EFFECTS OF HEAVY FEEDLOT MANURE APPLICATION RATES ON THE BASIC INFILTRATION RATE OF SOIL

by

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

An increased demand for quality food products along with a growth in the human population has led to an increase in beef production in the United States. In 1945, the annual per capita beef consumption was 74 pounds. By 1970, the annual per capita beef consumption had increased by 64% to 116 pounds (Midwest Research Institute, 1971).

To supply the beef for this increased consumption, the number of cattle has increased tremendously. In the last 25 years, there has been an increase of 36 million head of beef cattle, or an increase of about 50%. In the last eight years, the increase has been even more evident with an increase of 17 million head of cattle, or an increase equal to 19% (Loehr, 1971). This increase has been for the total beef cattle population. However, when considering cattle waste problems it is the animals on feed for slaughter in feedlots that are the cause of the major waste disposal problem. Waste handling problems develop in feedlots because of the large number of cattle confined to small areas. In 1969, there were 12 million cattle on feed for slaughter (Loehr, 1970b). This was a 66% increase in numbers over the previous eight year period. If the increase is evaluated during the previous fifteen year period, there was found to be a 120% increase in the number of cattle on feed for slaughter.

Not only has the number of cattle on feed increased, but the average size of the feedlots has increased. A phenomena exists in that there are more large feedlots now than ever before; while at the same time, the total number of feedlots has decreased. Kiesner (1970) summarized the number of cattle in feedlots and feedlot size in the top 22 major feeding states. His findings showed that the number of feedlots that feed less than 1,000 head has declined from 187,725 in 1969 to 180,329 in 1970. This is a sharp decrease in the number of small feedlots. However at the same time, there has been an increase in the number of larger feedlots of over 1,000 head. In 1970, there were 2,221 lots of over a thousand head compared to 2,069 such feedlots in 1969. Larger feedlots of over 16 thousand have also increased. In 1969, there were 132 such feedlots compared to 146 of this size in 1970. The number of the very largest feedlots has experienced an even larger percentage increase. In one year, the number of feedlots over 32 thousand head increased 33%. In 1970, there were 41 feedlots of this size compared to only 31 in 1969.

This increase in the size of feedlots explains how more cattle are on feed than ever before, and at the same time the total number of feedlots has decreased. The 31 feedlots of over 32 thousand head capacity fed 2,183,000 head of cattle in 1969. If this number of cattle is compared to the 2,807,000 produced by the 41 feedlots of over 32 thousand head capacity in 1970, it can be seen that the very large feedlots are producing a large number of the fat cattle that go to the consumer.

Manure is an unavoidable by-product of livestock feeding. Each animal produces from eight to ten times the amount of waste generated by one person, depending on the parameter being considered (Loehr, 1970a). Considering the number of cattle, this can be a tremendous amount of waste material. For the nation as a whole, farm animals produce ten times the waste of the human population (Loehr, 1970a). It has been estimated that 1.7 billion tons of animal waste are generated each year in the United States (Anderson, 1971).

The traditional method of manure disposal has been to spread it onto cropland. The plant nutrients in the manure would not be wasted but would provide a return in the form of increased crop production. Under these conditions, the manure was spread relatively thin to obtain maximum returns from the manure.

Many feedlots, experiencing rapid growth, have found that manure disposal is a major problem. The traditional method of land disposal of manure is still considered the least cost method of waste disposal. However, when the expense of transporting and spreading the manure is considered, it is found that the plant nutrients can be purchased as commercial fertilizer and applied to the cropland cheaper and with less trouble than can feedlot manure. Because the feedlot manure has a low economic value, it is not worth the labor and expense of transporting it great distances. The higher expense of transporting manure greater distances from the feedlot has encouraged many feedlot managers to make heavy applications of manure to cropland near the feedlot.

The application of large quantities of feedlot manure to cultivated soils naturally alters the soil composition and, therefore, changes the water intake rate as compared to a non-manured soil (Cross and Fischback, 1972). The purpose of this study was to evaluate the basic intake rate of a soil as it is affected by heavy applications of feedlot manure. Many simplifications were made in this evaluation. Factors such as flow rate down the furrow, hydrostatic head, and soil moisture were considered random and were neglected. The principal objective of this study was to determine the relationship between manure application rate and the basic infiltration rate of a soil. To study the relationship between manure application rate and the soil's basic infiltration rate, mathematical equations were developed.

REVIEW OF LITERATURE

Soil System

The soil system has long been used for the ultimate disposal of many wastes. The biological, chemical, and physical properties of the soil system provide the best facilities for treatment of biodegradable waste (Webber, 1971).

Phosphorus applied to the soil is fixed by the soil complex and rendered insoluble in a few hours. Phosphorus contamination in streams occurs mainly because of soil erosion (Webber, 1971). However, the soil complex is not effective in fixing high levels of nitrogen applied to the soil as animal waste. Nitrogen from animal waste is a potential source of environmental contamination from commercial feeding of livestock.

Nitrification and denitrification are the two opposing processes that occur in the soil system. Nitrification is the biological transformation of nitrogenous compounds into nitrate nitrogen. Nitrite and nitrate nitrogen are water soluble and therefore can be leached through the soil profile into the ground water. Denitrification is the biological reduction of nitrate nitrogen into volatile gases, principally nitrous oxide and molecular nitrogen (Webber, 1971).

Considerable amounts of salts, along with the phosphorus and nitrogen, are added to the soil with the application of manure. Rations fed to beef animals in feedlots commonly have 0.5% sodium chloride (Neumann and Sharp, 1969). Most of this salt is carried through the animal and is excreted in the manure and urine. Taiganides and Hazen (1966) indicated that 85% of the nutrients that an animal eats remain in the waste products of that animal.

This salt that is in the feedlot manure is added to the soil when the manure is removed from pens and spread on cropland.

Saline and Alkali Soils

The application of manure and/or effluent to cropland at very high rates may lead to excessive concentrations of soluble salts, exchangeable sodium, or both. For agriculture purposes, such soils can be considered undesirable because of possible changes in their physical structure and/or chemical composition. These changes can cause reduced crop yields and/or require special management practices. Three terms commonly used to describe soils with salt problems are saline, nonsaline-alkali, and saline-alkali.

The United States Department of Agriculture, Agricultural Handbook Number 60 (1954) defines saline soil, nonsaline alkali soils, and saline alkali soils as follows:

> Saline Soil - A nonalkali soil containing soluble salts in such quantities that they interfere with the growth of most crop plants. The electrical conductivity of the saturated extract is greater than 4 millimhos per centimeter (at 25 degrees C.), and the exchangeable-sodium percentage is less than 15. The pH reading of the saturated soil is usually less than 8.5.
>
> Nonsaline-Alkali Soil - A soil that contains sufficient exchangeable sodium to interfere with the growth of most crop plants and does not contain appreciable quantities of soluble salts. The exchangeable-sodium-percentage is greater than 15, and the electrical conductivity of the saturated extract is less than 4 millimhos per centimeter at 25 degrees C. The pH reading of the saturated soil paste is usually greater than 8.5.
>
> Saline-Alkali Soil - A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable-sodium-percentage is greater than 15, and the electrical conductivity of the saturated extract is greater than 4 millimhos per centimeter at 25 degrees C. The pH reading of the saturated soil is usually less than 8.5.

Saline soils are high in soluble salts, and can often be recognized by the presence of a white crusty layer on the soil surface. Sodium seldom comprises more than half the soluble cations in the soil solution. The amount of calcium and magnesium cations can vary considerably, while soluble and exchangeable potassium is usually available in small amounts, but can occur in higher concentrations. Because of the amount of excess salts and the relatively low amounts of exchangeable sodium, saline soils are generally well flocculated and as a consequence, can have a permeability equal to or greater than similar non-saline soils.

Non-saline-alkali refers to those soils that have a high exchangeable sodium percentage, above fifteen percent. Alkali soils often occur in semi-arid and arid areas as small irregular areas often referred to as slick spots. The high exchangeable sodium percentage is the most important factor, as it influences both the chemical and physical properties of the soil. As the percentage or proportion of exchangeable sodium increases, the soil tends to become more dispersed. When the soil becomes dispersed, the soil seals itself and movement of water into and through the soil is reduced considerably.

Saline-alkali soils are formed by the combined process of salinization and alkalization. They are high in total salts, their electrical conductivity is greater than 4 mmhos per centimeter, and their percentage of exchangeable sodium is greater than 15%. As long as excess salts are present, these soils are similar to saline soils in physical properties. However, if the excess salts are leached downward, the remaining sodium can cause the soil to take on the characteristics of a non-saline alkali soil.

The soluble salts that occur in soils are the cations of sodium, calcium, and magnesium, and the anions of chloride and sulfate. Potassium also occurs in varying amounts and is thought to have some influence on soil structure. The original source of soil salts is from the weathering of the parent material of the soil. However, weathering of parent material is not the main cause of soil salinity and soil alkalinity. Saline and alkali soils usually occur in locations where salts are brought into the area from other locations. Water is the primary carrier of soil salts. Saline soil conditions occur in areas that have a supply of salts moving into the area and poor drainage of water and salts out of the soil profile (United States Department of Agriculture, 1954).

Infiltration Rate

One physical characteristic of soils affected by soil salinity and alkalinity is the soil infiltration rate. Soil infiltration rate is defined as follows by the United States Department of Agriculture, Agriculture Handbook Number 60 (1954).

> Infiltration rate - Infiltration Capacity - The maximum rate at which a soil, in a given condition at a given time, can absorb rain. Also, the rate at which a soil will absorb water ponded on the surface at a shallow depth when the ponded area is infinitely large or when adequate precautions are taken to minimize the effect of divergent flow at the borders. It is the volume of water passing into the soil per unit of area per unit of time, and has the dimensions of velocity, (LT^{-1}).

The infiltration rate of a soil can be influenced by many factors. Condition of the soil surface, chemical and physical status, nature of the soil profile, and distribution of water in the soil profile, are some of the factors that influence the soil infiltration rate and also change with time during the infiltration period (United States Department of Agriculture, 1954).

Tests with different water qualities have indicated that infiltration rates of saline and alkali soils are influenced by the quality of the water being applied (Christiansen, 1947).

The influence of water quality and composition on soil permeability is very pronounced, but generally overlooked when permeability tests are made. The use of water very low in salt content may result in the soil sealing to such an extent that reclamation is not possible. However, the use of water with medium to high salt content might prove satisfactory for leaching and not cause the soil to disperse and seal itself (Christiansen, 1947).

Changes of Soil Characteristics Due to Addition of Waste

Changes in the physical and chemical structure of a predominantly sandy soil were reported by Merz (1959) after digested sludge was applied at rates of approximately 10 to 100 tons per acre on a dry basis. The electrical conductivity of the soils increased from 0.062 to 0.079 millimhos per centimeter prior to application to 0.55 to 5.80 millimhos per centimeter after application and drying of the sludge. Extensive mineralization and crop performance indicated that the soil had a high salinity hazard. Permeability tests indicated that the permeability was 16 inches per hour before application, and 24 inches per hour after treatment with the digested sludge.

Webster (1954) reported the waste from the processing of vegetables was applied to a wooded area with no adverse effects. He indicated that there was no clogging of the soil, and that the water intake rate probably had increased. The soil was a Sansafras loamy sand. The waste water had a pH of 5.50 to 6.0, and 425 ppm of sodium.

Ramati (1966) reported that the problem of soil salinization, which sometimes arises in connection with using sewage water containing considerable quantities of soluble salts, is less serious on shifting sands than on other types of soil. This was because the salts were leached out from the root zone by high winter rainfall.

Irrigation with waste water can influence the chemical equilibrium of a soil system. Waste waters can contribute organic solids and suspended minerals to the soil. This has been known to increase the clay content of a soil. Organic matter also improves the aggregate stability of the soil, thus waste-waters high in organics have been used to improve the physical properties of soils (Wilson, 1968).

Waste-waters can also be detrimental to soils if they are high in monovalent cations such as sodium and ammonium. These cations can replace the divalent cations on the soil complex which could lead to an accumulation of sodium. This accumulation of sodium could be harmful to the soil's physical and chemical properties (Wilson, 1968).

Travis et al. (1971) reported research work in which the soil cores from four soils that were 6.7 centimeters in diameter and 42 centimeters in length were loaded with lagoon water. The infiltration rate in each of the four cores dropped from a steady rate, established by leaching with 0.01 N $CeSO_4$ solution, to a few tenths of a centimeter per hour, and then to zero.

The most drastic decrease in flow velocity occurred in Ashland II soil (silty clay loam) when treated with lagoon water. The flow rate decreased from a nearly constant velocity of 1.5 centimeters per hour to approximately 0.3 centimeters per hour after receiving 75 milliliters of lagoon water in a 5 1/2 hour period. This volume of 75 milliliters would correspond to a surface application of 2.1 centimeters or 0.8 inches of lagoon water. Flow then gradually decreased to zero. When flow had ceased, the soil core had received 469 milliliters of lagoon water over a seven day period. This total application would equal 13.3 centimeters or 5.2 inches of lagoon water to the soil core.

A more gradual decrease in flow occurred in the coarser textured Ashland I soil (loam). The flow rate decreased from 0.9 centimeters per hour to 0.3 centimeters per hour after receiving 111 milliliters of lagoon water. This would be 3.1 centimeters or 1.2 surface inches of lagoon water. The flow continued to decline, and after receiving a total of 1120 milliliters of lagoon water over a seven day period the flow stopped. This treatment would be equal to a surface application of 31.8 centimeters or 12.5 inches of lagoon effluent.

The flow through the other two soil cores responded in a similar way. Flow through the Campbell soil (loam) stopped after a total of 543 milliliters of lagoon water was applied, or surface application of 15.4 centimeters or 6.1 inches. The Dixson soil (clay loam) sealed after receiving a total of 593 milliliters or 16.8 centimeters or 6.6 surface inches of lagoon water.

From the above data, Travis et al. (1971) concluded that a reduction in infiltration rate occurred in finer textured soils from a lighter application of lagoon water than in a coarser textured soil.

Soil analyses indicated that the treated soils had higher proportions of nitrogen, potassium and ammonia (NH_4) than did the untreated soils. This increase was also accompanied by a decrease in leachable calcium and magnesium. In general, the highest percentage of leachable sodium was found in the top few centimeters of the soil. The electrical conductivity of the saturated extract of the top 15 centimeters of each soil after treatment, had increased by more than 200% (Travis et al., 1971).

Table 1 provides the electrical conductivity of saturated extract found before and after treatment by Travis et al. (1971).

To determine if the sealing of the soil cores was due to the salts in the lagoon water or to the organic particles, additional cores of Ashland I and Ashland II soils were leached with a simulated lagoon water. The simulated lagoon water contained the same salts as the lagoon water, but lacked the organic material that the lagoon water contained. The coarser textured Ashland I soil (loam) remained permeable when treated with the simulated lagoon effluent. A gradual decrease and pluggage in flow was observed when the core of Ashland II soil (silty clay loam) was treated with the simulated lagoon effluent. The fact that flow through Ashland II soil (silty clay loam) stopped, while flow through the coarser textured Ashland I soil (loam) continued when treated with the simulated lagoon water, indicates that cessation of flow may have been related to the higher clay content and consequent smaller pore structure (Travis et al., 1971).

Infiltration did stop in the finer textured soil, so relative proportions of these ions do have an affect on infiltration rate (Travis et al., 1971).

Travis et al. (1971) concluded from their study that lagoon water was a saline and alkali hazard to soils. To make the lagoon water acceptable for irrigation, a dilution rate of 16.7 parts water to 1 part lagoon water should be used. The dilution rate depends on the quality of the lagoon water and the dilution water.

Cross and Fischback (1972) conducted field experiments on infiltration as it is affected by various manure application rates and different depths of plowing. Manure applications in the spring of 1970 were 0, 40, 120, and 260

Table 1. Electrical Conductivity of Saturated Extract of Surface Soil Before and After Treatment.

Soil	E C Before	E C After
Ashland I	0.90 mmhos/cm	5.05 mmhos/cm
Ashland II	0.58	2.80
Dixson	0.95	3.03
Campbell	1.04	4.90

tons of dry matter per acre. In the spring of 1971, the manure application levels were reduced so that for the two year operation, the applications were 0, 40, 90, and 185 tons of dry matter per acre per year. Manure was incorporated into the soil by disk plowing to depths of 4, 8, and 12 inches. The inflow-outflow method was used to determine the infiltration rates. The crops were irrigated three times in 1970 and four times in 1971. Based on the foregoing conditions, the following was concluded:

1. The initial water intake rate increased as the quantity of manure application increased.
2. The basic water intake rate increased as more time from date of manure application had elapsed.
3. Manure application decreased the basic intake rate of the manured silt loam soil.
4. Depth of plowing did not appreciably affect the basic intake rate.

FACILITIES

Feedlot Design

The field studies for this report were conducted at the Pratt Feedlot Inc., Pratt, Kansas, as part of the project "Demonstration and Development of Facilities for the Treatment and Ultimate Disposal of Cattle Feedlot Waste." Under this project, field applications of feedlot manure and rain-water runoff effluent have been applied to test plots continuously for three years. These same plots, treatments, and irrigation data were utilized to obtain infiltration and intake data for this report.

The soil in these plots was determined to be of the Naron-Farnum Association with a basic intake rate of 0.10 inches per hour (Soil Survey, 1968).

The Pratt feedlot now has capacity for about 32,000 head of cattle. The feedlot is located on the abandoned concrete runways of an old airbase. The feeding pens are located on the runways such that each pen has a fifty foot apron next to the feed bunk extending back to the dirt surface. The lots slope away from the concrete apron, across the dirt surface, and into the drainage ditches just outside the pens. The pens are considered well drained. Rainwater runoff, once in the drainage ditch, flows into one of three lagoons.

Manure Disposal

Manure removal from the pens is completed after the cattle have been sold and removed from the pen. When the pen is empty, earth moving equipment is used to clean the pens. Motor graders scrape and windrow the manure.

Then paddle wheel scrappers are used to load the manure and haul it out of the pen for stockpiling. The manure is stockpiled outside of the pens until cropland is available for spreading. Manure spreading is usually done in the fall of the year after the corn crop has been cut for silage. When cropland becomes available, the stockpiled manure is loaded onto trucks for spreading onto the land. After the manure is applied, it is plowed into the soil.

The methods of application of runoff effluent and manure to the research plots are similar to those used on the rest of the cropland by the feedlot.

PROCEDURES AND EQUIPMENT

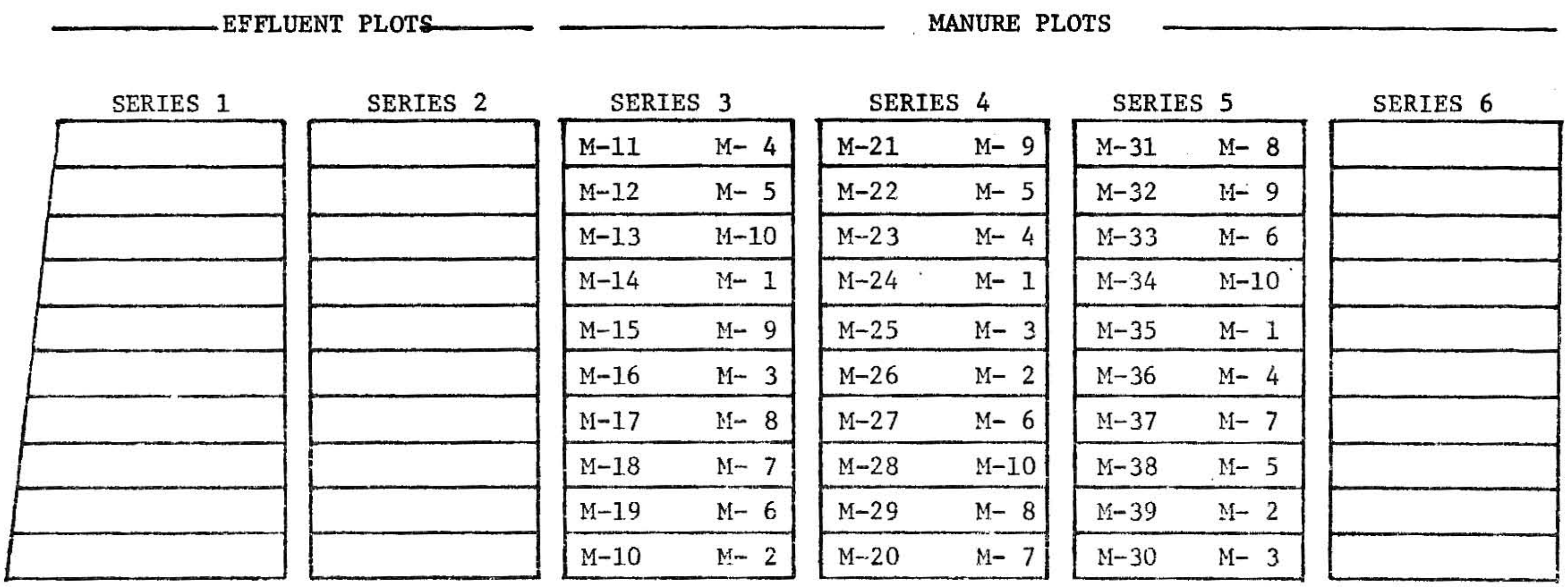
Manure Treatments

The research land was divided into six series of ten plots each. The layout is shown in Figure 1. The manure plots were in the last four series of the research area, just east of the effluent plots. The first two series, used for effluent treatment, were not considered in this study. The plots were thirty feet wide and about two hundred feet long. The treatments were assigned to each block in a random design to eliminate variation between blocks. One plot in each block was the control plot, and did not receive any manure over the three year period. The control plots were given the treatment numbers M-1.

Six plots of each series received manure applications each year. These treatments and applications rates ranged from a low rate of ten tons per acre per year to a high rate of 320 tons per acre per year. The desired treatments were 10, 20, 40, 80, 160, and 320 tons per acre per year, and treatment numbers assigned to these plots were M-2, M-3, M-4, M-5, M-7, and M-9, respectively. The three remaining treatments received first year applications of 80, 160, and 320 tons per acre, and treatment numbers of M-6, M-8, and M-10, respectively, were given to these plots.

Manure Application

Manure applications were completed in the fall of the year after the corn crop had been removed as silage. The manure was applied to the test plots with the same manure spreading trucks that were used to spread the rest of the feedlot's manure. Exact application rates were difficult to obtain because the test plots were too small for such large equipment.



MANURE PLOTS

TREATMENTS	TONS/ACRE	TREATMENTS	TONS/ACRE
M- 1	0	M- 6	80 first year
M- 2	10 every year	M- 7	160 every year
M- 3	20 every year	M- 8	160 first year
M- 4	40 every year	M- 9	320 every year
M- 5	80 every year	M-10	320 first year

Figure 1. Layout of Manure Test Plots.

To determine the actual amount of manure applied to each plot, a sixteen square foot sample was taken and weighed. The sample area was one foot wide, sixteen feet long, and was located near the center of the plot with its axis perpendicular to the axis of the plot. To obtain the desired sample size, a 3 ft. x 16 ft. sheet of four mil plastic was laid down on each plot before manure was applied. The manure truck drivers spread what they considered to be the correct application to each plot. A manure sample was collected from an area one foot wide and sixteen feet long and was weighed. The total sample weight and moisture content were used to determine the amount of manure applied on a dry weight basis. The collected samples were also used for chemical analyses of the manure.

Irrigation Procedure

A gated pipe and furrow irrigation system was used to irrigate the research plots. Water was supplied to the research plots by an underground supply system from an irrigation well. An eight-inch Badger measure-rite flow meter was installed in the mainline. The meter read in accumulative cubic feet of flow. The meter also had a sweep hand that could be used in conjunction with a stopwatch to determine the rate of flow. This meter was used to help establish the rate of application during an irrigation.

The main supply line was located on the north side of the research plots. Gated pipe laterals were placed on the west side of each of the six series. The layout of the irrigation system and drainage ditches are shown in Figure 2. All gates were opened to a predetermined setting prior to irrigation. Flow into each lateral was controlled by a gate valve at the head end of each lateral. These gate valves were adjusted to maintain a predetermined head in the standpipe. A gate valve and standpipe are shown

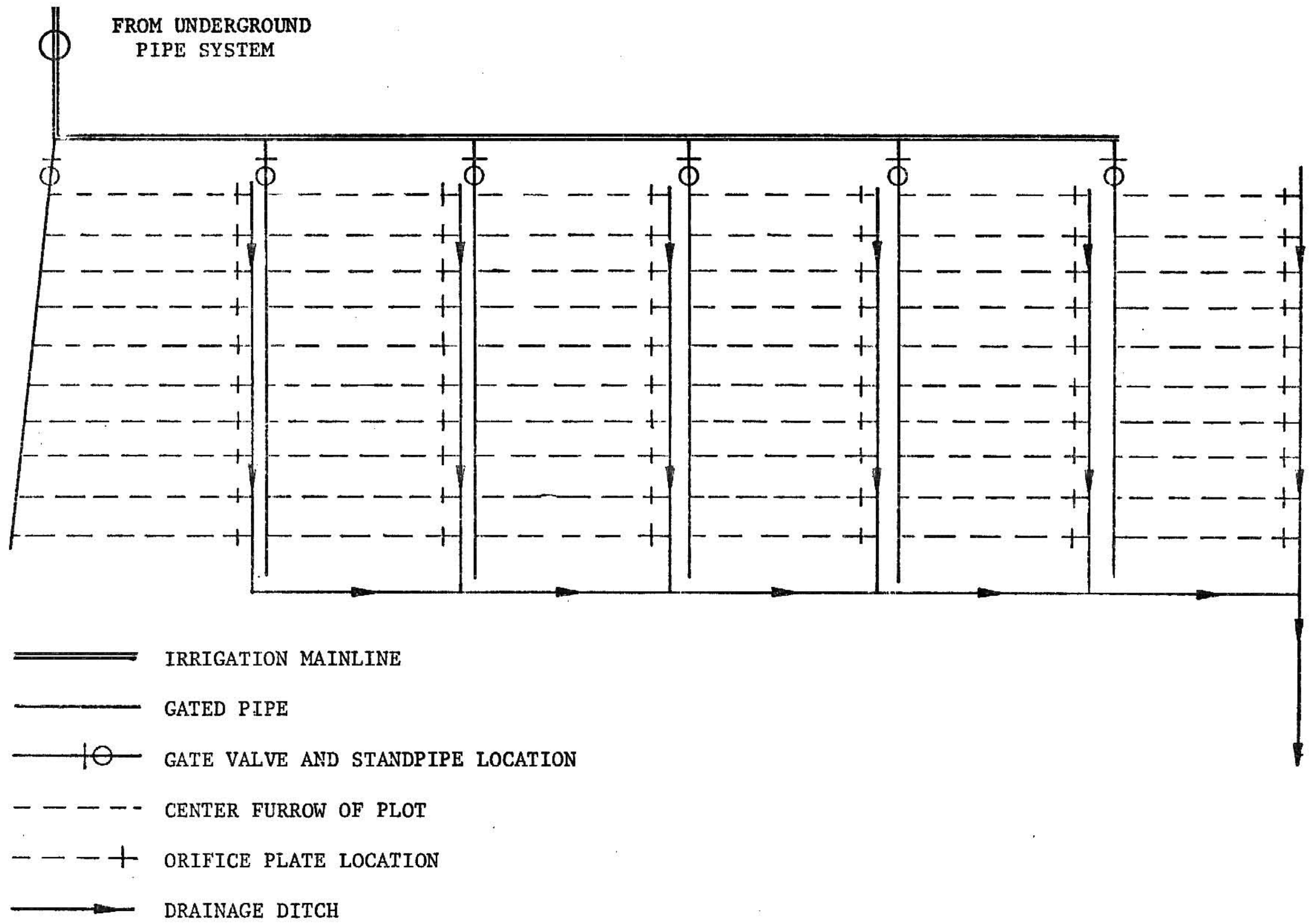


Figure 2. Layout of Irrigation System.

in Figure 3. The standpipes were 4.33 feet high from the center line of the lateral pipe, and open at the top for observation and measurements. Measurements of head in the standpipes were taken from the top of the standpipe and later converted to head.

The orifice equation was used for the determination of the inflow into the test rows. To determine the calibration coefficient for the orifice equation the time to fill a one-gallon container with the water from the gate in question was measured with a stop watch as shown in Figure 4. The head in the standpipe was also measured. The value of the calibration coefficient was determined from the equation given by Ohmes (1971):

$$C_g = q \ / \ \sqrt{2Gh_g}$$

where C_g = calibration coefficient considering both orifice coefficient and orifice area

q = inflow rate, in gallons per minute, determined by dividing one by the time in minutes required to fill the one gallon container

G = force of gravity, 32.2 feet per second squared

h_g = head in the standpipe, in feet, measured from the center line of the gated pipe lateral to the water level in the standpipe.

Standpipe head measurements were taken at intervals during the irrigation period. By using the orifice equation, standpipe head measurements (h_g), and calibration coefficients (C_g), it was possible to determine the inflow rate (q) during the irrigation period.

<u>Runoff Measurements</u>

The runoff rates for each test plot were measured with an orifice plate. The orifice plate was three feet long and one foot high, and was made out

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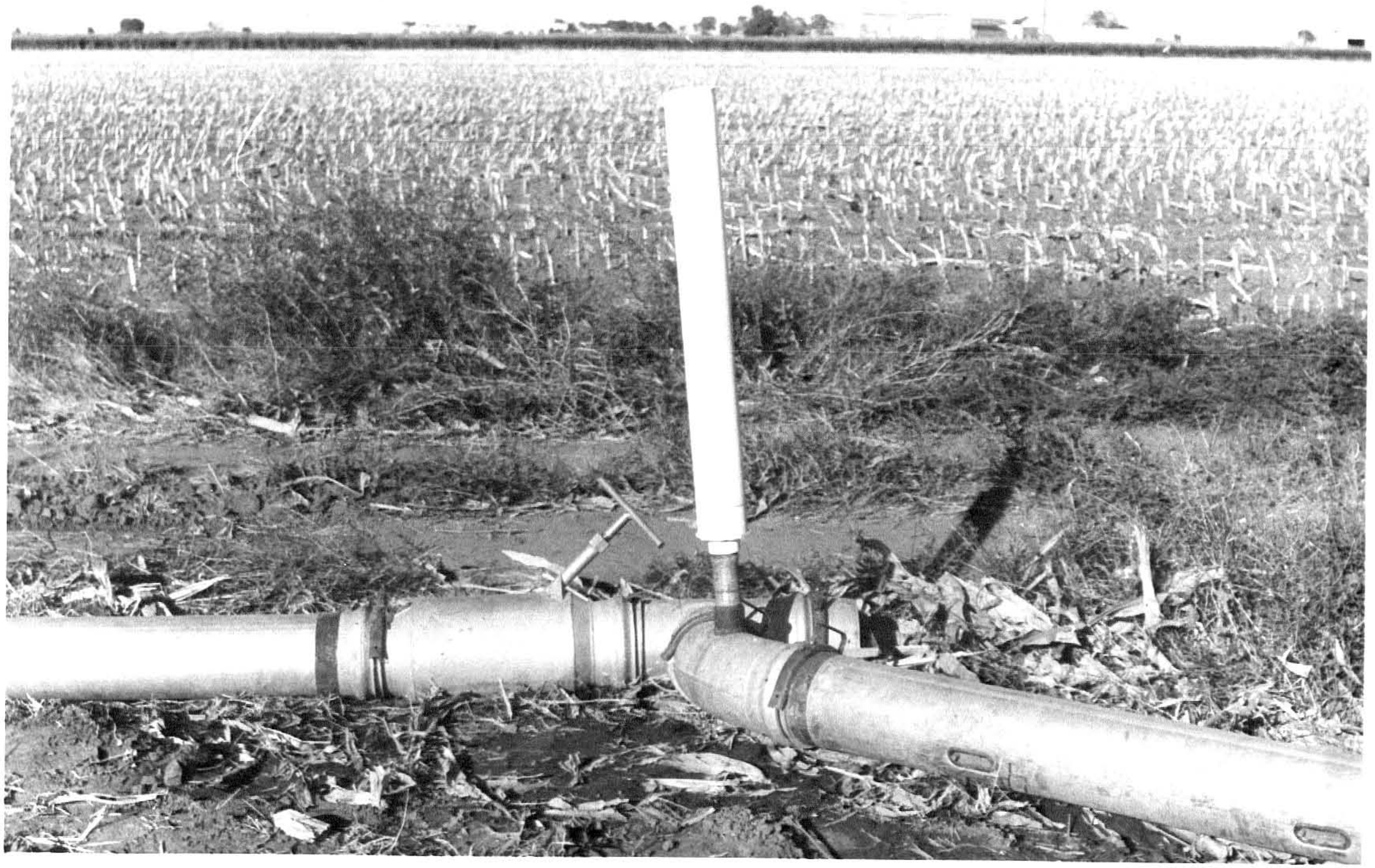

Figure 3. Irrigation Gate Valve and Standpipe.

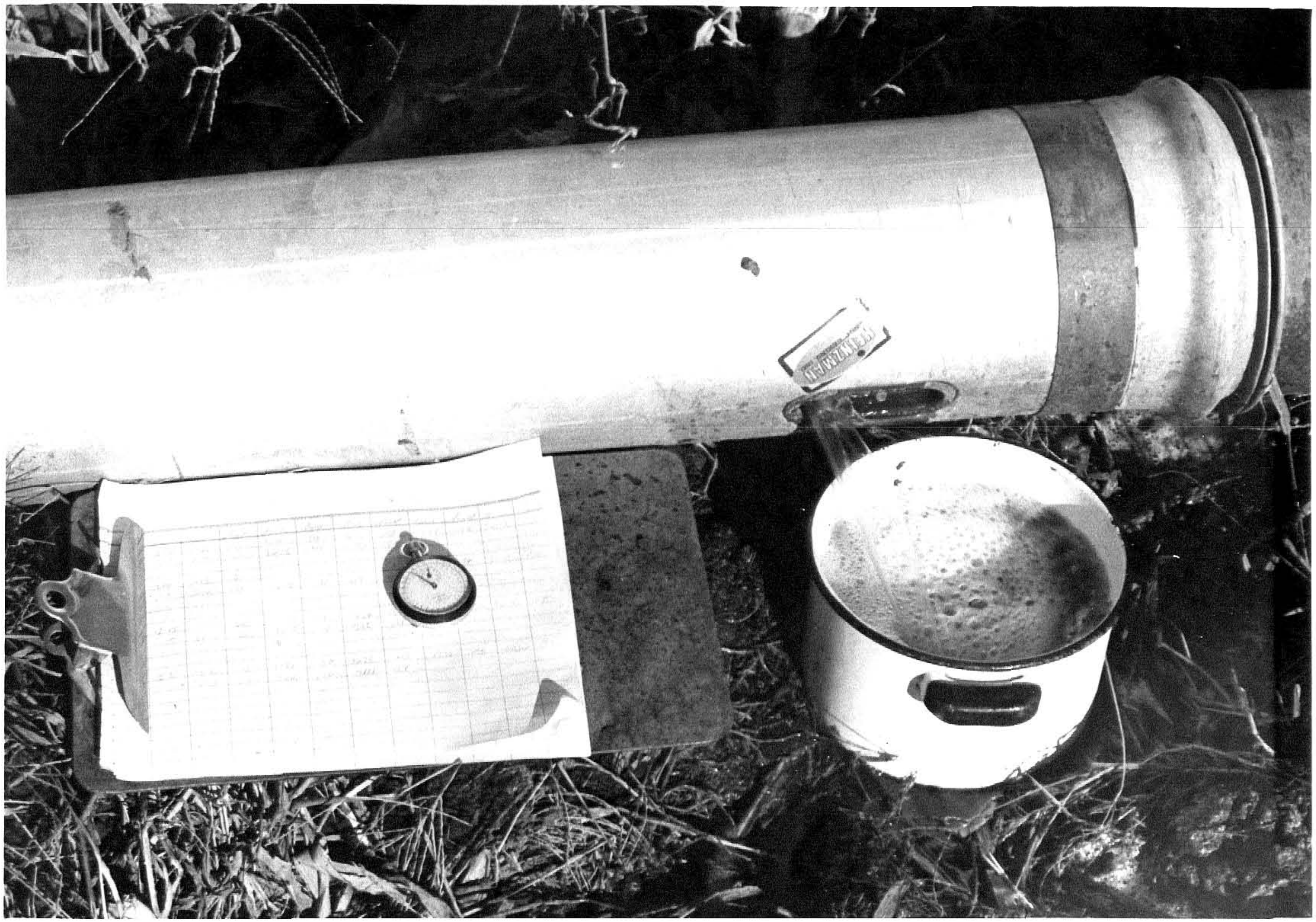

Figure 4. Measurement of Gate Flow for Determining Calibration Coefficients.

of 16-gauge sheet metal. A one inch hole was drilled 0.62 feet from the top of the plate and centered in the plate (Figure 5). In case of rainfall or excessive runoff, a slot two-inches deep and three-inches long was placed in the top center of each plate to provide an extra outlet for water and prevent the plate from being washed out.

The orifice plate was installed in the center row of each plot. The orifice plate was driven vertically into the ground so that the one inch hole was 0.2 feet above the bottom of the irrigation furrow. Dikes were placed in the furrows on each side of the orifice plate and channels were cut so that the flow from three rows was channeled through the orifice plate (Figures 6 and 7).

As shown in Figure 7, it was necessary to place a half-inch screen in front of the channel to prevent trash from plugging the orifice plates. Drainage water was carried away from the plots through drainage ditches at the lower end of each series of plots.

Measurement of the runoff rate from each plot required that the level of the water behind the orifice plate be measured. The water level was measured down from the top of the plate. This measurement was later converted to head. Using the equation for flow through an orifice, the runoff rate for a given head was determined from the following equation (Ohmes, 1971):

$$q = C_o A_o \sqrt{2Gh_o} / 0.002228 \qquad (2)$$

where C_o = orifice coefficient

A_o = orifice area, in square feet

h_o = head on orifice, measured from the center of the orifice in feet.

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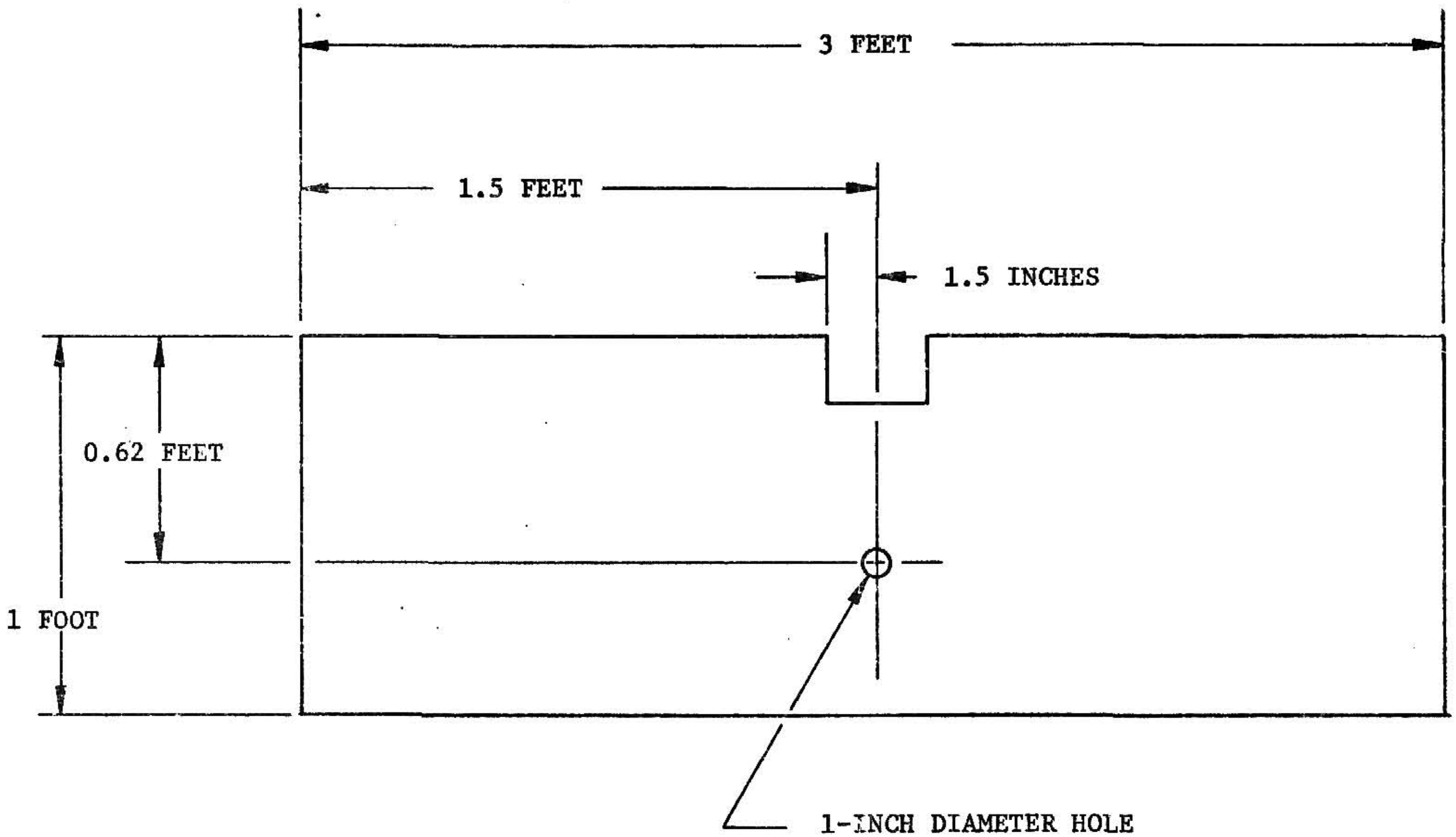

Figure 5. Orifice Plate Construction.

Figure 6. Orifice Plate Installation in Test Plot.

Figure 7. Orifice Plate, Side View.

The value of the orifice coefficient (C_o) was determined in the laboratory by subjecting each plate to given heads and measuring the resultant outflow. Since the heads were small compared to the size of the orifice, the value of C_o could be represented by an equation in which the value of C_o varied as a function of the head (Ohmes, 1971). Each orifice plate was individually calibrated and an orifice calibration equation was determined for each.

When water first flows through the orifice until it is above the top of the orifice, the flow will be weir flow instead of orifice flow. The weir flow can be calculated by the following equation (Ohmes, 1971):

$$q = C_w A_w \sqrt{2Gh_w} / 0.002228 \qquad (3)$$

where C_w = weir coefficient

A_w = weir area, in square feet

h_w = weir head, measured from bottom of the orifice, in feet.

The value for C_w was determined in the laboratory for various heads, and was found not to be a constant. When subjected to a linear analysis, C_w was found to be an exponential function of the head measured from the bottom of the orifice. Each orifice plate was individually calibrated and a weir calibration equation was determined for each (Ohmes, 1971).

Although drainage ditches were provided, water often did not drain away from the lower series of plots. Experience from previous years indicated that the drainage was so poor that it was not possible to obtain any runoff reading from series six because of the flooding of the orifice plates.

Because of this drainage problem, the orifice plates were not installed in the plots in series six.

Water did back up to the plates of series four and five during some of the irrigation periods. When this occurred, submerged or partially submerged orifice flow occurred. This usually occurred late enough in the irrigation period that no partially submerged weir flow occurred.

When submerged orifice flow occurred, the level of water above and below the orifice plates were recorded. With these head measurements, it was possible to calculate the submerged orifice flow with the following equation when necessary (Ohmes, 1971):

$$q = C_o A_o \sqrt{2G (h_u - h_1)} / 0.002228 \qquad (4)$$

where C_o = orifice coefficient

h_u = upper head, in feet

h_1 = lower head, in feet.

Partially submerged orifice flow can be calculated if the upstream water level (upper head) and the downstream water level (lower head) are known. However, partially submerged orifice flow is made up of two parts; the part that includes the flow through the orifice above the lower head, and the part below the lower head.

Flow above the lower head can be calculated using the following equation (Ohmes, 1971):

$$q_1 = C_o a_1 \sqrt{2G (h_u - h_1)} / 0.002228 \qquad (5)$$

where q_1 = flow rate from the part of the orifice above the lower head, in gallons per minute

a_1 = only that orifice area above the lower head, in feet squared.

Flow from the orifice below the lower head acts as a submerged orifice flow, and can be calculated by using the following equation (Ohmes, 1971):

$$q_2 = C_o \, a_2 \sqrt{2G \, [(h_u - h_1) + h_d] / 2} \; / \; 0.002228 \tag{6}$$

where q_2 = flow rate from the portion of the orifice below the lower head, in gallons per minute

a_2 = only that orifice area below the lower head, in feet squared

h_d = distance from the upper water level to the top edge of the orifice, in feet.

Total flow rate from a partially submerged orifice then can be calculated by adding the flow from both portions (Ohmes, 1971):

$$q = q_1 + q_2 \tag{7}$$

The time that it took the irrigation water to reach the orifice plate was recorded. After runoff had started, the head readings were taken every hour or two until the runoff rate reached its maximum. When the maximum orifice-plate head readings were reached, readings were taken every four to eight hours until irrigation was terminated. The last two or three runoff readings at the end of the irrigation period were used for the determination of the basic infiltration rate.

Infiltration Rate

The basic infiltration rate for each plot was determined using the equation:

$$I = \frac{100 \times (Q_i - Q_o)}{L \times W} \qquad (8)$$

where I = basic infiltration rate, in inches per hour

Q_i = flow into the three test furrows, gpm

Q_o = outflow from three test furrows, gpm

L = length of test furrows, in feet

W = combined width of test furrows, 7.5 feet.

A program was written for use on the Kansas State University IBM 360/50 computer for analyzing the field data. The program calculated the intake rates from the field data for each plot. A copy of the program is included in Appendix A.

Statistical Analysis

To obtain more field data and to evaluate the effects of the manure treatments, three years of irrigation data were used for the statistical analyses. All irrigation procedures and data collection procedures were the same each year.

A multiple regression stepdel deletion program, provided by the statistical laboratory at Kansas State University, was used to evaluate the various equations to determine the effects of manure application on the soil's infiltration rate.

RESULTS

Manure Application

Manure application rates to the test plots were reported in tons per acre on a dry weight basis. The actual amount of manure applied varied considerably from the desired amount. The drivers of the spreader trucks found it difficult to spread manure thin enough on the low treatment plots, and as a result, application rates were higher than desired. The application rate on the 320 tons per acre per year plots was found to be somewhat less than the desired amount most of the time. In the plots that were to receive medium application rates, considerable variation was also noticed. Table 2 gives the manure application rates for the years 1969, 1970, and 1971.

The manure was analyzed for nitrogen (N), phosphorus (P), calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). The chemical analyses indicate the amounts of each chemical added to the soil system by the manure applications. The results of the analyses are given in Table 3.

Basic Intake Data

Irrigation data for three years, 1970, 1971, and 1972, were used to evaluate the effects of manure application rates on the basic intake rate of soil. The basic intake rates used for this study are given in Table 4. The basic intake rates were determined for the test plots near the end of the irrigation period. Plots of the inflow and outflow rates for each plot during the 1972 irrigation season indicated that the basic intake rates were not reached until ten to twenty hours had elapsed after the start of the

Table 2. Manure Application Rates.

Plot	Treatment	1969 t/a	1970 t/a	2-Year Total t/a	1971 t/a	3-Year Total t/a
M-11	M-4	61	29	90	68	158
M-12	M-5	71	82	153	84	237
M-13	M-10	203	0	203	0	203
M-14	M-1	0	0	0	0	0
M-15	M-9	210	194	404	309	713
M-16	M-3	28	14	42	34	76
M-17	M-8	120	0	120	0	120
M-18	M-7	146	132	278	196	474
M-19	M-6	96	0	96	0	96
M-10	M-2	9	15	24	14	38
M-21	M-9	185	249	434	189	623
M-22	M-5	63	50	113	90	203
M-23	M-4	32	57	89	49	138
M-24	M-1	0	0	0	0	0
M-25	M-3	24	13	37	35	72
M-26	M-2	9	8	17	15	32
M-27	M-6	55	0	55	0	55
M-28	M-10	263	0	263	0	263
M-29	M-8	166	0	166	0	166
M-20	M-7	135	198	333	174	507
M-31	M-8	104	0	104	0	104
M-32	M-9	272	254	526	436	962
M-33	M-6	91	0	91	0	91
M-34	M-10	226	0	226	0	226
M-35	M-1	0	0	0	0	0
M-36	M-4	34	57	91	108	199
M-37	M-7	101	153	254	152	406
M-38	M-5	78	101	179	95	274
M-39	M-2	21	7	28	14	42
M-30	M-3	17	18	35	46	81

Table 3. Chemical Analyses of Feedlot Manure.

Year	N ppm	P ppm	Ca ppm	Mg ppm	Na ppm	K ppm
1969	10400	4166	7757	3934	3280	10900
1970	31200	7100	5580	4450	1675	3880
1971	8900	5700	9800	4200	2490	9700

Table 4. Basic Infiltration Rates in Inches Per Hour.

	Irrigation Date										
	1970				1971				1972		
Plot	6/25	7/9	7/23	8/6	4/6	7/6	7/21	8/5	7/20	8/3	8/20
M-11	.108	.062	.088	.157	.115	.098	.093	.054	.122	.137	.140
M-12	.069	.043	.038	.067	.103	.050	.059	.054	.112	.096	.094
M-13	-	.024	.019	.018	.067	.083	.070	.070	.168	.063	.070
M-14	-	.076	.087	.111	.055	.065	-	.154	.171	.065	.081
M-15	.158	.045	.069	.081	.064	.012	.024	.048	.156	.052	.105
M-16	-	.082	.122	.155	.082	.038	.034	.045	.107	.022	.065
M-17	-	-	.038	.055	.059	.031	.050	.060	.113	.059	.059
M-18	-	.058	.070	.084	.020	.011	.006	.054	.112	.051	.066
M-19	-	-	-	-	.104	.047	.029	.031	.174	.122	.068
M-10	-	.057	.049	.070	.044	.045	.048	.049	-	-	.074
M-21	.050	.048	.048	.049	.081	.075	.054	.039	-	.092	.122
M-22	.119	.151	.144	.147	.125	.147	.098	.102	.122	.068	.066
M-23	.034	.043	.029	.012	-	.015	.028	-	.029	-	.019
M-24	.086	.065	.066	.075	.018	.053	.045	.018	-	-	.031
M-25	.026	.035	.028	.031	.056	.040	.042	.022	-	-	.031
M-26	.083	.042	.058	.057	.010	-	-	-	.078	.004	.023
M-27	.064	.051	.064	.070	-	.096	.070	.036	.026	.017	.043
M-28	-	-	-	-	.014	.046	.012	.031	.153	.021	.056
M-29	.026	.017	.007	-	.096	.054	.031	.046	.136	.076	.084
M-20	.072	.058	.069	.065	.095	.073	.023	.051	.014	.015	.044
M-31	.053	.067	.028	.066	.071	.093	.109	.077	-	-	-
M-32	.033	.030	.018	.009	.012	.028	.008	.009	.061	.017	.013
M-33	-	-	-	-	.115	.100	.074	.073	.107	.031	.041
M-34	-	-	.022	.040	-	.040	.014	.033	.081	.041	.045
M-35	.041	.048	.050	.047	-	-	-	-	-	-	.055

Table 4. Continued

	Irrigation Date										
	1970				1971				1972		
Plot	6/25	7/9	7/23	8/6	4/6	7/6	7/21	8/5	7/20	8/3	8/20
M-36	.076	.072	.055	.057	.084	.142	.052	.035	.082	.047	.056
M-37	.043	.025	.023	.045	.005	.077	.012	.041	.058	-	.021
M-38	.024	.028	.031	.038	-	.007	.050	-	.078	-	.034
M-39	.096	.102	.096	.174	.034	.056	.038	.009	.089	-	.067
M-30	.067	.024	.039	.049	.029	.111	-	.079	-	-	.029

irrigation. Therefore, all intake data used in this study were taken near the end of the thirty hour long irrigation period.

An analysis of the basic intake rates indicated a considerable amount of variation. This variation was within individual plots, as well as between plots. On occasion, especially the irrigation on August 3, 1972, negative infiltration rates were found. These values were found because the orifice plates in series four and five were flooded by runoff water from the previous irrigation of series one, two and three the day before. This drainage water increased the outflow from the plot to a rate higher than the inflow. When the data were analyzed, negative infiltration rates resulted. Negative intake rates are not possible; therefore, these data were not used for model development.

Infiltration rates were not available for certain plots for several reasons. Under a high flow condition, the capacity of the orifice plate was often exceeded. The high flow rates often caused the water behind the orifice plate to reach a level that overflowed the tops of the furrows. When loss of water from the test furrows occurred, accurate measurement of outflow was not possible. Before the half-inch screens were placed in the furrows, plugging of the orifice plates occurred. This plugging caused the water to overflow the furrows. Some plots, for example M-30 and M-31, were low and were prone to flooding by drainage water near the end of the irrigation period.

Statistical Design

The manure treatment plots were laid out in a random block design with four replications of ten treatments. With this type of design, it would have been possible to run an analysis of variance on the data. However, missing field data and the variation of the manure application rates made the statistical analysis more difficult. For example, the treatment plots M-4 were to receive 40 tons per acre per year of manure. The quantity of manure applied to these plots ranged from a low of 29 tons per acre to a high of 91 tons per acre.

This variation in manure application rates made it impractical to lump all plots of each treatment together as identical treatments. Analysis of variance was dropped in favor of using linear and multiple regression techniques. By using a multiple regression stepdel deletion program, it was possible to evaluate various equations to predict infiltration from the manure applications.

Differences in soil moisture and field conditions would change the basic intake rates of the test plots between irrigations. Because of these differences, each irrigation was evaluated separately first, and then all irrigations for a year were evaluated together.

Statistical parameters used to evaluate the equations that were provided by the regression program were R^2 and the significance level alpha. The R^2 is the proportion or percentage of the variation of the dependent variable that is accounted for by the equation or model. The mean square regression (MS_r), mean square error (MS_e), and F value were also calculated. Dividing the mean square regression by the mean square error gives the F value. The F value can be taken to the appropriate tables and used in conjunction with degrees of freedom to determine the level of significance. However, the program provides the significance level alpha, which is the level at which the F value is significant. The significance level saves the time and trouble of going to the tables with the F value and degrees of freedom to find out if, and at what significance level, the hypothesis is rejected.

The hypothesis used in the regression analysis was that R^2 equals zero. If the significance level is high enough, the hypothesis was rejected in favor of the null hypothesis. The null hypothesis used in the regression analysis was that R^2 was significantly different from zero.

Plots Used

Ten manure treatments were included in the study. The control plots, M-1, did not receive any manure throughout the study. Three treatments, M-6, M-8, and M-10, received manure in the fall of 1969 only. The other treatments, M-2, M-3, M-4, M-5, M-7, and M-9 received manure in the fall of 1969, 1970, and 1971.

For the evaluation of equations for the 1970 irrigation season, all treatments were included because all the treatments, except the control, had received manure applications the previous fall. Infiltration rates from treatments M-6, M-8, and M-10 were omitted from the data used to evaluate equations for 1971 and 1972. These first year treatments were omitted because they did not receive manure applications the previous fall. The control plots (M-1) were included in all equation developments.

Equation Development

With the use of the computer and the multiple regression program, considerable amounts of data were analyzed using different mathematical equations. The first equation developed was as follows:

$$I = B_1 + B_2 M_t \qquad (9)$$

where: I = infiltration rate in inches per hour

B_1 = empirical coefficient

B_2 = empirical coefficient

M_t = manure total in tons per acre.

The manure total (M_t) was the total application of manure to the plot at the time of the irrigation. For example, the manure total for a plot in 1972 would be the sum of the 1969, 1970, and 1971 manure applications.

The equation was evaluated for each year and for each irrigation period. Table 5 provides the statistical analyses of equation 9 by year. Further breakdown of equations by individual irrigation periods is provided in Appendix B.

The R^2s for equation 9 are 0.080, 0.054, and 0.005 for the years 1970, 1971, and 1972, respectively. These R^2s are significantly different from zero at the alpha level of 0.06 or less, indicating that there is a correlation between the variation of infiltration rates and the manure treatments. However, the low R^2s indicate that equation 9 does not give a good fit. Equation 9 only explains eight percent of the variation in infiltration rate in 1970, and less in 1971 and 1972.

A second equation developed was essentially the same as equation 9, except infiltration was replaced with the $\log_e$ of infiltration. This equation is given below as:

$$\text{Log}_e I = B_1 + B_2 M_t \qquad (10)$$

Table 5. Statistical Analyses of Infiltration Equations by Year.

Year	Number of Observations	R^2	MS_e	F	Significance Level
		$I = B_1 + B_2 M_t$			
1970	98	0.080	0.0012	8.40	0.00
1971	71	0.054	0.0012	3.94	0.05
1972	48	0.005	0.0017	0.27	0.06
		$\mathrm{Log}_e I = B_1 + B_2 M_t$			
1970	98	0.139	0.3363	15.5	0.00
1971	71	0.080	0.6450	6.03	0.02
1972	48	0.010	0.6270	0.46	0.49
		$I = B_1 + B_2 M_t + B_3 M_t^2$			
1970	98	0.088	0.3433	4.56	0.01
1971	71	0.092	0.6358	3.45	0.03
1972	48	0.031	0.6120	0.73	0.48
		$\mathrm{Log}_e I = B_1 + B_2 M_t + B_3 M_t^2$			
1970	98	0.154	0.0012	8.61	0.00
1971	71	0.107	0.0012	4.05	0.02
1972	48	0.054	0.0017	1.03	0.28

Table 5. Continued

Year	Number of Observations	R^2	MS_e	F	Significance Level
		$I = B_1 + B_2 M_{69} + B_3 M_{70} + B_4 M_{71}$			
1970	98	0.080	0.0012	8.40	0.00
1971	71	0.054	0.0013	1.94	0.15
1972	48	0.190	0.0015	3.43	0.02
		$\text{Log}_e I = B_1 + B_2 M_{69} + B_3 M_{70} + B_4 M_{71}$			
1970	98	0.139	0.3363	15.5	0.00
1971	71	0.084	0.6516	3.15	0.05
1972	48	0.138	0.5707	2.35	0.08
		$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$			
1970	98	0.088	0.3343	4.56	0.01
1971	71	0.135	0.0012	2.58	0.04
1972	48	0.297	0.0014	2.88	0.02
		$\text{Log}_e I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$			
1970	98	0.154	0.0012	8.61	0.00
1971	71	0.172	0.6071	3.42	0.01
1972	48	0.264	0.5227	2.42	0.04

where: $\text{Log}_e\ I$ = log of infiltration in inches per hour

B_1 = empirical coefficient

B_2 = empirical coefficient

M_t = manure total in tons per acre.

The statistical results of this equation are also given in Table 5. When $\log_e$ of infiltration is used, a small increase in R^2 is noticed over that of equation 9. The R^2 increases were: 0.080 to 0.139 in 1970, 0.054 to 0.080 in 1971, and 0.005 to 0.010 in 1972. However, these differences are so small that it cannot be concluded that one equation is better than the other.

The highest R^2 for equation 10 was for the 1970 irrigation season. When the 1971 and 1972 data were subjected to analyses by this equation, there was a progressive decrease in the R^2. The R^2 for equation 10 dropped from 0.139 in 1970 to 0.080 in 1971, and down to 0.010 in 1972. The reduction in R^2 was an indication that when manure applications over a three year period were added together, the equation did not fit.

Because the variable manure total did not fit well into equations 9 and 10, a manure total-squared-term was added. This produced two more equations for evaluation. They are as follows:

$$I = B_1 + B_2\ M_t + B_3\ M_t^{\ 2} \qquad (11)$$

and

$$\text{Log}_e\ I = B_1 + B_2\ M_t + B_3\ M_t^{\ 2} \qquad (12)$$

where: I = infiltration rate in inches per hour

$\text{Log}_e I$ = log of infiltration rate in inches per hour

B_1 = empirical coefficient

B_2 = empirical coefficient

M_t = manure total in tons per acre

B_3 = empirical coefficient

M_t^2 = manure total squared in (tons per acre)^2.

Adding the manure total squared term (M_t^2) to the equations increased the R^2 slightly in both equations (Table 5). The maximum R^2 increased from 0.139 in equation 10 to 0.154 in equation 12 for the year 1970. The increase in R^2 was small and may not be significant. The reduction in the R^2 value still occurred in each equation for the years 1971 and 1972. However, the reductions of R^2 were not as great for equations 11 and 12 as they were for equations 9 and 10.

The author felt that, because the R^2 was decreasing for each year, that equations 9, 10, 11, and 12, were not correct for the years 1971 and 1972. In equations 9, 10, 11, and 12, the manure from each year would be of equal importance in determining the infiltration. It would be expected that the infiltration rates would change with time after the application of manure. For example, in the 1972 irrigation season, it would be expected that the effects of the 1969 manure applications would be less important than the 1971 applications. Therefore, the manure total was broken up into yearly applications. With this in mind, two more equations were developed. The equations included a variable for each year manure was applied. The equations are as follows:

$$I = B_1 + B_2 M_{69} + B_3 M_{70} + B_4 M_{71} \quad (13)$$

and

$$\text{Log}_e I = B_1 + B_2 M_{69} + B_3 M_{70} + B_4 M_{71} \quad (14)$$

where: I = infiltration rate in inches per hour

$\text{Log}_e I$ = log in infiltration rate in inches per hour

B_1 = empirical coefficient

B_2 = empirical coefficient

M_{69} = manure applied in 1969 in tons per acre

B_3 = empirical coefficient

M_{70} = manure applied in 1970 in tons per acre

B_4 = empirical coefficient

M_{71} = manure applied in 1971 in tons per acre.

It must be kept in mind that in equations 13 and 14, when data are evaluated from 1970's irrigation data, the values of M_{70} and M_{71} are zero, and that B_3 and B_4 would also be zero. For the 1971 irrigation data, M_{71} and B_4 are zero.

It should also be pointed out at this time that for the year 1970, the statistical analyses of equations 9 and 13 are identical. Equations 10 and 14 also produce the same statistical analyses for the year 1970. This duplication of results occur because M_t for equation 9 and 10 are the same as M_{69} for equations 13 and 14.

The results of the statistical analyses for equations 13 and 14 are also given in Table 5. The important point to notice about the R^2 of these two equations is that they do not decrease for the years 1971 and 1972 as they did in previous equations. The R^2s for equation 13 for the years 1970, 1971, and 1972 are 0.080, 0.054, and 0.190, respectively. Comparison of equation 9 with equation 13 will indicate that, for the 1971 irrigation data, the R^2s for both equations 9 and 13 are 0.054. The same R^2 values of equation 9 and 13 would indicate the same degree of fit. However, the significance level gives further indication of the degree of fit and significance. The significance level of the R^2 for equation 9 is 0.05. The significance level of R^2 for equation 13 for the 1971 data is 0.15. The significance level of equation 13 for the 1971 data indicates that R^2 is not significantly different from zero at an acceptable alpha level.

Equation 13 shows a much greater increase in R^2 and significance level for the 1972 data. The R^2 for equation 13 increased from 0.005 for equation 9, to 0.190. The increase in significance level was from 0.06 to 0.02.

The R^2s and significance levels of equation 13 indicate that equation 13 is a better fit than equation 9.

Equation 14 indicated the same trends as did equation 13. For the 1971 data, the R^2s for equations 10 and 14 were 0.080 and 0.084, respectively. The significance level of R^2 for equation 10 was 0.05. The analysis of equation 14 gave a significance level of 0.02. The R^2s and significance levels indicate that, for the 1971 data, equations 10 and 14 were about equal in their ability to explain the variation of infiltration.

Equation 14 explains the variation of infiltration of the 1972 data much better than equation 10. The R^2 for equation 10 was 0.010 compared to 0.138 for equation 14. The R^2 for equation 10 was not significant at an acceptable level; while equation 14 was significant at the 0.08 level. The increase in the R^2 values for 1972 indicated that each year's application of manure over the three year period has a different amount of importance on the infiltration rate for 1971 and 1972.

Equations that have the manure applied separately for each year explain a much larger proportion of the variation of infiltration. The last two equations evaluated in this study are similar to equations 13 and 14. In equations 15 and 16, a manure-squared-term is included for each year. The equations are as follows:

$$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2 \quad (15)$$

and

$$\text{Log}_e I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2 \quad (16)$$

where: I = infiltration rate in inches per hour

$\text{Log}_e I$ = log of infiltration in inches per hour

B_1 = empirical coefficient

B_2 = empirical coefficient

M_{69} = manure applied in 1969 in tons per acre

B_3 = empirical coefficient

M_{69}^2 = manure applied in 1969 squared

B_4 = empirical coefficient

M_{70} = manure applied in 1970 in tons per acre

B_5 = empirical coefficient

M_{70}^2 = manure applied in 1970 squared

B_6 = empirical coefficient

M_{71} = manure applied in 1971 in tons per acre

B_7 = empirical coefficient

M_{71}^2 = manure applied in 1971 squared.

The results of the statistical analyses of equations 15 and 16 are found in Table 5. For the 1970 irrigation data, equations 11 and 15 produced the same results as did equations 12 and 16. This duplication of results occurred because the parameters M_{70}, M_{70}^2, M_{71}, and M_{71}^2 were zero.

Equations 15 and 16 provide the highest R^2s of any of the equations tested. The R^2 values for the years 1971 and 1972 were about twice as high as those obtained from equations 13 and 14. The R^2s for equation 15 were 0.088, 0.135, and 0.297 for the years 1970, 1971, and 1972, respectively. The R^2s for equation 16 were 0.154, 0.172, and 0.264 for the years 1970, 1971, and 1972, respectively. The R^2s for equations 15 and 16 were significant for all three years at the alpha equals 0.05 level.

The increase in the R^2s of equations 15 and 16 over the R^2s produced by the analyses of equations 13 and 14 indicate that the effects of the manure treatments are not linear. As the application rates are increased, the effects on infiltration rate are increased. At the higher application rates, the changes in infiltration rate per unit of manure are greater than at the lower application rates.

The R^2 is the proportion or percentage of the variation in infiltration that is accounted for by the equation. The difference between the two equations is very little. Equation 15 has a higher R^2 for 1972, but equation 16 has a higher R^2 for the years 1970 and 1971. The significance levels for equations 15 and 16 are also about equal. Evaluation of these R^2 values and significance levels indicates that there was very little, if any, difference in the goodness of fit of equations 15 and 16.

Table 5 provides only the statistical results for the tested equations when applied to the irrigation data for a year as a whole. Appendix B, Table 14 breaks each irrigation year down into the individual irrigations. This breakdown is provided for each equation.

The R^2s for many of the individual irrigations were higher than for the year as a whole. However, these R^2 values are often not significant. The number of degrees of freedom of an individual irrigation was less than the number of degrees of freedom for the accumulated irrigations for the year as a whole. The lower number of degrees of freedom required higher F values to be significant. Because of the higher F values required, R^2s for many of the individual irrigation periods were not significant. With fewer data points, the variation in infiltration was more pronounced.

Several variables that were not accounted for by the equations developed can influence the basic infiltration rates. The soil moisture level previous to an irrigation influences the infiltration rate. The net effect is for the initial intake rate to be higher for the low moisture content soils. But after long periods of time, infiltration rates into soils with higher initial moisture content sometimes exceed that for the soils with lower moisture content (Nagmoush, 1956). With the passage of time from the manure application, the intake rate increases (Cross and Fischback, 1972). Increased hydrostatic head in the furrow and increased water to soil surface area are two factors that also increase the infiltration rate of soil (Rowe, 1952).

Each of these variables will have an effect on the infiltration rate. However, to keep the equations as simple as possible, these parameters were not considered. For the purpose of this study these parameters were considered to be random.

The R^2 indicated only that proportion or percentage of the variation of the infiltration rate that is accounted for by the equation. The R^2 did not give any indication of the basic infiltration increases or decreases with increased application rate of feedlot manure to the soil. The empirical coefficients were used to determine the effects of the manure applications. A positive coefficient indicated that the infiltration rate increased with increased manure application. Conversely, a negative coefficient indicated that as the manure applications increased, the basic infiltration rates decreased. The empirical coefficients are given in Tables 6 and 7 for equations 15 and 16.

The data from the 1970 irrigations provided the analyses that show a definite trend in change of infiltration rate. The analyses for the year of 1970 for equation 15 showed that the empirical coefficients for the variables M_{69} and M_{69}^2 were negative. The coefficients for M_{69} for equation 16 were positive for the 1970 irrigation data. However, when the standard partial-betas were evaluated, it was found that this coefficient was of little importance compared to the negative coefficient of the M_{69}^2 variable. These negative coefficients support the theory that with increased manure applications, the basic infiltration rate will decrease.

The empirical coefficients for the 1971 and 1972 analyses are not as consistently negative as for those of the 1970 analyses. Some of the empirical coefficients had positive values. This indicated there was enough variation in the infiltration rate that positive coefficients provided a better fit of the equation. The standard partial-betas indicated which

Table 6. Empirical Coefficients for Equation 15.

$$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$$

Date	B_1	B_2	B_3	B_4	B_5	B_6	B_7
6/25/70	6.60×10^{-2}	2.47×10^{-2}	-1.37×10^{-7}				
7/9/70	6.12×10^{-2}	-1.90×10^{-5}	-4.54×10^{-7}				
7/23/70*	6.58×10^{-2}	-8.75×10^{-5}	-3.10×10^{-7}				
8/6/70*	7.86×10^{-2}	1.02×10^{-4}	1.27×10^{-6}				
70*	6.83×10^{-2}	-6.31×10^{-6}	-5.38×10^{-7}				
4/6/71	3.68×10^{-2}	1.73×10^{-4}	-5.39×10^{-6}	-9.79×10^{-4}	2.26×10^{-6}		
7/13/71	6.87×10^{-2}	4.12×10^{-4}	-2.67×10^{-6}	-5.26×10^{-4}	2.50×10^{-6}		
7/27/71	4.72×10^{-2}	9.42×10^{-4}	-3.06×10^{-6}	-8.77×10^{-4}	2.30×10^{-6}		
8/10/71	5.51×10^{-2}	1.66×10^{-5}	4.06×10^{-7}	7.38×10^{-5}	-4.79×10^{-7}		
71*	5.11×10^{-2}	8.07×10^{-4}	-2.81×10^{-6}	-5.74×10^{-4}	1.45×10^{-6}		
7/20/72	9.61×10^{-2}	3.14×10^{-4}	3.32×10^{-6}	-1.31×10^{-3}	2.13×10^{-8}	8.24×10^{-4}	-1.97×10^{-6}
8/3/72	4.29×10^{-2}	1.48×10^{-3}	-1.22×10^{-6}	-9.92×10^{-4}	1.45×10^{-6}	-8.34×10^{-5}	-7.95×10^{-7}
8/15/72*	4.49×10^{-2}	1.34×10^{-3}	-9.95×10^{-7}	-1.44×10^{-3}	3.32×10^{-6}	3.71×10^{-4}	-1.67×10^{-6}
72*	5.73×10^{-2}	1.21×10^{-2}	-6.43×10^{-7}	-1.34×10^{-3}	2.23×10^{-6}	3.64×10^{-4}	-1.40×10^{-6}

* Significant at Alpha = 0.10.

Table 7. Empirical Coefficients for Equation 16.

$$\text{Log}_e\ I = B_1 + B_2\ M_{69} + B_3\ M_{69}^2 + B_4\ M_{70} + B_5\ M_{70}^2 + B_6\ M_{71} + B_7\ M_{71}^2$$

Date	B_1	B_2	B_3	B_4	B_5	B_6	B_7
6/25/70	-2.79	-2.46×10^{-4}	-2.58×10^{-6}				
7/9/70	-2.85	-1.61×10^{-3}	-4.11×10^{-6}				
7/23/70*	-2.78	-3.18×10^{-3}	-3.56×10^{-6}				
8/6/70*	-2.81	4.22×10^{-3}	-4.09×10^{-5}				
70*	-2.80	5.24×10^{-5}	-1.31×10^{-5}				
4/6/71	-3.49	3.75×10^{-2}	-1.04×10^{-4}	-2.42×10^{-2}	4.38×10^{-5}		
7/13/71	-2.65	8.68×10^{-3}	-6.34×10^{-5}	-2.00×10^{-2}	9.85×10^{-5}		
7/27/71	-2.95	1.45×10^{-2}	-6.95×10^{-5}	-2.01×10^{-2}	7.01×10^{-5}		
8/10/71	-3.39	5.86×10^{-3}	-3.55×10^{-5}	5.87×10^{-3}	-2.27×10^{-3}		
71*	-3.17	1.90×10^{-2}	-7.36×10^{-5}	-1.63×10^{-2}	5.08×10^{-5}		
7/20/72*	-2.51	9.37×10^{-3}	2.09×10^{-5}	-1.42×10^{-2}	-3.97×10^{-5}	7.50×10^{-3}	-6.83×10^{-6}
8/3/72	-3.78	1.61×10^{-2}	5.03×10^{-5}	-1.43×10^{-2}	-2.56×10^{-6}	8.22×10^{-3}	-4.40×10^{-5}
8/15/72*	-3.22	1.85×10^{-2}	7.07×10^{-6}	-2.32×10^{-2}	4.56×10^{-5}	9.23×10^{-3}	-3.98×10^{-5}
72*	-3.15	1.62×10^{-2}	8.45×10^{-6}	-2.06×10^{-2}	2.62×10^{-5}	9.19×10^{-3}	-3.16×10^{-5}

* Significant at Alpha = 0.10.

variables and empirical coefficients were the most important in the equation. The manure application of 1969 (M_{69}) had positive coefficients in the 1971 and 1972 analyses. Positive values for the other coefficients seemed to be random.

The empirical coefficients indicate that with increased manure application rates, the basic infiltration rates are decreased. This reduction of infiltration rate was supported most strongly by the 1970 irrigation analyses. The analyses of the data from the years 1971 and 1972 did not support this theory as strongly as the 1970 analysis. However, with the increased number of parameters, it is more likely that some of them will be positive in nature. The change from negative values of coefficients to positive values of coefficients for the 1969 manure application from 1970 to 1971 indicated the possibility that the soil's infiltration rate recovered from the manure application.

Partial Standard Betas

The multiple regression program provides the standard partial betas for each of the independent variables of the equation being tested. The standard partial betas can be used to compare the relative importance of the empirical coefficients and variables. The standard partial betas can be compared numerically. Disregarding the negative signs, the largest standard partial beta indicates which variable is the most important parameter in the equation. The standard partial betas will decrease in value down to the smallest, which indicates the variable that is the least important in the equation. The standard partial betas are unitless numbers that allow a direct comparison of variables that do not have the same unit. For the equations tested, it allows direct comparison of manure applied and the manure applied squared variables. The standard partial betas for equations 15 and 16 are given in Tables 8 and 9, respectively.

Upon evaluation of the data, it can be seen there was no consistent trend in the importance of the standard partial betas. For the irrigation data of 1970, the manure squared term was the most important. However, for the 1971 and 1972 years, the manure applied was more important than the manure-applied-squared term.

The standard partial betas can also be used as an indication of which year's application has the most influence on the 1971 and 1972 infiltration rates. The expected trend would be that the most recent manure application would have the greatest influence on the infiltration rate. The 1971 irrigation analyses were not significant except for the year as a whole. The manure applied in the fall of 1969 was more important than the manure applied in the fall of 1970 for determining the 1971 infiltration rate. The analyses of the 1972 irrigation data using equation 16 indicated that the most recently applied manure was the most important factor in influencing the infiltration rate. Of the three years of application, the 1971 was the most important, followed by the 1970 application and the 1969 application. When the 1972 irrigation data were analyzed by using equation 15, the 1970 manure application was found to be the most important. The 1970 application was closely followed by the 1971 application in importance. The 1969 application was found to be of the least importance. The order of importance of the manure applications indicated that the most recent manure application was the most important. With the passage of time, the effects of the manure application are reduced.

The range of manure application rates was from 10 to 320 tons per acre

Table 8. Partial Standard Betas for Equation 15.

$$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$$

Date	$B_2 M_{69}$	$B_3 M_{69}^2$	$B_4 M_{70}$	$B_5 M_{70}^2$	$B_6 M_{71}$	$B_7 M_{71}^2$
6/25/70	0.0535	-0.0748				
7/9/70	-0.0513	-0.2956				
7/23/70*	-0.2133	-0.1841				
8/6/70*	0.1816	-0.5596				
70*	-0.0135	-0.2831				
4/6/71	3.6607	-2.8385	-2.0967	1.0979		
7/13/71	0.7741	-1.2639	-1.0933	1.2797		
7/27/71	2.8503	-2.4078	-2.9383	1.9393		
8/10/71	0.0384	-0.2359	0.2012	-0.3018		
71*	1.7556	-1.5459	-1.3561	0.8331		
7/20/72	0.5671	1.5956	-2.4570	0.0096	2.3816	-2.3842
8/3/72	3.2975	-0.7234	-2.4220	0.9205	-0.2731	-1.1337
8/15/72*	2.9554	-0.5375	-3.5110	1.8920	1.2290	-2.1654
72*	2.3209	-0.3162	-2.7607	1.1390	1.0581	-1.6736

* Significant at Alpha = 0.10.

Table 9. Partial Standard Betas for Equation 16.

$$\text{Log}_e\ I = B_1 + B_2\ M_{69} + B_3\ M_{69}^{\ 2} + B_4\ M_{70} + B_5\ M_{70}^{\ 2} + B_6\ M_{71} + B_7\ M_{71}^{\ 2}$$

Date	$B_2\ M_{69}$	$B_3\ M_{69}^{\ 2}$	$B_4\ M_{70}$	$B_5\ M_{70}^{\ 2}$	$B_6\ M_{71}$	$B_7\ M_{71}^{\ 2}$
6/25/70	-0.0347	-0.0920				
7/9/70	-2.4810	-0.1532				
7/23/70*	-0.3789	-0.1033				
8/6/70*	0.6427	-0.1094				
70*	0.0065	-0.3981				
4/6/71	3.2362	-2.2279	-2.1080	0.8675		
7/13/71	0.6752	-1.4173	-1.9649	2.3854		
7/27/71	1.4496	-1.8107	-2.2357	1.9665		
8/10/71	0.6363	-0.9705	0.7105	-0.6731		
71*	1.7796	-1.7433	-1.6616	1.2592		
7/20/72*	1.1142	0.6624	-1.7497	-1.1761	1.4296	-0.5454
8/3/72	1.4080	1.1622	-1.3721	-0.0634	1.0533	-2.4575
8/15/72*	2.1842	0.2047	-3.0310	1.4360	1.6390	-2.7568
72*	1.6274	0.2176	-2.2313	0.6997	1.4016	-1.9812

* Significant at Alpha = 0.10.

per year. The author felt that with this wide range in manure application, that different results might be obtained if the treatments were broken up. The treatments were separated into two groups. Treatments M-1, M-2, M-3, and M-4 were lower application rates of up to forty tons per acre per year. The second group of treatments were M-5, M-7, and M-9. These treatments were the higher application rates of 80 to 320 tons per acre per year. Both groups of treatments for the years 1971 and 1972 were evaluated with equations 15 and 16 using the multiple regression program. The complete statistical analyses of the two groups are given in Tables 10, 11, and 12.

The R^2s for the lower manure treatments rates for 1971 were 0.358 and 0.301 for equations 15 and 16, respectively. These R^2s were significant at the alpha level of 0.01. The standard partial betas from these analyses indicated that the 1969 application had the most influence on the infiltration rate. The analyses of the lower application rates for 1972 produced R^2s of 0.422 and 0.367 for equations 15 and 16, respectively. The R^2s for equations 15 and 16 were significant at the 0.06 and 0.12 alpha levels. The standard partial betas indicated that the 1971 manure application was the most important. The 1970 manure application was second in importance, followed by the 1969 application.

The treatments M-5, M-7, and M-9 were evaluated the same way as the low application rates. For the high application rates of the 1971 irrigation data, the R^2s were 0.191 for both equations 15 and 16. The significance levels were not acceptable for these analyses at 0.24 and 0.23 for equations 15 and 16. The standard partial betas indicated that the 1970 manure application was more important than the 1969 application for determining the infiltration rates. The analyses of the 1972 irrigation data produced

Table 10. Statistical Analyses of Low and High Manure Application by Equations 15 and 16.

Year	Treatments	R^2	MS_e	F	Significance Level
	$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$				
1971	1,2,3&4	0.358	0.0011	5.03	0.00
1972	1,2,3&4	0.422	0.0013	2.43	0.06
1971	5,7&9	0.191	0.0008	1.47	0.24
1972	5,7&9	0.629	0.0009	3.96	0.02
	$\log_e I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$				
1971	1,2,3&4	0.301	0.3768	3.87	0.01
1972	1,2,3&4	0.367	0.5293	1.93	0.12
1971	5,7&9	0.191	0.7942	1.47	0.23
1972	5,7&9	0.669	0.2930	4.71	0.01

Table 11. Partial Standard Betas of Low and High Manure Applications for Equations 15 and 16.

Year	Treatments	$B_2\ M_{69}$	$B_3\ M_{69}^2$	$B_4\ M_{70}$	$B_5\ M_{70}^2$	$B_6\ M_{71}$	$B_7\ M_{71}^2$
	$I = B_1 + B_2\ M_{69} + B_3\ M_{69}^2 + B_4\ M_{70} + B_5\ M_{70}^2 + B_6\ M_{71} + B_7\ M_{71}^2$						
1971	1,2,3&4	-1.0444	1.3561	0.5810	-0.3208		
1972	1,2,3&4	0.9709	0.1523	1.0389	-1.2409	-2.9981	2.4244
1971	5,7&9	1.5400	-2.0410	-2.0538	2.2421		
1972	5,7&9	-13.9023	18.4628	-2.8368	1.8441	12.4777	-16.7208
	$\text{Log}_e\ I = B_1 + B_2\ M_{69} + B_3\ M_{69}^2 + B_4\ M_{70} + B_5\ M_{70}^2 + B_6\ M_{71} + B_7\ M_{71}^2$						
1971	1,2,3&4	-1.0621	1.2693	1.0871	-0.8224		
1972	1,2,3&4	1.5785	-0.3753	0.9328	-1.0995	-3.5819	2.9477
1971	5,7&9	-1.9397	-2.3989	-2.3838	2.5761		
1972	5,7&9	-12.6110	16.7964	-3.7220	2.6173	12.1233	-15.9628

Table 12. Empirical Coefficients of Equations 15 and 16 for the Low and High Manure Application Rates.

Year	Treatments	B_1	B_2	B_3	B_4	B_5	B_6	B_7
		$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$						
1971	1,2,3&4	0.0548	-1.94×10^{-3}	3.71×10^{-5}	1.12×10^{-3}	1.01×10^{-5}		
1972	1,2,3&4	0.0720	1.85×10^{-3}	4.32×10^{-6}	2.01×10^{-3}	-3.96×10^{-5}	-3.40×10^{-3}	2.55×10^{-5}
1971	5,7&9	0.0787	6.76×10^{-4}	-2.62×10^{-6}	-1.00×10^{-3}	3.17×10^{-6}		
1972	5,7&9	0.3614	-8.44×10^{-3}	3.28×10^{-5}	-1.91×10^{-3}	3.61×10^{-6}	4.49×10^{-3}	-1.14×10^{-5}
		$\text{Log}_e I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$						
1971	1,2,3&4	-3.1955	-3.56×10^{-2}	6.28×10^{-4}	3.78×10^{-2}	-4.70×10^{-4}		
1972	1,2,3&4	-2.8920	5.74×10^{-2}	-2.03×10^{-4}	3.44×10^{-2}	-6.69×10^{-4}	-7.76×10^{-2}	5.91×10^{-4}
1971	5,7&9	-2.3855	2.73×10^{-2}	-9.85×10^{-5}	-3.73×10^{-2}	1.17×10^{-4}		
1972	5,7&9	2.8705	-1.46×10^{-1}	5.69×10^{-4}	-4.77×10^{-2}	9.78×10^{-5}	8.31×10^{-2}	-2.07×10^{-4}

higher R^2 values and higher significance levels than previously obtained. The R^2s for equations 15 and 16 were 0.629 and 0.669 respectively. Both R^2s were significant at the alpha level of 0.02 or less. The standard partial betas indicated that the 1969 and 1971 manure applications had considerably more influence on the infiltration rate than did the 1970 manure application. Between the 1969 and 1971 application, the 1969 manure application was slightly more important.

The differences in the standard partial betas were often very small. There was also little consistency that would establish strong trends. Because of this inconsistency, any trends present are not clearly evident. However, equations 15 and 16 indicate that for the years 1971 and 1972, the most recent manure application had the most influence on infiltration rates.

First Year Application Plots

Infiltration data from the treatments M-6, M-8, and M-10 were included with the infiltration data from the other treatments and analyzed by equations 15 and 16.

In equation 15, the R^2 increased in 1971 from 0.135 to 0.166. For equation 16, the R^2 increased from 0.172 to 0.219. In all cases, the R^2 for the yearly evaluations were significant at the alpha = 0.05 level. When the first year application plots were included in the 1972 data, the R^2 decreased considerably. The R^2 for equation 15 decreased from 0.297 to 0.139. Equation 16's R^2 decreased from 0.264 to 0.164. When the first year treatments were included in the 1972 data, a loss of significance occurred.

The R^2 values for 1971 increased slightly when the first year application plots were included. However, the R^2 decreased considerably when the first year treatments were added to the 1972 data. These changes in R^2 indicate that the first year application plots do not fit into equations 15 and 16.

The previous equations tested on the 1970 irrigation data had indicated a reduction in the infiltration with applications of manure. However, because these plots did not receive additional applications the following years, they did not fit into previous equations. To determine if any change in infiltration with time occurred, the following equations were evaluated for the zero treatment plots and for the first year plots.

$$I = B_1 + B_2 T \tag{17}$$

and

$$\text{Log}_e I = B_1 + B_2 T \tag{18}$$

where: I = infiltration rates in inches per hour

$\text{Log}_e I$ = log of the infiltration rate in inches per hour

B_1 = empirical coefficient

B_2 = empirical coefficient

T = time in months

The variable time (T) is the time in months the irrigation occurred after manure was applied to the first year application plots. The zero treatment plots used the same measurements of time.

When the equations were run on the zero treatment plots, the R^2 was not found to be significant. There was no correlation between infiltration or the log of infiltration and time. However, when equations 17 and 18 were run on the first year application plots, the R^2s were significant at the alpha = 0.01 level. The R^2s for equations 17 and 18 were 0.139 and 0.119, respectively. The significance of the R^2 for the first year application plots when there was no significant R^2 for the zero treatment plots, indicated that the infiltration does change with time. The data from the statistical analysis is given in Table 10.

With the information provided in Table 13, equations 17 and 18 can be rewritten as follows:

$$I = 0.0254 + 0.0152T \tag{19}$$

and

$$I = e^{-3.586 + 0.0254T} \tag{20}$$

where: I = infiltration rate in inches per hour

T = time in months after application of manure.

The positive values of the empirical coefficient indicated that after the initial decrease in infiltration rate that occurred when manure was applied to the soil, the infiltration rate increased with time. The infiltration rate data and time were plotted in Figures 8 and 9 for equations 19 and 20, respectively. The line for each equation is also drawn through the data points. These graphs show a definite increase in the infiltration rate with time.

Table 13. Statistical Analyses of the Linear Regression of Infiltration Rate on Time for the First Year Application Plots and the Control Plots.

Equation	Treatments	R^2	MS_e	F	Significance	B_1	B_2
$I = B_1 + B_2 T$	6,8&10	0.139	0.0012	12.31	0.00	0.0254	0.0152
$Log_e I = B_1 + B_2 T$	6,8&10	0.119	0.3999	10.28	0.00	-3.5867	0.0254
$I = B_1 + B_2 T$	1	0.012	0.0013	0.30	0.58	0.0565	0.0004
$Log_e I = B_1 + B_2 T$	1	0.000	0.2972	0.00	0.98	-2.8758	0.0003

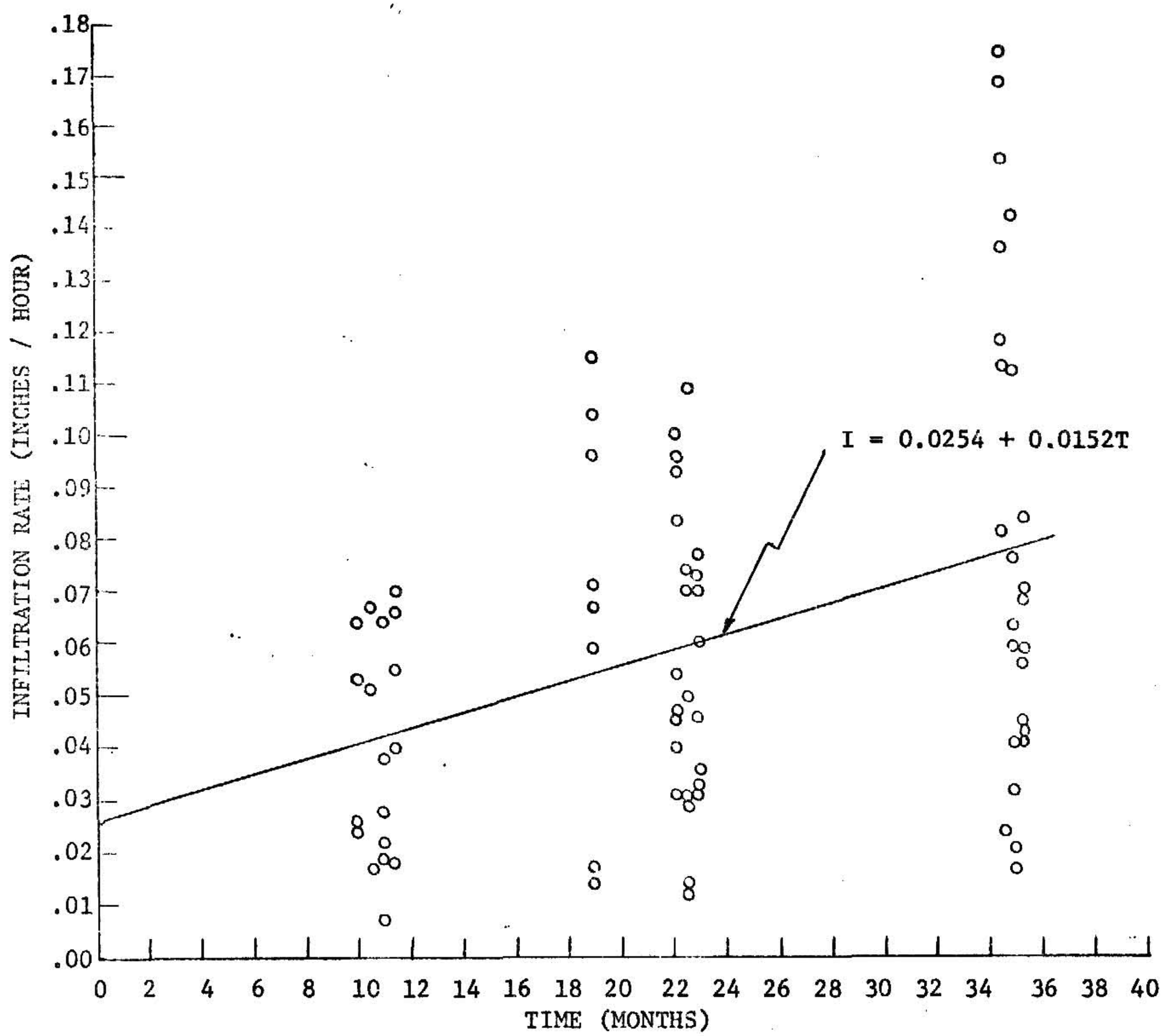

Figure 8. Infiltration Rate Calculated by Equation 19 for Plots Receiving Manure the First Year Only.

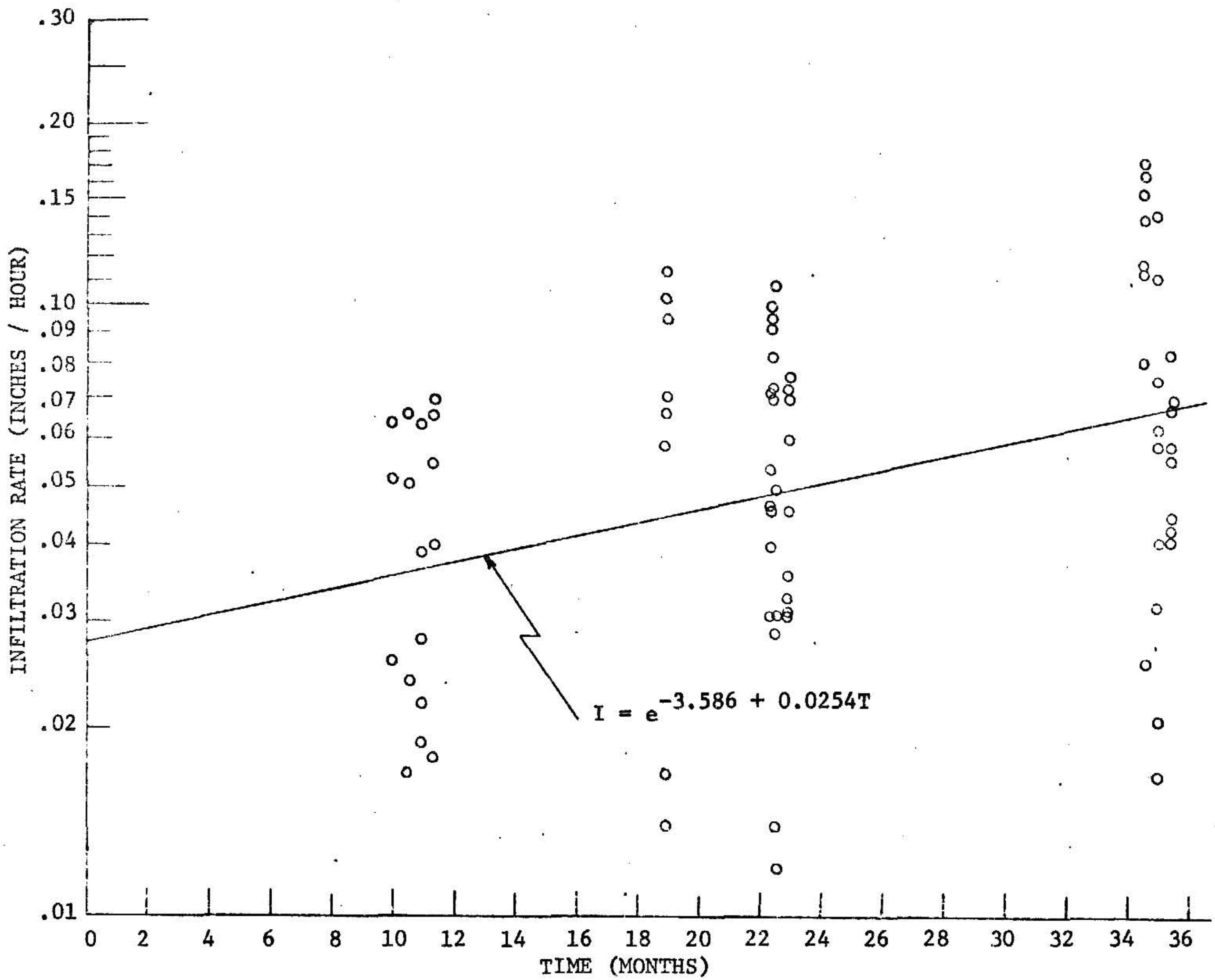

Figure 9. Infiltration Rate Calculated by Equation 20 for Plots Receiving Manure the First Year Only.

DISCUSSION

The results of this study indicate the presence of several trends concerning the effects of manure applications to cropland and the basic infiltration rate of the soil. The equations developed had significant R^2 values. These equations indicated that there was a relationship between the manure applied to the soil and the soil's infiltration rate. The empirical coefficients for the manure application and the manure application squared from the analyses of the 1970 data were negative. These negative empirical coefficients indicated that as the manure application increased, the basic infiltration rate decreased. The analyses of the 1971 and 1972 irrigation data did not provide empirical coefficients that were as consistently negative as the 1970 irrigation data. However, with the larger number of variables in the 1971 and 1972 irrigation data, some positive coefficients were more probable.

The author concluded from the equations tested that increases in manure application rates will result in reductions in the soil's basic infiltration rates.

The equations developed that provided the highest R^2 values had separate variables for each year's manure application and each year's manure application squared. The inclusion of the manure squared term increased the R^2 considerably over those equations that did not have them. This indicated that the effects of the manure application were not completely linear. From this, it can be concluded that the infiltration rate drops off faster at higher application rates than it does at lower application rates.

Other tests ran support the conclusion that the infiltration dropped off more rapidly for the higher application rates. The continuous application treatment plots were broken into two groups. Treatments M-1, M-2, M-3, and M-4 were in one group of lower application rates of 0 to 40 tons per acre. The second group was of higher application rates of 80 to 320 tons per acre. The second group were treatments M-5, M-7, and M-9. When the 1971 and 1972 irrigation data were divided into these two groups and analyzed by equations 15 and 16, R^2 values of as high as 0.669 were obtained. From the analyses of the irrigation data, the author concluded that the higher the application rate of manure, the greater the decrease in infiltration. The higher R^2s obtained when the manure squared terms were used led to the conclusion that the infiltration dropped off much more rapidly at the higher application rates than they did at the lower application rates.

For the years 1971 and 1972, the analyses indicated that each year's manure application entered separately produced a higher R^2 value. This indicated that when two or three year's applications had accumulated, there was a difference in the relative influence of each on infiltration rate. It was expected that the most recent manure application would have the most influence on the infiltration rate. The standard partial betas provided some indication of this trend. However, the inconsistency of the standard partial betas made the evaluation more difficult.

The analyses of the 1970 irrigation data indicated that the basic infiltration rates decreased with increased application rates of manure applied the previous fall. The first year application plots did not receive further applications of manure the following years. When the change in infiltration rates of these plots were compared to the change in infiltration rates of the control plots, a significant relationship was found. The basic infiltration rates of the first year application plots increased over the three year period. This indicated that after the initial reduction of the infiltration rate, there was an increase in the infiltration rate with time.

The increase in the infiltration rate of the first year application plots explains part of the variation of the continuous application plots. The empirical coefficients for the 1969 manure application were positive when entered into the 1971 and 1972 analyses. The increase in the infiltration rate of the first year application plots would indicate that the variables M_{69} and M_{69}^2 would have lost their effects in the analyses of the 1971 and 1972 irrigation data. The author concluded from the increase in the infiltration rates of the first year application plots and the standard partial betas of the analyses of the 1971 and 1972 irrigation data, that the most recent manure application has the most influence on the soil's infiltration rate.

CONCLUSIONS

1. Development of equations that have significant R^2 values indicate that heavy manure applications have an effect on the basic infiltration rate of soil. The negative empirical coefficients of the equations developed indicate that as the manure application rate is increased, the basic infiltration rate will be reduced.

2. The inclusion of the manure squared terms in the equations and the higher R^2 values produced when the lower and higher application rates were analyzed separately indicates that the effects of the manure application are not linear. The basic infiltration rate drops off faster at higher application rates than it does at lower application rates.

3. The infiltration rate of the first year application plots decreased the first year. After this initial reduction in the infiltration rate, the infiltration rate increased with time when further applications were not made. The soil's infiltration rate will recover from the effects of heavy manure applications.

4. The equations developed with each year's manure application entered separately produced higher R^2 values. When more than two years manure applications had accumulated, there was a difference in the relative influence of each on the soil's infiltration rate. An evaluation of the statistical results lead to the conclusion that the most recent manure application had the most influence on the soil's basic infiltration rate.

SUMMARY

The increased size and capacity of many feedlots have created many new waste handling and disposal problems. Manure is an unavoidable by-product of livestock feeding. Disposal of livestock manure on cropland has been recommended as a method to obtain the maximum benefits from the plant nutrients in the manure. When manure is spread on cropland as fertilizer, it is spread relatively thin to obtain the maximum return from it. However, in recent years, the rapid growth of feedlots has led to heavy applications of manure to cropland near the feedlot. Heavy applications of manure will naturally alter the nature and composition of a soil system.

In this study, manure applications were applied to test plots in the falls of 1969, 1970, and 1971. The desired manure applications were 0, 10, 20, 40, 80, 160, and 320 tons per acre per year. Other treatment plots received one year applications of 80, 160, and 320 tons per acre in the fall of 1969. These first year application plots did not receive any additional manure applications after the initial treatments.

The test plots were irrigated with a gated pipe and furrow irrigation system. The inflow-outflow method was used to determine the infiltration rate for each plot. The primary objective of this study was to evaluate effects of heavy manure application rates on the basic infiltration rates of the test plots. To evaluate the effects of the manure applications, equations were developed using manure applications as independent variables to predict the soil's infiltration rate. The two equations developed that accounted for the greatest amount of variation in the infiltration rate were as follows:

$$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2 \quad (15)$$

and

$$\text{Log}_e I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2 \quad (16)$$

where: I = infiltration rate in inches per hour

$\text{Log}_e I$ = log of infiltration in inches per hour

B_1 = empirical coefficient

B_2 = empirical coefficient

M_{69} = manure applied in 1969 in tons per acre

B_3 = empirical coefficient

M_{69}^2 = manure applied in 1969 squared

B_4 = empirical coefficient

M_{70} = manure applied in 1970 in tons per acre

B_5 = empirical coefficient

M_{70}^2 = manure applied in 1970 squared

B_6 = empirical coefficient

M_{71} = manure applied in 1971 in tons per acre

B_7 = empirical coefficient

M_{71}^2 = manure applied in 1971 squared.

From the analyses of the irrigation data, the author made several conclusions. From the significant R^2s of equations 15 and 16, it was concluded that heavy manure applications affect the soil's basic infiltration rate. The empirical coefficients from the analyses verified that the manure applications caused a decrease in the soil's infiltration rates. From the irrigation data analyzed, it was concluded that the greater the manure application, the greater the decrease in infiltration rates. The manure application squared terms substantiated that the infiltration rate decreased more rapidly at the higher application rates than they did at the lower application rates. The analyses also established that, if manure was applied only one year, after the initial decrease in the infiltration rate, the infiltration rate would increase with elapsed time from the application. When several year's applications had accumulated on the cropland, the most recent application had the most influence on the infiltration rate.

SUGGESTIONS FOR FUTURE RESEARCH

This study determined only the effects of heavy manure applications on the basic infiltration rate of a soil. A large amount of variation in infiltration rate was encountered. Observation of data indicated that inflow rate into the furrows influence the infiltration rate. Other factors such as soil moisture and water-soil area also influenced the infiltration rate. To obtain a better evaluation of the effects of heavy manure applications these variables should also be accounted for.

The effluent plots were not considered in this study. Because of the tremendous amount of runoff effluent from feedlots, this area also needs further study.

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APPENDIX A

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

THIS IS THE BEST COPY AVAILABLE

P-474

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$JOB        HLM,TIME=300,PAGES=90
C     COMPUTES FURROW INTAKE RATE
C     WRITTEN BY HARRY MANGES
      DIMENSION IRO(3),OBW(3),OH(3),QIN(3),CH(3),RUN(100),ZIN(100)
  100 FORMAT(1X,A4,F7.4,F8.4,14X,F5.0,F4.1)
  101 FORMAT(I1)
  102 FORMAT(A4,I2,2A4,4X,F5.2,3F5.1,3(I5,F5.2,F4.2))
  200 FORMAT(///1X,A4,2X,12HC(ORIFICE) =,F7.4,4H H**,F9.4,10H  LENGTH =
     1,F5.0,9H  WIDTH =,F4.1/)
  202 FORMAT(1X,A4,2X,6HRUNOFF,1X,2A4,3(I5,1X,3HIN=,F6.2,1X,4HOUT=,F6.2
     1,1X,4HIAN=,F6.3))
  201 FORMAT(1X,A4,2X,6HCLEAR ,1X,2A4,3(I5,1X,3HIN=,F6.2,1X,4HOUT=,F6.2
     1,1X,4HIAN=,F6.3))
      ASTG=SQRT(64.4)*3.1416*0.25/144.0
    3 READ(5,100)PLOT,CO,AH,ZLEN,WIDE
      READ(5,101)N
      WRITE(6,200)PLOT,CO,AH,ZLEN,WIDE
      DO 1 J=1,N
      READ(5,102)PLOT,KIW,ZMO,YR,COBW,FR,SR,TR,IRO(1),OBW(1),OH(1),IRO(2
     1),OBW(2),OH(2),IRO(3),OBW(3),OH(3)
      OHC=SQRT(4.33-COBW)
      CFR=60.0/(FR*OHC)
      CSR=60.0/(SR*OHC)
      CTR=60.0/(TR*OHC)
      DO 2 K=1,3
      IF(IRO(K).EQ.0)GO TO 6
      OBWH=SQRT(4.33-OBW(K))
      QFR=CFR*OBWH
      QSR=CSR*OBWH
      QTR=CTR*OBWH
      QIN(K)=QFR+QSR+QTR
      IF(OH(K).LT.0.90)GO TO 5
    6 RUN(K)=0.0
      ZIN(K)=0.0
      QIN(K)=0.0
      GO TO 2
    5 CH(K)=0.62-OH(K)
      RUN(K)=SQRT(CH(K))*448.8*ASTG*CO*CH(K)**AH
      ZIN(K)=100.*(QIN(K)-RUN(K))/(ZLEN*WIDE)
    2 CONTINUE
      IF(KIW.EQ.1)WRITE(6,201)PLOT,ZMO,YR,IRO(1),QIN(1),RUN(1),ZIN(1),IR
     1O(2),QIN(2),RUN(2),ZIN(2),IRO(3),QIN(3),RUN(3),ZIN(3)
      IF(KIW.EQ.2)WRITE(6,202)PLOT,ZMO,TR,IRO(1),QIN(1),RUN(1),ZIN(1),IR
     1O(2),QIN(2),RUN(2),ZIN(2),IRO(3),QIN(3),RUN(3),ZIN(3)
    1 CONTINUE
      GO TO 3
    4 STOP
      END
```

APPENDIX B

Table 14. Statistical Analyses of Infiltration Equations by Individual Irrigation Period and by Year.

Date	Number of Observations	R^2	MS_e	F	Significance Level
		$I = B_1 + B_2 M_t$			
6/25/70	20	0.000	0.0010	0.00	0.94
7/9/70	25	0.111	0.0008	2.86	0.10
7/23/70	27	0.151	0.0009	4.46	0.04
8/6/70	26	0.125	0.0018	3.42	0.07
70	98	0.080	0.0012	8.40	0.00
4/6/71	18	0.001	0.0016	0.02	0.88
7/6/71	19	0.061	0.0017	1.11	0.30
7/21/71	17	0.194	0.0006	3.61	0.07
8/5/71	17	0.073	0.0012	1.18	0.29
71	71	0.054	0.0012	3.94	0.05
7/20/72	15	0.039	0.0019	0.53	0.47
8/3/72	12	0.024	0.0016	0.25	0.62
8/20/72	21	0.003	0.0013	0.05	0.82
72	48	0.006	0.0017	0.27	0.60
		$\text{Log}_e I = B_1 + B_2 M_t$			
6/25/70	20	0.015	0.3030	0.27	0.61
7/9/70	25	0.155	0.2212	4.22	0.05
7/23/70	27	0.228	0.3589	7.38	0.12
8/6/70	26	0.175	0.4501	5.08	0.03
70	98	0.139	0.3363	15.54	0.00
4/6/71	18	0.015	0.9221	0.24	0.62
7/6/71	19	0.081	0.7464	1.50	0.23
7/21/71	17	0.303	0.4516	6.53	0.02
8/5/71	17	0.044	0.5758	0.69	0.42
71	71	0.080	0.6450	6.03	0.02
7/20/72	15	0.046	0.4362	0.63	0.43
8/3/72	12	0.000	1.0998	0.00	0.97
8/20/72	21	0.010	0.4444	0.21	0.65
72	48	0.010	0.6270	0.46	0.50

Table 14. Continued

Date	Number of Observations	R^2	MS_e	F	Significance Level
		$I = B_1 + B_2 M_t + B_3 M_t^2$			
6/25/70	20	0.001	0.0014	0.00	0.99
7/9/70	25	0.119	0.0008	1.48	0.25
7/23/70	27	0.153	0.0010	2.49	0.13
8/6/70	26	0.152	0.0018	2.05	0.15
70	98	0.087	0.0012	4.56	0.01
4/6/71	18	0.206	0.0013	1.95	0.17
7/6/71	19	0.069	0.0018	0.59	0.56
7/21/71	17	0.202	0.0006	1.77	0.20
8/5/71	17	0.093	0.0013	0.71	0.50
71	71	0.092	0.0012	3.45	0.04
7/20/72	15	0.064	0.0020	0.41	0.67
8/3/72	12	0.145	0.0016	0.76	0.49
8/20/72	21	0.072	0.0013	0.70	0.51
72	48	0.031	0.0017	0.73	0.48
		$Log_e I = B_1 + B_2 M_t + B_3 M_t^2$			
6/25/70	20	0.016	0.3204	0.13	0.87
7/9/70	25	0.157	0.2307	2.05	0.15
7/23/70	27	0.229	0.3734	3.56	0.04
8/6/70	26	0.281	0.4095	4.48	0.02
70	98	0.153	0.3343	8.61	0.00
4/6/71	18	0.114	0.8845	0.96	0.40
7/6/71	19	0.094	0.7822	0.83	0.45
7/21/71	17	0.304	0.4835	3.59	0.08
8/5/71	17	0.244	0.4882	2.26	0.14
71	71	0.107	0.6358	4.06	0.02
7/20/72	15	0.088	0.4522	0.58	0.57
8/3/72	12	0.171	1.0131	0.92	0.43
8/20/72	21	0.130	0.4127	1.34	0.28
72	48	0.054	0.6120	1.30	0.28

Table 14. Continued

Date	Number of Observations	R^2	MS_e	F	Significance Level
		$I = B_1 + B_2 M_{69} + B_3 M_{70} + B_4 M_{71}$			
6/25/70	20	0.000	0.0010	0.00	0.94
7/9/70	25	0.111	0.0008	2.86	0.10
7/23/70	27	0.151	0.0009	4.46	0.04
8/6/70	26	0.125	0.0018	3.42	0.07
70	98	0.080	0.0012	8.40	0.00
4/6/71	18	0.011	0.0016	0.08	0.92
7/6/71	19	0.099	0.0017	0.87	0.43
7/21/71	17	0.200	0.0006	1.75	0.21
8/5/71	17	0.076	0.0013	0.58	0.57
71	71	0.054	0.0013	1.94	0.15
7/20/72	15	0.466	0.0013	3.19	0.06
8/3/72	12	0.307	0.0015	1.18	0.37
8/20/72	21	0.338	0.0010	2.90	0.06
72	48	0.190	0.0015	3.43	0.02
		$\mathrm{Log}_e\, I = B_1 + B_2 M_{69} + B_3 M_{70} + B_4 M_{71}$			
6/25/70	20	0.015	0.3030	0.27	0.61
7/9/70	25	0.155	0.2212	4.22	0.05
7/23/70	27	0.228	0.3589	7.38	0.12
8/6/70	26	0.175	0.4501	5.08	0.03
70	98	0.139	0.3363	15.54	0.00
4/6/71	18	0.057	0.9414	0.45	0.64
7/6/71	19	0.135	0.7470	1.24	0.31
7/21/71	17	0.316	0.4749	3.24	0.07
8/5/71	17	0.082	0.5925	0.63	0.54
71	71	0.084	0.6516	3.13	0.05
7/20/72	15	0.627	0.2013	6.18	0.01
8/3/72	12	0.148	1.1710	0.46	0.71
8/20/72	21	0.326	0.3385	2.73	0.07
72	48	0.138	0.5707	2.35	0.08

Table 14. Continued

Date	Number of Observations	R^2	MS_e	F	Significance Level
$I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$					
6/25/70	20	0.001	0.0014	0.00	0.98
7/9/70	25	0.119	0.0008	1.48	0.25
7/23/70	27	0.154	0.0010	2.49	0.13
8/6/70	26	0.152	0.0018	2.05	0.15
70	98	0.087	0.0012	4.56	0.01
4/6/71	18	0.321	0.0013	1.53	0.25
7/6/71	19	0.153	0.0010	0.63	0.64
7/21/71	17	0.383	0.0005	1.86	0.18
8/5/71	17	0.248	0.5660	0.99	0.45
71	71	0.135	0.0012	2.58	0.05
7/20/72	15	0.544	0.0015	1.58	0.26
8/3/72	12	0.380	0.0021	0.51	0.78
8/20/72	21	0.531	0.0008	2.64	0.06
72	48	0.297	0.0014	2.88	0.02
$\text{Log}_e\, I = B_1 + B_2 M_{69} + B_3 M_{69}^2 + B_4 M_{70} + B_5 M_{70}^2 + B_6 M_{71} + B_7 M_{71}^2$					
6/25/70	20	0.015	0.3204	0.13	0.87
7/9/70	25	0.157	0.2307	2.05	0.15
7/23/70	27	0.229	0.3734	3.56	0.04
8/6/70	26	0.281	0.4095	4.48	0.02
70	98	0.153	0.3343	8.61	0.00
4/6/71	18	0.247	0.8677	1.06	0.41
7/6/71	19	0.304	0.6866	1.53	0.25
7/21/71	17	0.442	0.4521	2.38	0.11
8/5/71	17	0.093	0.0015	0.31	0.86
71	71	0.172	0.6071	3.43	0.01
7/20/72	15	0.711	0.2150	3.27	0.06
8/3/72	12	0.308	1.1525	0.37	0.87
8/20/72	21	0.557	0.2698	2.94	0.05
72	48	0.264	0.5227	2.45	0.04

EFFECTS OF HEAVY FEEDLOT MANURE APPLICATION RATES ON THE BASIC INFILTRATION RATE OF SOIL

by

ROBERT DEAN STRITZKE

B. S., Kansas State University, 1970

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Agricultural Mechanization

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1973

Increased size and capacity of feedlots have created waste handling and dispoasl problems. In the last fifteen year period, the number of cattle on feed for slaughter has increased 120%. Spreading manure on cropland is recommended as a least cost method of manure disposal. When manure is utilized as a fertilizer it is spread relatively thin to obtain the maximum return from it. However, in recent years, the rapid growth of feedlots has led to heavy applications of manure to cropland near the feedlot. The primary purpose of this study was to determine the effects of heavy manure applications on the basic infiltration rate of soils.

In this study, manure applications were applied to test plots in the falls of 1969, 1970, and 1971. The desired manure applications were 0, 10, 20, 40, 80, 160, and 320 tons per acre per year. Other treatment plots received one year applications of 80, 160, and 320 tons per acre in the fall of 1969. These first year application plots did not receive any additional manure applications after the initial treatments. The test plots were irrigated with a gated pipe and furrow irrigation system. The inflow-outflow method was used to determine the infiltration rate for each plot.

A statistical multiple regression technique was utilized to evaluate the effects of the manure applications on the soil's basic infiltration rate. Development of statistical analyses indicated that heavy manure applications do influence the soil's basic infiltration rate. As the manure application rate is increased, the soil's basic infiltration rate is reduced. The reduction of the infiltration rate is not linear. At higher application rates, the soil's infiltration rate drops off faster than it does at the lower application rates. The infiltration rate of the first year application plots decreased the first year after the manure application. After the initial reduction in the infiltration rate, the infiltration rate increased with time when further applications were not made. It was found that the soil's infiltration rate will recover from the effects of heavy manure applications. When more than two years manure applications had accumulated, there was a difference in the relative influence of each on the soil's infiltration rate. An evaluation of the statistical results led to the conclusion that the most recent manure application had the most influence on the soil's basic infiltration rate.