^A	15	2884.2^A	14	781.7^A	14	170.8^B	15	561.7^A	15	257.2^A	15	289.8	15	0.02^A	9	86.0^B	4	35.3	10	45.0	15	74.9	15
300	2458.3^A	11	21420.1^B	7	16296.3^A	8	1655.7^A	7	6235.1^A	11	2153.0^A	12	876.0	12	2.09^B	10	0.8^A	4	65.3	8	604.6	8	151.1	12

Means with different letters are significantly different at the 95 percent confidence level.

TABLE 15. TOTAL POLLUTANT YIELD FROM TEST PLOTS AS AFFECTED BY TIME DELAY FOR SEMI-SOLID AND LIQUID MANURE LOADING RATE OF 300 #N/ACRE

Time Delay Before Rainfall (HR)	COD (GM)	OBS	TSS (GM)	OBS	FSS (GM)	OBS	VSS (GM)	OBS	TS (GM)	OBS	FS (GM)	OBS	VS (GM)	OBS	NO_3 (GM)	OBS	NH_4 (GM)	OBS	N (GM)	OBS	P (GM)	OBS	K (GM)	OBS
											SEMI-SOLID MANURE - 1981													
0	3706.3^{A}	3	287.6^{A}	3	98.9^{A}	3	771.1^{A}	3	1882.5^{A}	3	386.8	3	2111.0^{A}	3	0.13^{A}	3	131.2	1	198.9^{A}	3	37.4^{A}	2	175.5^{A}	3
24	1013.4^{B}	3	179.1^{A}	2	243.2^{A}	1	$299.0^{A,B}$	3	447.0^{A}	3	431.4	2	1170.3^{A}	3	0.03^{A}	3	6.6	1	63.7^{B}	3	0.5^{A}	2	66.4^{A}	2
48	371.5^{B}	3	117.2^{A}	3	136.3^{A}	3	13.5^{B}	3	233.6^{A}	3	110.6	3	194.6^{A}	3	0.18^{A}	3	0.02	1	$20.5^{B,C}$	3	4.8^{A}	3	46.9^{A}	3
120	306.8^{B}	2	98.0^{A}	1	33.4^{A}	1	5.6^{B}	2	856.2^{A}	2	580.6	2	313.7^{A}	2	1.17^{A}	3	3.9	1	$17.5^{B,C}$	2	--	--	69.0^{A}	2
Control	5.9^{B}	3	38.7^{A}	2	295.5^{A}	2	6.4^{B}	3	15.5^{A}	4	--	--	1.0^{A}	2	0.45^{A}	4	--	--	0.15^{C}	4	1.0^{A}	2	0.6^{A}	4
											LIQUID MANURE - 1982													
0	6164.9^{A}	3	20910^{A}	3	22375^{A}	3	3204.5^{A}	3	12588^{A}	3	8515^{A}	3	3243.2^{A}	3	$.004^{A}$	3	0.25	2	166.8^{A}	3	332.8^{A}	3	219.0^{A}	3
24	2677.5^{A}	3	29021^{A}	3	21027^{A}	3	658.5^{A}	3	10264^{A}	3	87.2^{A}	3	1.2^{A}	3	$.01^{A}$	3	0.01	1	2.7^{A}	3	1270.7^{A}	3	6.5^{A}	3
48	107.6^{A}	3	146.1^{A}	1	159.4^{A}	1	1.0^{A}	1	7.0^{A}	3	5.7^{A}	3	180.5^{A}	3	2.3^{A}	2	2.5	1	12.3^{A}	1	26.0^{A}	1	31.4^{A}	3
120	95.6^{A}	2	--	--	1.6^{A}	1	--	--	5.4^{A}	2	4.1^{A}	3	79.2^{A}	3	8.2^{B}	2	--	--	1.6^{A}	1	0.05^{A}	1	64.5^{A}	3
Control	12.9^{A}	3	1900.5^{A}	2	1781.2^{A}	2	849.1^{A}	2	4.8^{A}	3	3.8^{A}	3	1.0^{A}	3	0.15^{A}	3	--	--	0.2^{A}	3	1.0^{A}	3	16.2^{A}	3

Means with different letters are significantly different at the 95 percent confidence level.

TABLE 16. TOTAL POLLUTANT YIELD FROM TEST PLOTS AS AFFECTED BY TIME DELAY FOR SEMI-SOLID AND LIQUID MANURE

Time Delay Before Rainfall (HR)	COD (GM)	OBS	TSS (GM)	OBS	FSS (GM)	OBS	VSS (GM)	OBS	TS (GM)	OBS	FS (GM)	OBS	VS (GM)	OBS	NO_3 (GM)	OBS	NH_4 (GM)	OBS	N (GM)	OBS	P (GM)	OBS	K (GM)	OBS
SEMI-SOLID MANURE - 1981																								
0	1533.8^A	9	163.5^A	9	73.9^A	8	286.3	9	829.1^A	9	211.2^A	9	911.9^A	9	0.06^A	9	31.0^A	5	87.2^A	9	28.5^A	5	83.7^A	9
24	573.8^B	6	139.5^A	5	204.1^A	3	193.2	6	503.3^A	6	177.8^A	5	694.4^A	6	0.12^A	6	5.1^A	3	39.2^B	6	5.0^A	5	46.7^A	5
48	212.1^B	8	93.6^A	7	114.8^A	6	--	--	125.6^A	8	68.6^A	8	110.5^A	8	0.13^A	8	1.1^A	2	12.6^B	8	2.9^A	7	48.9^A	8
Control	5.9	3	38.7	3	295.5	2	6.4	3	15.5	4			1.0	2	0.45	4	--	--	0.2	4	1.0	2	0.6	4
LIQUID MANURE - 1982																								
0	2436.2^A	9	9178.2^A	7	9677.6^A	7	1339.7^A	8	4567.6^A	9	2944.2^A	9	1304.6^A	9	0.13^A	7	1.01	4	90.4^A	8	141.5^A	8	104.4^A	8
24	1204.9^A	8	10948^A	8	7070.7^A	9	271.6^A	9	3583.7^A	9	92.9^A	9	76.9^A	9	0.01^A	5	0.01	1	3.9^A	5	441.4^A	9	29.6^A	9
48	118.1^A	7	197.6^A	3	298.2^A	3	65.6^A	3	154.6^A	7	113.9^A	7	148.3^A	7	1.14^A	4	2.5	1	9.1^A	2	13.5^A	5	178.5^A	7
Control	12.9	3	1900.4	2	1781.2	2	849.1	2	4.8	3	3.8	3	1.0	3	0.15^A	3	--	--	0.2	3	1.0	3	16.2	3

Means with different letters are significantly different at the 95 percent confidence level.

#N/Acre. The control COD yield was only 5 percent of the COD yield at 75 #N/Acre. The effect of time delay before a rainfall event indicated that the mean COD yield was reduced with increased time delay for a nitrogen loading rate of 300 #N/Acre. The mean COD yield was reduced by 95 percent after 48 hours for semi-solid manure and 98 percent for liquid manure. The repeated runoff test at 120 hours on the zero time delay plot also showed the same percent decrease in the COD yield for both manure forms.

The effect of time delay for all nitrogen loading rates on the COD yield means were comparable with a 70 percent reduction for semi-solid manure and a 50 percent reduction for liquid manure after 24 hours.

Total Suspended Solids (TSS)

The effect of increased nitrogen loading rate was to increase the mean TSS yield. Liquid manure plots gave TSS yields two to three orders of magnitude higher than for the semi-solid manures. The 300 #N/Acre loading rate gave a mean TSS yield (21420 grams) significantly higher than the other loading rates for liquid manure.

The effect of time delay for the 300 #N/Acre loading rate was to reduce the mean TSS yield. After 48 hours the mean TSS yield was reduced 60 percent for semi-solid manure and 99 percent for liquid manure.

The effect of time delay for all nitrogen loading rates was to reduce the mean TSS yield. After 24 hours only a 15 percent decrease was found for semi-solid manure while a 20 percent increase was found for liquid manure. But after 48 hours the mean TSS yield was reduced 60 percent for semi-solid manure and 99 percent for liquid manure.

Fixed Suspended Solids (FSS)

The effect of nitrogen loading levels for semi-solid manure was to reduce FSS yield from 55-78 percent below the control and zero manure plot. For the liquid manure plots at 75 #N/Acre, the FSS yield was reduced 95 percent and for the 150 #N/Acre 55 percent. For 300 #N/Acre the FSS yield increased one order of magnitude over the control plots.

The effect of time delay of the 300 #N/Acre plots was to reduce the FSS yield for 48 hours delay and the repeated rainfall test at 120 hours. All the mean FSS yields for semi-solid manure were below the control plot while 0 and 24 hour delays for liquid manure were one order of magnitude higher than the control plots. The implication is that besides soil erosion, the liquid manure plots yield substantially higher FSS from the manure while the semi-solid manure reduced soil erosion and did not yield much FSS from the manure itself.

Volatile Suspended Solids (VSS)

The effect of nitrogen loading rate was to increase the mean VSS yield. The VSS was from the erosion of the applied manure. The VSS yields were three to four times higher for liquid manures than for semi-solid manure. The mean VSS increased from 23.8 grams at 75 #N/Acre to 296.5 grams/Acre at 300 #N/Acre for semi-solid manure, more than an order of magnitude. Similarly the mean VSS increased from 95.4 grams for 75 #N/Acre to 1655.7 grams for 300 #N/Acre for the liquid manure.

The effect of increased time delay dramatically illustrated the reduction in the mean VSS yield. For 300 #N/Acre plots a 48 hour delay reduced the mean VSS yield more than 99 percent for both manure types.

The effect of increased time delay for all manure loading rates was similar. After 24 hours, the mean VSS yield was reduced by 33 percent for semi-solid manure and 80 percent for liquid manure.

Total Solids (TS)

The effect of increased nitrogen loading rate was to increase the mean TS yield for both semi-solid and liquid manures. The TS yield for 300 #N/Acre for semi-solid manure was an order of magnitude higher than at 75 #N/Acre while liquid manure showed approximately a one and one-half order of magnitude increase.

The effect of time delay was to decrease the mean TS yield for 300 #N/Acre plots. After 48 hours the mean TS yield was reduced 88 percent for semi-solid manure and than 99.9 percent for liquid manure. The repeated long term test at 120 hours reduced TS by 45 percent for semi-solid manure and greater than 99.9 percent for liquid manure.

The effect of time delay for all nitrogen loading rates was parallel. A 30 percent reduction in TS yield was found after 24 hours for both manure types and, at 48 hours, 85 percent for semi-solid manure and 98 percent for liquid manure.

Fixed Solids (FS)

The effect increased nitrogen loading was to increase mean VS yield for both semi-solid and liquid manure. The FS yield at 75 #N/Acre was only 9 percent of the FS yield at 300 #N/Acre for semi-solid manure but only 3 percent for liquid manure.

The effect of time delay of the 300 #N/Acre indicated no relative change in FS yield for semi-solid manure but very dramatic effects for liquid manure where there was a 99.9 percent reduction in FS yield after 48 hours and on the 120 hour repeated plot.

The effect of time delay for all manure loading rates was that a 67 percent decrease was found after 48 hours for semi-solid manure with similar yields at 0 and 24 hours. There was a 96 percent decrease after 24 and 48 hour delay for liquid manures.

Volatile Solids (VS)

The results of the time delay and nitrogen loading effects for VS yield were parallel to the FS yields. The effect of increased nitrogen loading was increased mean VS yields with yields comparable for semi-solid and liquid manures at the same nitrogen loading rates. The mean FS yields at 75 #N/Acre were 3 percent of the 300 #N/Acre loading for semi-solid manure and 15 percent for liquid manures.

A 24 hour time delay for 300 #N/Acre plot reduced the VS yield by 45 percent and 90 percent at 48 hours. For liquid manure there was a 99.9 percent reduction at 24 hours and 96% at 48 hours. The 120 hour repeated rainfall plots were comparable in VS yield reduction to that of 48 hours for both manure types.

Nitrate - Nitrogen (NO_3)

The effect of increased nitrogen loading rate showed little trend on mean NO_3 yield for semi-solid manure. All the mean NO_3 yields were less than the control of 0.45 gm NO_3 - nitrogen. But a 300 #N/Acre loading rate for liquid manure increased the mean NO_3 yield over the control and other loading rates. It gave a 2.09 gm yield of NO_3-nitrogen.

The effect of time delay showed increased mean yield of NO_3-nitrogen with the liquid manured plots giving higher values. On the 300 #N/Acre plots time delays of 0, 24 and 48 hours on semi-solid manure plots gave NO_3-nitrogen yields less than the control yields. But the 120 hour repeated plot gave a value of 1.17 gm. NO_3-nitrogen which was 3 times that of the control. The liquid manure plot yields for 48 hours and 120 hour repeated plot were 2.3 and 8.2 gm. NO_3-nitrogen respectively or between one and two orders of magnitude higher than the control plots.

The effect of increased time delay for all nitrogen loading rates were that no NO_3-nitrogen yields were greater than the control plots for all time delays for semi-solid manure; and only at 48 hours for liquid manure did the yield exceed the control plot. The value of 1.14 gm. NO_3-nitrogen was an order of magnitude higher than the control plot.

Ammonia Nitrogen (NH_4)

The NH_4-nitrogen yields values were limited in number due to laboratory equipment failure and higher variability of the data. Therefore it was difficult to assess the yields. The effect of increased nitrogen loading on semi-solid manure plots gave higher mean NH_4 yields. The 75 #N/Acre NH_4 yields were only 13 percent of the 300 #N/Acre plot yields. The effect of longer time delays for all nitrogen loading rates was to reduce the NH_4-nitrogen yield. An 83 and a 96 percent reduction in NH_4-nitrogen yield were found at 24 and 48 hours respectively when compared to the zero hour time delay plots.

Total Nitrogen (N)

The effect of increased nitrogen loading rates was found to increase the mean N yield for both the semi-solid and liquid manures. The mean N yields were comparable for both manures at all nitrogen loading rates. The 75 #N/Acre plots were found to have mean N yields that were 13 and 14 percent of the yields found at 300 #N/Acre for semi-solid and liquid manures respectively.

The effect of increased time delays decreased the mean N yields with zero hour N yields for liquid manure and semi-solid being comparable. The increased time delays and the repeated plot gave lower mean N yields for liquid manure than for semi-solid manure. The N yields decreased after a 24 hour delay by 93 to 98 percent for liquid manure plots with 300 #N/Acre and the repeated 120 hour plot decreasing 99 percent. Semi-solid manure 300 #N/Acre plots gave reductions in the mean N yields of 68 percent at 24 hours and 90 percent at 48 hours and 120 hour repeated plot. Similar reductions were found for the increased time delay plots when considering all the nitrogen loading rates.

Phosphorus (P)

The effect of increase nitrogen loading rate increased the mean P yield for both semi-solid and liquid manures. P yields were 5 to 30 times higher for liquid manures than the semi-solid manures. The mean P yields at 75 #N/Acre was 10 percent of the P yield at 300 #N/Acre for semi-solid manure and on 2 percent for liquid manures.

The effect of increased time delay indicated at different trend for the liquid manure or semi-solid manures than previously found. The mean P yield increased three to four fold after 24 hours and then decreased to 92 percent of the zero hour plot after 48 hours for the liquid manure. The semi-manure plots followed the typical trends with 80 to 85 percent decrease in N yields after 24 hours.

Potassium (K)

The effects of increased nitrogen loading rate gave increased mean K yields with the 75 #N/Acre loading rate being 68 percent lower than the 300 #N/Acre plot for semi-solid manure while being 89 percent lower for liquid manure.

The effect of increased time delay on the K yield for liquid manure followed a trend not comparable to other pollutants. The K yield decreased 97 percent after 24 hours, increased to 90 percent reduction from the zero hour plot at 48 hours. The same pattern occured when the time delays were compared for all the nitrogen loading rates. The mean K yield decreased 70 percent at 24 hours but increased after 48 hours to where the K yield was 71 percent higher than the zero hour plot.

The semi-solid manure plots followed the more typical pattern with K yields descreasing with increased time delays. After 24 hours K yields were found to decrease 45 to 60 percent from the zero hour plots.

Summary - Pollutant Yields

In general the increased nitrogen loading of plots gave increased pollutant yields except for FSS yields for semi-solid manure. Pollutant yields in general were higher for liquid manures than for the semi-solid manures. The pollutant yields though decreased more rapidly with increased time delays with liquid manure than semi-solid manure except for NO_3 yields. Increased time delays for liquid manures increased the NO_3 yields. Finally, those pollutants that interact strongly with the soil, P and K, showed different trends for liquid manures with increased time delays. There was a trend to increase pollutant yield after 24 hours for the P yield and then decrease. The K yield decreased at 24 hours and increased at 48 hours.

CHAPTER IV

CONCLUSIONS

Dairy manure was surface spread on 12 ft x 12 ft plots on an established fescue pasture in the summer and fall of 1981 and 1982. The soil was a Maury silt loam. A simulated rainfall was applied to plots to test the effects of nitrogen loading rate (75, 150, and 300 #N/acre) time delay between manure application and the simulated rainfall events (0, 3, 6, 24, 48, 96 hours and a 120 hour test repeated on 0 hr plot with 300 #N/acre), and type manure (semi-solid - 1981 and liquid - 1982) on the concentrations of pollutants in the surface runoff. The pollutants measured were COD, TSS, FSS, VSS, TS, FS, VS, NO_3, NH_4, N, P, and K. The simulated rainfall rates were 3.42 in/hr for 1981 and 4.02 in/hr for 1982. The average field infiltration rate for the non-manured test plots were 3.40 in/hr in 1981 and 4.42 in/hr in 1982. The following conclusions were made from this study:

Field infiltration rates:

1) Semi-solid manured plots with zero hour time delay were found to have reduced infiltration rates of 5.8 to 15 percent when compared to the control plots for all nitrogen loading rates. No significance at the 95 percent confidence level was found between the different nitrogen loaded plots and the control plots.
2) Liquid manured plots with zero hour time delay were found to have reduced infiltration rates of 23 to 31 percent when compared to the control plots for all nitrogen loading rates. Significant differences at the 95 percent level were found between the control plots and the nitrogen loaded plots.
3) The infiltration rates increased to within 94 percent on the semi-solid manured plots and 92 percent on the liquid manured plots of the average infiltration rates of the respective control plots on 300 #N/acre plots after a 120 hour time delay.

Runoff pollutant yields for 150 liters of runoff:

1) The various pollutant mean yields in the runoff from semi-solid manured plots increased with increased manure nitrogen loading rates except for FSS and NO_3.
2) The pollutant mean yield for FSS in the runoff from semi-solid manured fields was reduced by 54 to 78 percent for the nitrogen loading rates when compared to the control plots.
3) The pollutant mean yield for NO_3 in the runoff from semi-solid manured plots did not exceed the yield from the control plots.
4) The various pollutant mean yields in the runoff from liquid manured plots increased with increased manure nitrogen loading rates.
5) The pollutant mean yields for TSS, FSS, VSS, and NO_3 in the runoff from liquid manured plots did not exceed the control plots except at 300 #N/acre loading rate.
6) The pollutant mean yields (not including FSS or NO_3) in the runoff from semi-solid manured plots when compared to the zero time delay plots were reduced an average of 46 percent after 24 hours and 76 percent after 48 hours.
7) The pollutant mean yields for all loading rates for COD, VSS, TS, FS, VS, N in the runoff from liquid manured plots when compared to the zero time delay plots were reduced an average of 75 percent after 24 hours and 94 percent after 48 hours.
8) The pollutant mean yields for all loading rates for FSS and NO_3 in the runoff from semi-solid manured plots did not exceed the control plots yields at any time delay.
9) The pollutant mean yields for all loading rates for TSS, FSS and VSS from liquid manured plots did not exceed the control plot yields after a 48 hour time delay.
10) The pollutant yield for all loading rates for NO_3 in the runoff from the liquid manured plot exceeded the control plot yield 10 fold after 48 hours.

11) The pollutant yield for all loading rates for P and K in the runoff from the liquid manured plots exceeded the zero time delay plots by 3 fold at 24 hours for P and 75 percent for K at 48 hours while at other time delays were below the zero hour plots.

12) The pollutant yield for the 120 hour repeated plot for the 300 #N/acre plots was comparable to the 48 hour plot for COD, TSS, FSS, N and K for liquid manure plots and for COD, TSS, FSS, VS and K for liquid manure.

13) The pollutant yield for the 120 hour repeated plot for 300 #N/acre plots was comparable to the control plot yields for VSS and P of semi-solid manure and to VSS, TS, FS, N and P of liquid manure.

REFERENCES

1. Biggerstaff, S. D. and I. D. Moore. 1982. Effect of surface condition on infiltration, runoff and erosion reconstructed soils. ASAE Winter Meeting. Paper No. 82-2586, Chicago, IL. December 14-17.

2. Bouma, J., C. F. M. Belmans, and L. W. Dekker. 1982. Water infiltration and redistribution in a silt loam subsoil with vertical worm channels. Soil Science Soc. Am. J. 46, 917.

3. Bradstreet, R. B. 1965. The Kjeldahl method for organic nitrogen. Academic Press, NY.

4. Brustkem, R. L. and H. J. Morel-Seytorex. 1970. Analytical treatment of two-phase infiltration. J. Hydr. Div., Proc. ASCE, 96, 2535.

5. Chien, S. H. and W. R. Clayton. 1980. Application of Elovich equation to the kinetics of phosphate release and soption in soils. Soil Sci. Soc. Am. J., 44, 265.

6. Fiske and Subbarow. 1925. J. Biol. Chem. 66, 375.

7. Frere, M. H. 1975. Integrating chemical factors with water and sediment transport. J. Env. Qual. 4, 12.

8. Green, W. H. and S. A. Ampt. 1911. Studies on soil physics-1. The flow of air and water through soils. J. Agr. Sci. 4, 1.

9. Hirschi, M. D., B. J. Barfield, I. D. Moore, R. I. Barnhisel, M. Ruetten, M. Leopold and R. G. Williams. 1981. Portable rainfall simulator for erosion studies. ASAE Summer Meeting. Paper No. 81-2058. Orlando, FL June 21-24.

10. Holtan, H. N. 1961. A concept for infiltration estimates in watershed engineering. USDA, ARS, 41.

11. Horton, R. E. 1939. Analysis of runoff-plot experiments with varying infiltration capacity. Trans. Am. Geophys. Union, Hydr. Pap. 693.

12. Khaleel, R., G. R. Foster, K. R. Reddy, M. R. Overcash and P. W. WEsterman. 1979a. A nonpoint source model for land areas receiving animal wastes: III. A conceptual model for sediment and manure transport. Trans. ASAE, 22, 1353.

13. Khaleel, R., G. R. Foster, K. R. Reddy, M. R. Overcash and P. W. Westerman. 1979b. A nonpoint source model for land areas receiving animal wastes: IV Model inputs and verification for sediment and manure transport. Trans. ASAE 22, 1362.

14. Khaleel, R., K. R. Reddy and M. R. Overcash. 1979c. Transport of potential pollutants in runoff water from land areas receiving animal wastes: a review. Water Research 14, 421.

15. McCaskey, T.A., G. H. Rollins and J. A. Little. 1971. Water quality of runoff from grassland applied with liquid, semi-liquid, and dairy "dry" waste. Livestock Waste Management and Pollution Abatement. Proc. Interl. Symp. on Livestock Wastes. ASAE, Publ. Proc-271. 239.

16. McKeague, J. A. C. Wang and G. C. Topp. 1982. Estimating saturated hydraulic conductivity from soil morphology. Soil Sci. Soc. Am. J. 46, 1239.

17. Methods of soil analysis. 1965. Agronomy No. 9, Part 1. American Society of Agronomy, Madision, WI.

18. Moore, I. D. 1981. Infiltration equations modified for surface effects. J. Irr. Drain. Div., Proc. ASCE, 107, 71.

19. Moore, I. D. and J. D. Eigel. 1981. Infiltration into two-layered soil profiles. Trans. ASAE 24 , 1496.

20. Moore, I. D., C. L. Larson, and D. C. Slack. 1980. Predicting infiltration and micro-relief surface storage for cultivated soils. Water Res. Res. Center., Univ. Minn., Bull. 102, 122 pp.

21. Nobleanc,A. and J. H. Morel-Seytorux. 1972. Perturbation analysis of two-phased infiltration. J. Hydr. Proc. ASCE, 98, 1527.

22. National Engineering Handbook. 1972. Soil Conservation Service, USDA.

23. Orion Instructional Manual - Nitrate Model 92-07. 1971. Orion Research Inc, Cambridge, MA.

24. Orion Instructional Manual - Ammonia Model 95-10. 1974. Orion Research Inc. Cambridge, MA.

25. Overcash, M. R. 1976. Unpublished data. Biological and Agricultural Engineering Department, North Carolina State University, Raleigh, NC.

26. Phillips, J. R. 1957. The theory of infiltration: The infiltration equation and it's solution. Soil Sci. 83, 345.

27. Reddy, K. R., R. Khaleel, M. R. Overcash and P. W. Westerman. 1979a. A nonpoint source model for land areas receiving animal wastes: I. Mineralization of organic nitrogen. Trans. ASAE, 22, 863.

28. Reddy, K. R., R. Khaleel, M. R. Overcash and P. W. Westerman. 1979b. A nonpoint source model for land areas receiving animal wastes: II. Ammonia volatilization. Trans. ASAE 22, 1398.

29. Reddy, K. R., R. Khaleel, and M. R. Overcash. 1980a. Carbon transformations in the land areas receiving organic wastes in relation to nonpoint source pollution: A conceptual model. J. Env. Qual. 9, 434.

30. Reddy, K. R., M. R. Overcash, R. Khaleel and P. W. Westerman. 1980b. Phosphorous adsorption-desorption characteristics of two soils utilized for disposal of animal wastes. J. Env. Qual. 9, 86.

31. Ross, I. J., S. Sizemore, J. P. Bowden, and C. T. Haan. 1978. Effects of soil injection of liquid dairy manure on the quality of surface runoff. University of Kentucky Water Resources Research Institute, Lexington, KY. Research Report No. 113, 66 pp.

32. Schroeder, S. A. G. R. Foster, W. C. Moldenhauer, J. V. Mannering. 1982. Hydraulic conductivity of soil as determined from cumulative runoff. Soil Sci. Soc. Am. J. 46, 1267.

33. Sharma, M. L., G. A. Gander, and C. G. Hunt. 1980. Spatial variability of infiltration in a watershed. J. Hydrol., 45, 101.

34. Sharpley, A. N., L. R. Ahuja, and R. G. Menzel. 1981a. The release of soil phosphorus to runoff in relation to the kinetics of desorption. J. Env. Qual., Vol. 10, No. 4, pp. 386-391.

35. Sharpley, A. N., L. R. Ahuja, M. Yamamoto and R. G. Menzel. 1981b. The kinetics of phosphorus desorption from soil. Soil Sci. Am. J. 45, 493.

36. Sharpley, A. N., R. G. Menzel, S. J. Smith, E. D. Rhoades and A. E. Olness. 1981c. The sorption of soluble phosphorus by soil material during transport in runoff from cropped and grassed watersheds. J. Env. Qual., 10, 211.

37. Standard methods for the examination of water and wastewater, 14th Ed. 1975. American Public Health Association, Washington, D.C. pp. 874.

38. Statistical analysis system. Users Guide. 1979. SAS Institute Inc. Cary, MC.

39. Steenhuis, T. S., R. E. Muck, T. R. McCarty. 1979. Conceptualization of water nutrient and pesticides transport in shallow soils. ASAE Summer Meeting. Paper No. 79-2012. Winnipeg, Man. Canada, June 24-27.

40. Streeter, V. L. and E. B. Wylie. 1979. Fluid Mechanics, 7th Ed. McGraw-Hill Inc., New York.

41. Technicon Auto Analyzer I. 1965. Industrial Method 348R-61-31-5. Technicon Inc. Terrytown, NY.

42. Timmons, D. R. and R. F. Holt. 1977. Nutrient losses in surface runoff from a native prairie. J. Envi. Qual., 6, 369.

43. Walter, M. F., T. S. Steenhuis, and D. A. Haith. 1979. Nonpoint source pollution control by soil and water conservation practices. Trans. ASAE, 22, 834.

44. Wadleigh, C. H. 1968. Wastes in relation to agriculture and forestry. USDA Misc. Publ. 1065.

45. Wendt, R. C. and R. B. Corey. 1980. Phosphorous variations in surface runoff from agricultural lands as a function of land use. J. Envi. Qual., 9, 130.

46. Westerman, P. W. and M. R. Overcash. 1980. Dairy open lot and lagoon irrigated pasture runoff quantity and quality. Trans. ASAE, 23, 1157.

47. Williams, R. G., B. J. Barfield and R. I. Barnhisel. 1978. Laboratory rainfall simulator for erosion studies of strip mine spoil material. Institute for Mining and Minerals Research, Kentucky Center for Energy Research Laboratory, University of Kentucky, Lexington, 91 pp.

NOMENCLATURE

A	Surface are of the top of a soil core
a	Constant equal to $(b + 3)/(2b + 3)$
b	Slope of log-log plot of moisture content versus suction curve.
C	Constant equal to $(\Delta L/A)\ \Delta H$
COD	Percent of COD applied/liter of runoff
f	Infiltration rate
F	Infiltration volume
ΔH	Head of water above test soil core
K	Saturated hydraulic conductivity in wetted soil zone
K_s	Saturated hydraulic conductivity of the soil
$K_r(\theta)$	Relative hydraulic conductivity of the soil at given soil moisture (θ)
ΔL	Length of soil core
N	Percent of N applied/liter of runoff
P	Simulator rainfall pulses/minute
R	Liters of runoff
RR_A	Actual rainfall rate given by simulator pulse/rate (P)
RR_g	Rainfall rate using standard rainfall gauges
S_{AV}	Average soil suction
Sw	Capillary suction at the wetting front
Δt	Percent TS applied/liter of runoff
V	Volume of water passed through the soil media over test period

x	Intercept of the log-log plot of soil moisture content versus suction curve
y_{el}	Air entry matric potential
γ_b	Soil bulk density
Θ_i,Θ_f	Initial and final soil moisture content - volume basis
Θ_s	Saturated soil moisture content-volume basis
Θ_{vol}	Soil moisture content-volume basis
θ_{weight}	Soil moisture content-weight basis
$\Delta\Theta$	Initial soil moisture deficit $(\Theta_s - \Theta)$ - volume basis

APPENDIX

RAW DATA FOR TOTAL POLLUTANT YIELD IN RUNOFF FROM EACH TEST PLOT

TABLE 17. POLLUTANT YIELDS IN RUNOFF FROM TEST PLOTS WITH SEMI-SOILD MANURE - 1981.

REP.	Time Delay (Hr)	Nit. Load (#N/A)	COD	TSS	FSS	VSS	TS	FS	VS	NO$_3$	NH$_4$	N	P	K
			(Mg.)											
1	0	75	199800	8281	.	48950	222800	7303	134400	21.23	12710	12140	.	82080
2	0	75	7840	72600	49590	1873	11920	90520	6219	25.86	.	44300	.	294
3	0	75	10210	125700	121000	2157	340700	16170	7408	39.52	149	559	16.6	460
1	24	75	220000	184900	205000	14050	8682	7357	1615	10.98	.	64	4063.0	27550
3	24	75	174300	7654	.	41950	18030	10270	122500	601.60	3738	12280	4123.0	11200
2	48	75	2670	192800	150200	57710	133600	94350	2554	25.22	.	2912	58.9	49240
1	48	75	391500	.	.	.	10860	7878	2792	33.40	.	19180	6033.0	60470
3	48	75	5370	2352	.	1100	9854	5642	4208	16.11	2207	7811	108.2	11050
1	0	150	202200	166900	117000	56810	364600	232000	140600	12.98	41	10520	5975.0	814
2	0	150	406800	141400	3962	94910	543600	254000	289600	41.33	.	23520	.	46520
3	0	150	1858000	93970	2821	58770	331200	140600	1296000	36.20	10950	97190	61480.0	96610
1	3	150	3110000	.	.	265500	2764000	151600	1197000	28.12	.	145600	28670.0	235100
2	3	150	528600	3048	52980	648	13870	148100	4403	516.90	.	216	9526.0	130000
3	3	150	351800	14830	11300	71040	448200	211400	233100	26.41	21920	126900	52820.0	1137
1	6	150	395600	895900	.	156600	1015000	562000	377100	12.84	.	18340	.	21890
2	6	150	96060	44850	21020	23440	174300	99850	73810	.	.	6211	.	27960
3	6	150	2087000	178900	8353	556600	327200	218700	760600	.	5053	48970	16980.0	117700
3	24	150	8467	146600	164000	206200	1652000	6547	531200	22.72	4957	32110	16090.0	61840
1	48	150	180100	57810	64910	.	5297	3575	288300	14.36	.	8886	11.3	20550
2	48	150	2171	50680	64600	6997	143900	105300	2329	426.00	.	132	.	109400
1	72	150	326600	.	.	.	6821	72330	300000	260.80	.	17700	6186.0	57840
1	96	150	314800	74130	215200	343000	7324	.	322100	415.50	.	17070	4822.0	52610
1	0	300	3835000	189400	4797	918400	4150000	221400	2496000	355.80	.	193300	74300.0	1122
2	0	300	4319000	255400	5266	1234000	44500	19180	3382000	14.30	131200	229100	563.3	492500
3	0	300	2965000	418100	286500	160900	1453000	919900	454900	21.40	.	174400	.	32930
1	24	300	304000	27650	.	93210	37960	23580	229000	36.46	.	18700	382.9	1413
2	24	300	842100	.	.	2122	21940	.	869000	24.32	6575	53750	586.8	131300
3	24	300	1894000	330600	243200	801600	1281000	839300	2413000	23.29	.	118500	.	.
1	48	300	115100	68850	49510	23970	202800	105400	98800	491.20	.	7506	2082.0	22100
2	48	300	318100	278400	301300	15640	486600	108100	480900	25.51	.	14010	572.0	50910
3	48	300	681400	4297	57990	1010	11490	118200	4010	9.30	18	40020	11700.0	67640
1	120	300	.	.	.	959	.	.	.	11.04	.	.	.	.
2	120	300	520300	98030	33430	10230	1707000	1157000	468000	37.29	3945	27430	.	120400
3	120	300	93370	.	.	.	5436	4130	159400	3469.00	.	7523	.	17590
1	0	0	3805	.	525500	5839	44460	40090	.	5.46	.	128	1906.0	173
2	0	0	1066	2332	.	96	5272	.	1095	38.14	.	34	16.8	1762
3	0	0	12900	74970	65510	13330	6209	3968	.	17.43	.	42	.	199
4	0	0	.	.	.	.	5990	5051	935	1733.00	.	405	.	240

TABLE 18. POLLUTANT YIELDS IN RUNOFF FROM TEST PLOTS WITH LIQUID MANURE - 1982.

REP.	TIME DELAY (Hr)	NIT. LOAD (#N/A)	COD	TSS	FSS	VSS	TS	FS	VS	NO_3	NH_4	N	P	K
								(Mg.)						
1	0	0	37130	3700000	3462000	1698000	3601	2632	975	10.7	.	26	1952	3017
2	0	0	571	.	.	295	5037	4246	820	421.0	.	18	74	39820
3	0	0	1028	100900	100300	.	5715	4532	1176	17.6	.	646	1098	5763
1	0	75	223800	.	.	.	4688	2770	276200	11.2	.	7979	.	.
2	0	75	482800	437500	591	566	642400	315400	325200	834.2	3161	21360	32720	27580
3	0	75	475800	.	.	328000	4272	8	147100	.	.	.	13010	15970
1	24	75	70150	41470	47900	24960	3643	2546	1107	8.7	.	.	3727	13940
2	24	75	.	133600	164400	7599	81220	65590	16000	.	.	.	2921	301
3	24	75	245700	99690	93480	115800	5731	3952	245500	.	.	8280	19070	33430
1	48	75	19340	.	.	.	5035	3762	1356	9.1	.	.	6719	27830
3	48	75	14380	.	.	.	5541	4247	20220	17.3	.	.	1207	55
1	0	150	1401000	810800	297800	501200	1321000	509600	819000	28.1	385	65460	54670	63680
2	0	150	533600	264000	315900	273800	1365000	119200	416700	.	.	119000	33180	47360
3	0	150	314100	3542	2787	656	7252	5432	27970	23.8	.	8730	137	23860
1	3	150	420100	35380	396800	9188	645400	32410	269400	49.4	147	12550	24250	20000
2	3	150	993100	220300	250800	410500	268000	165000	730500	18.9	5720	44320	61980	105000
3	3	150	997300	63350	368700	168500	878300	634600	250300	9.8	.	.	6271	153500
1	6	150	2160000	218500	.	304600	283800	203500	416300	9.8	.	77390	152400	61570
2	6	150	1831000	2103000	3475000	190900	1217000	891400	289600	.	.	.	153800	143000
3	6	150	947500	3538	2332	89450	.590	4099	225100	10.1	.	16970	18930	26910
1	24	150	89170	.	4503	449	5933	4508	1346	.	.	2806	12	278
2	24	150	982000	98520	133000	72340	673100	53780	199700	17.3	.	.	13210	68820
3	24	150	219500	151400	110000	248100	692400	444500	225200	.	.	.	122000	130300
2	48	150	273300	380500	654200	140400	1045000	767800	272600	.	.	.	16350	106500
3	48	150	196900	66080	81280	55540	5875	4582	202300	.	.	5803	17330	172800
1	48	300	267	.	.	.	5376	4415	976	12.7	.	.	.	40
2	48	300	416	.	.	.	6571	4801	252200	4523.0	.	.	.	640100
3	48	300	322100	146100	159400	969	9024	7817	288200	.	2498	12320	26040	302200
1	120	300	177100	.	.	.	.	4340	207000	.	.	.	.	190500
2	120	300	14100	.	.	.	6846	4883	29660	10740.0	.	1582	.	3092
3	120	300	.	.	1619	.	3887	3001	896	5574.0	.	.	48	38
2	96	150	1909	35400000	4850000	95900	16840	17110	1394	6.5	.	28	99	34
1	0	300	637	725	367	364	1665	1126	592	2.8	5	26	13	40
2	0	300	3934000	5311000	3546000	2311000	4572000	2244000	2314000	4.6	493	167900	164000	140500
3	0	300	14560000	57420000	63580000	7302000	33190000	23300000	7415000	4.8	.	332600	834500	516500
1	24	300	106	2575	4455	153	3201	3572	356	4.0	.	3	17	10
2	24	300	4429	52030000	62860000	1421	427700	255100	3034	15.5	11	8186	3812000	19630
3	24	300	8028000	35030000	218800	1974000	30360000	2887	239	3.0	.	4	21	9