CALIBRATION OF A RAINFALL SIMULATOR
FOR DETERMINATION OF
SOIL CONSERVATION SERVICE
RUNOFF CURVE NUMBERS

by

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LIMITATIONS OF THE STUDY

The findings presented should be used only as a comparison with other rainfall simulator research and not extrapolated without caution. Some of the limitations were the small plots, runs were not repeated on the tillage treatment plots, and the experiments were limited to three subsamples of each treatment in July, 1980. Other researchers' simulator experiments were made with two runs on each plot, the first with low antecedent moisture condition, a pause, and a second with high antecedent moisture condition (Rawls, et al. 1976). Only one set of runs was performed on the tillage treatment plots.

Quantity measurement of runoff water was the objective of field tests. Water quality samples were not taken, but color and consistency of the runoff water were observed.

The rainfall simulator experiments were conducted on nonirrigated land towards the end of a much above average hot and dry summer. The antecedent moisture conditions were not in a typical state, but very dry. The soil samples' dry-basis moisture content averaged 10.3%, which is near the permanent wilting point for both locations.

PURPOSE

In northwestern and northcentral Kansas, a serious water supply problem has arisen. Three reservoirs, Kirwin Reservoir, Webster Reservoir, and Glen Elder Reservoir of the Solomon River basin have had lower than predicted water levels, even though the annual precipitation has been near normal (Figure 1). Because the amount of runoff was significantly less, farmers in irrigation districts below the reservoirs had to find other sources of water for their crops or switch to dryland farming. Some of the causes are increased numbers of permanent conservation structures (terraces, stockwater and erosion control dams, and grassed waterways), contouring and land leveling, more effective land management practices, and reduced base flow (Koelliker and Zovne, 1979).

The objective of this research was to quantify some of the rainfall-runoff relationships for wheat stubble ground in common cropping rotations at Hays and Colby, Kansas.

The specific objectives were:

1. Calibration of the nozzle pressure, rainfall distribution, rainfall rate and runoff amount for the rainfall simulator.

2. Determination of the effect of rainfall intensity on Soil Conservation Service (SCS) runoff curve numbers on the same plot of pasture at Manhattan, Kansas from repeated storms using the rainfall simulator.

3. Determination of SCS curve numbers on wheat-fallow rotation land at Colby, Kansas and on wheat-sorghum-fallow rotation land at Hays,

Kansas for several tillage and surface residue treatments immediately after wheat harvest.

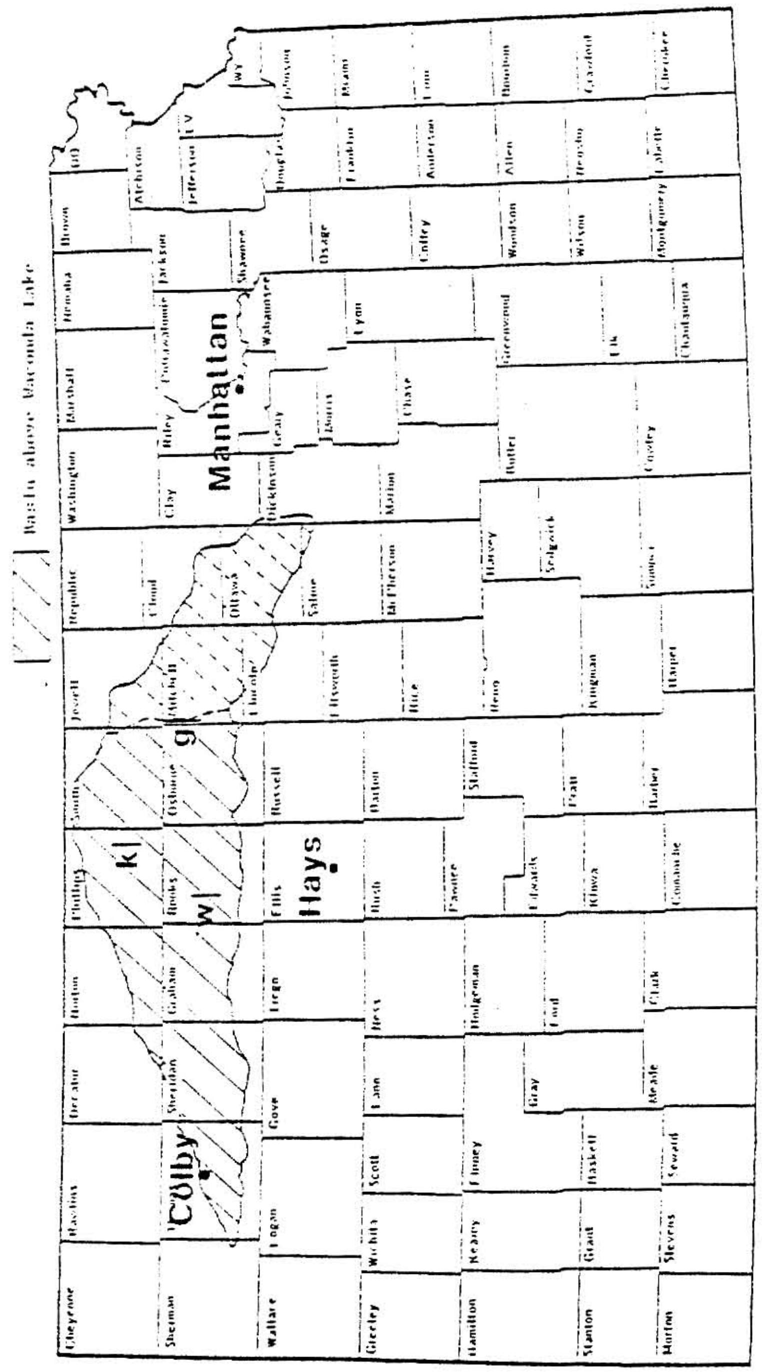


Figure 1. Map of Kansas with the rainfall simulator experiment locations and the Solomon River basin; K, Kirwin Reservoir, W, Webster Reservoir, and G, Glen Elder Reservoir

LITERATURE REVIEW

Surface runoff and infiltration have been studied extensively by engineers and scientists for over a hundred years. Over fifty years ago, infiltration and runoff research were conducted at Kansas State University (KSU) (Duley and Hays, 1932). O. E. Hays (1931) used simulated rainfall to determine the effect of slope upon runoff and soil loss. More recently, Nail (1978) at the University of Missouri in Columbia, Missouri, investigated the tillage and infiltration properties of a claypan soil using a rainfall simulator. Nail found that certain tillage operations increased infiltration, by altering the structure of the soil and changing the infiltration capacity of the soil.

One of the most common methods of estimating runoff is the United States Department of Agriculture (USDA), Soil Conservation Service (SCS) Method. The method assigns a runoff curve number for a given hydrologic soil-cover complex and antecedent soil moisture condition to determine the volume of runoff from a given storm when the ground is not frozen (USDA, SCS, 1964).

Principal uses of this empirical equation are for the design of dams, terraces, and other structures. The curve number indicates the runoff potential for a soil-cover complex. The curve number is a transformation of the runoff potential, S so that it can only vary between 0, no runoff, and 100, all runoff.

S consists of two parts, the initial abstraction and the infiltrated amount after runoff starts. Hawkins (1979) defined S as "an index of potential site moisture storage." Hawkins also differentiated the SCS equation:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{1}$$

where

$$P \geq 0.2S \tag{2}$$

P = precipitation, inches

Q = runoff depth, inches

$S = \frac{1000}{CN} - 10$, potential maximum difference between rainfall and runoff, inches (3)

CN = runoff curve number

and derived:

$$q(t) = i(t) - i(t) \left(\frac{S}{P(t) + 0.8S}\right)^2 \tag{4}$$

$$f(t) = i(t) \left(\frac{S}{P(t) + 0.8S}\right)^2 \tag{5}$$

where

f(t) = momentary infiltration intensity

i(t) = momentary rainfall intensity

P(t) = cumulative amount of rainfall at time t

q(t) = momentary runoff rate

In rainfall simulation studies, P, Q, i, q(t) can be measured whence S can be derived. One of its limitations is as time approaches infinity, the infiltration capacity approaches zero.

The curve number can be estimated from the soil-cover complex and the antecedent moisture condition. For cropland and rangeland, the curve number changes with the amount of cover and the amount of soil moisture. Barren soil has the highest runoff potential. The period preceeding crop harvest has the lowest potential for runoff. Between these two extremes, the runoff potential varies. The SCS guidelines assume the runoff curve number varies linearly from the fallow curve number at the time of planting to the peak growth curve number at the time of harvesting during the growing season. The peak growth curve number is the difference between twice the average curve number and the fallow curve number. When the land lies fallow, SCS (1964) recommends using the peak growth curve number when more than two-thirds of the soil is covered with residue, the fallow curve number when less than one-third of the soil is covered, and the average curve number when the amount of soil is covered between the two extremes.

Rawls and Onstad (1980) proposed that the runoff curve number varies with the type of tillage practice. He chose residue left on the ground as the independent variable to represent the effects of differing tillage practices. Rawls reported that runoff has been observed to be less from land under conservation tillage (except no-till) compared with land under conventional tillage. Rawls' conclusion was that the amount of residue left on the surface can reduce the fallow curve number approximately ten percent. Rawls developed a curve that gives a percent change in the fallow runoff curve number based on the percent of surface covered with residue (Figure 2). As no-till produces more runoff than land under conservation tillage, surface roughness should be considered in curve number estimation. Soil compaction has been proved to increase runoff (Jamison and Thornton, 1961).

As some people are concerned with runoff others are concerned with infiltration. Horton (1911) made an assumption that the infiltration rate approaches a final infiltration rate that is a constant value that may or may not be zero. His infiltration equation is:

$$f_t = f_c + (f_o - f_c)e^{-kt} \tag{6}$$

where:

f_c = final infiltration rate

f_o = initial infiltration capacity

t = momentary time

k = constant rate of decrease in infiltration capacity

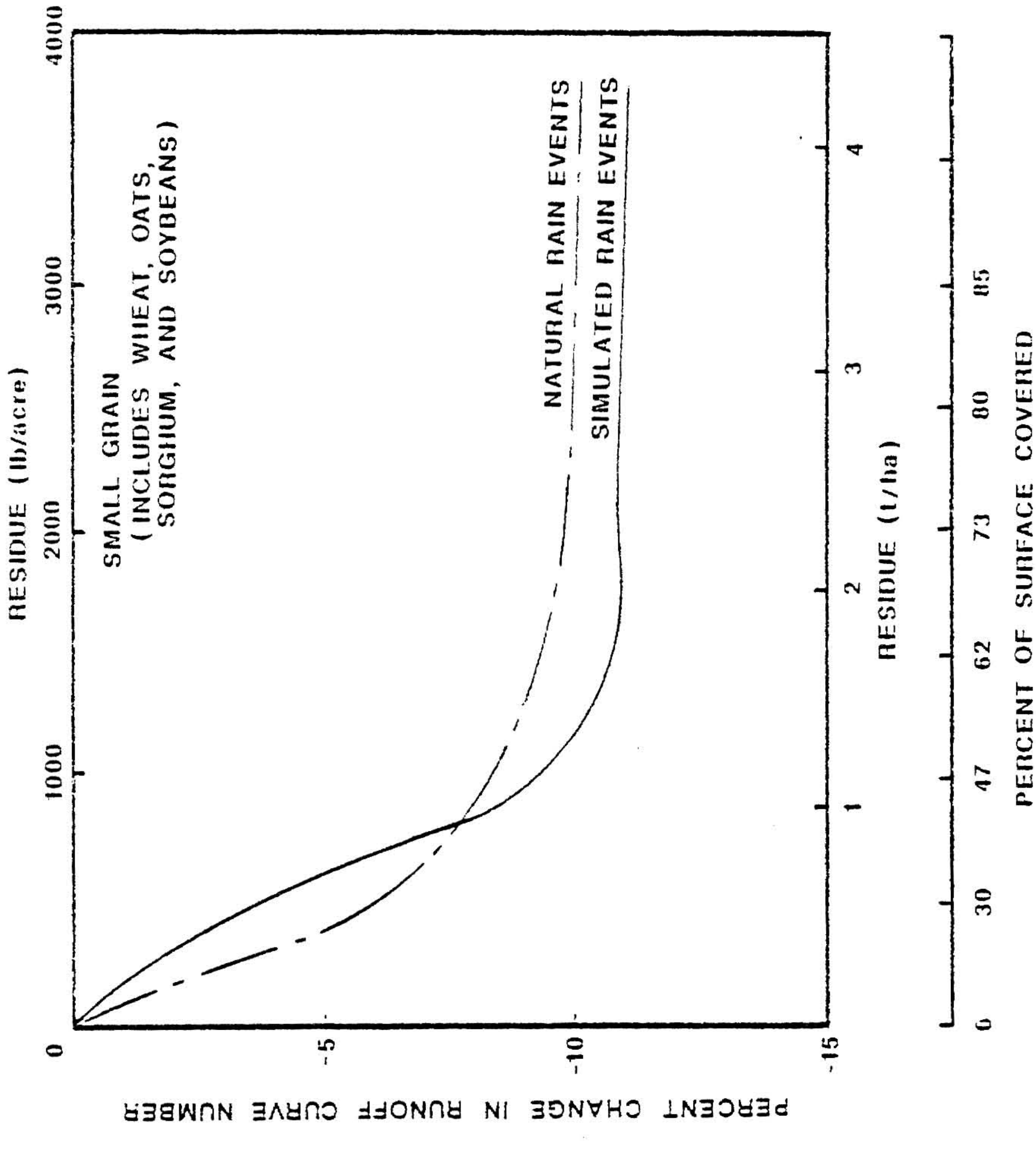


Figure 2. Percent change in SCS runoff curve number as a function of crop residue. (From Rawls and Onstead, 1980)

Some limitations to Horton's equation are the determination of the initial infiltration capacity and the rate of decrease in infiltration capacity, the rainfall intensity is constant and has to be higher than the momentary infiltration rate, and the equation is time-dependent instead of mass-dependent. Rainfall storms do not last the same amount of time and also vary with intensity.

The hydrologic budget is another method that is used. The equations are:

$$Q = P - F \tag{7}$$

where:

P = precipitation amount

F = infiltration amount

Q = runoff amount

and

$$q_t = i_t - f_t \tag{8}$$

where:

i_t = rainfall intensity

f_t = infiltration rate

q_t = runoff rate

The numerical method is useful as a simplification of the hydrologic budget. By graphical analysis, one can interpret the results and derive a mathematical relationship between the variables. However, as runoff and infiltration are complex functions, several variables play a major part in determining runoff.

Mathematical relationships can tell how one variable relates to another variable, but all the factors that determine the relationship are not always known. The factors may be dependent upon conditions that cannot be precisely controlled. Ideally, optimum relationships between variables are derived from theory, adaptable to many conditions, simple and easy to use.

Soil and water relationships are dynamic, not static. Soil moisture is constantly equilibriating with its surroundings. In unsaturated and nonhomogenous soils, water is affected by capillary and hygroscopic forces causing lateral movement besides the force of gravity.

Schiff and Dreibelbis (1949) used the term transmission rate to help describe infiltrated soil moisture storage process. The transmission rate is defined as the average lineal velocity of a particle of water as it travels between two points. This is contrasted with percolation rate and infiltration rate which are the amount of water passing through a perpendicular cross-sectional area in the soil per unit time and the amount of water passing through a perpendicular cross-sectional area of the surface of the soil per unit time, respectively.

Schiff and Dreibelbis (1949) came to the conclusion that infiltration capacity was not affected by surface crusting for residue covered soils. Skidmore (1975) supported Schiff and Dreibelbis by research at Colby, Kansas. Long term pastured ground had a higher infiltration rate than cultivated soil that was adjacent to it. The cultivated soil had poorer physical properties than that of the pasture yet the soil was of the same type. The pastured ground had a higher intake rate due to an extensive root system that had developed and also because the soil was worked less.

Soils are classified by texture and drainage properties. Some soils have a high infiltration rate until the soil is completely saturated. Other soils have low infiltration rates fairly quickly after a storm has started.

Freeze and Cherry (1979) stated that if in layered soils, the saturated hydraulic conductivities differ by an order of magnitude, the layer with the lower hydraulic conductivity will act as a boundary to water movement. Water movement would greatly slow down at the lower boundary and build up behind the boundary until the soil has been fully saturated. Once the soil has been saturated, runoff occurs if the rainfall rate is greater than the permeability of the confining layer which can be the surface layer, plowpan layer or a claypan layer.

The condition of the soil surface also is important in determining the infiltration rate. Moore (1980) showed that surface sealing occurs from external forces such as raindrop impact and mechanical compaction or through slaking and breakdown of soil aggregates during wetting. Surface sealing resulted in a significant reduction of the infiltration amount and the infiltration rate on silt loam and silty clay loam soils.

EXPERIMENTAL EQUIPMENT

Rainfall simulators are a useful tool for soil and water research. Many different types of simulators have been built. Simulators are used for erosion, infiltration, runoff, and transport research. The area under study varies from 0.005 m^2 to over 100 m^2. Simulators use either nozzles, yarn, hypodermic needles, or hollow tubes to form droplets. The intensities varied from 0.2 cm/h to 200 cm/h. Large rainfall simulators are more suited toward studying the response of a watershed. Medium sized simulators are used for erosion studies. Small simulators are used in evaluating infiltration. Very small simulators are used for measuring soil detachment and soil chemical effects (Römkens, 1979).

The multiple-intensity rainfall simulator (Meyer, 1979) was selected for several reasons. The simulator is portable. The nozzles produce a drop-size distribution and kinetic energy similar to rainfall in the Midwest. It is capable of a wide range of intensities. This simulator can be used in the field and in the laboratory.

Four functional categories divide the equipment by their purpose: rainfall simulator, water supply, data collection, and electrical (Figures 3 and 4).

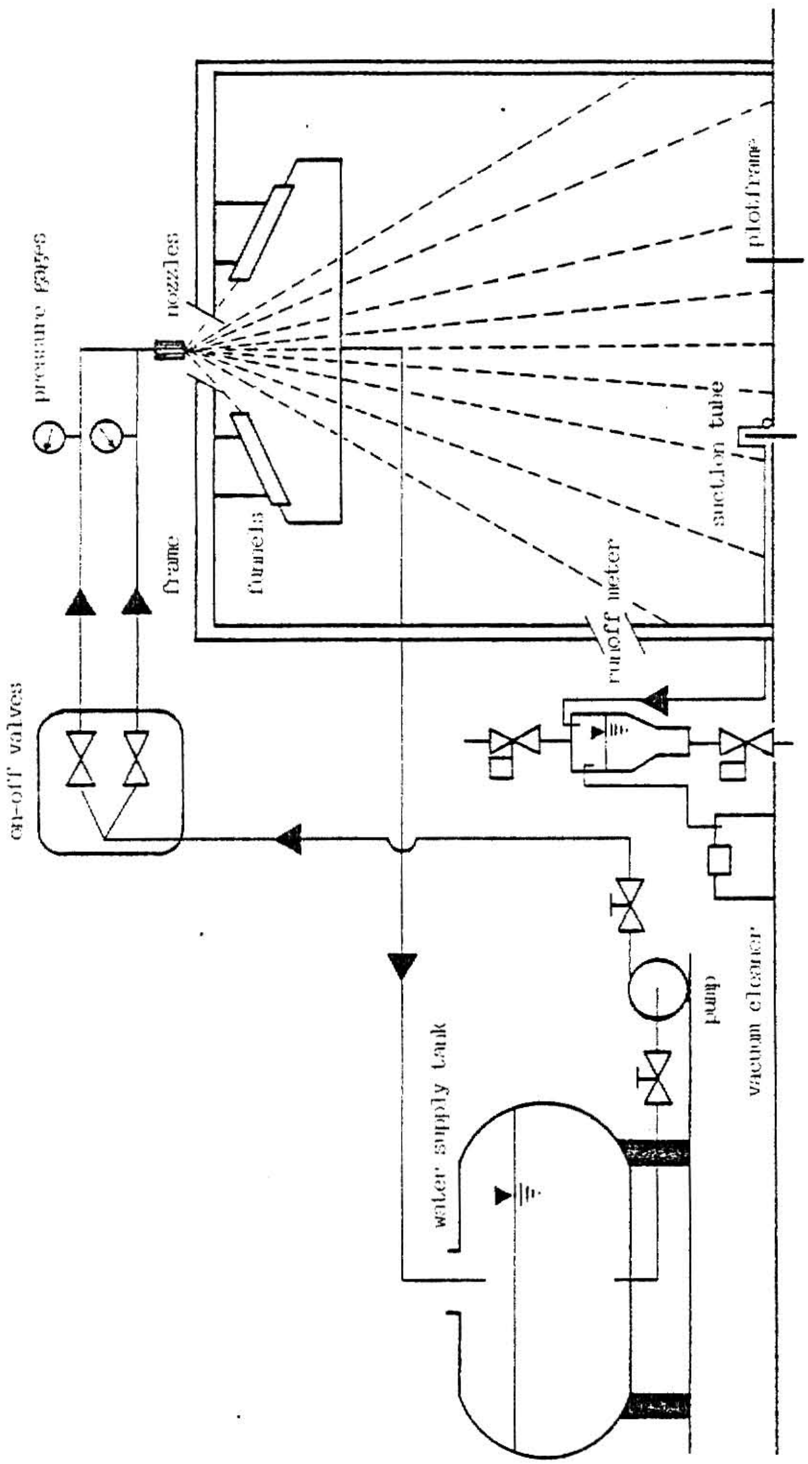
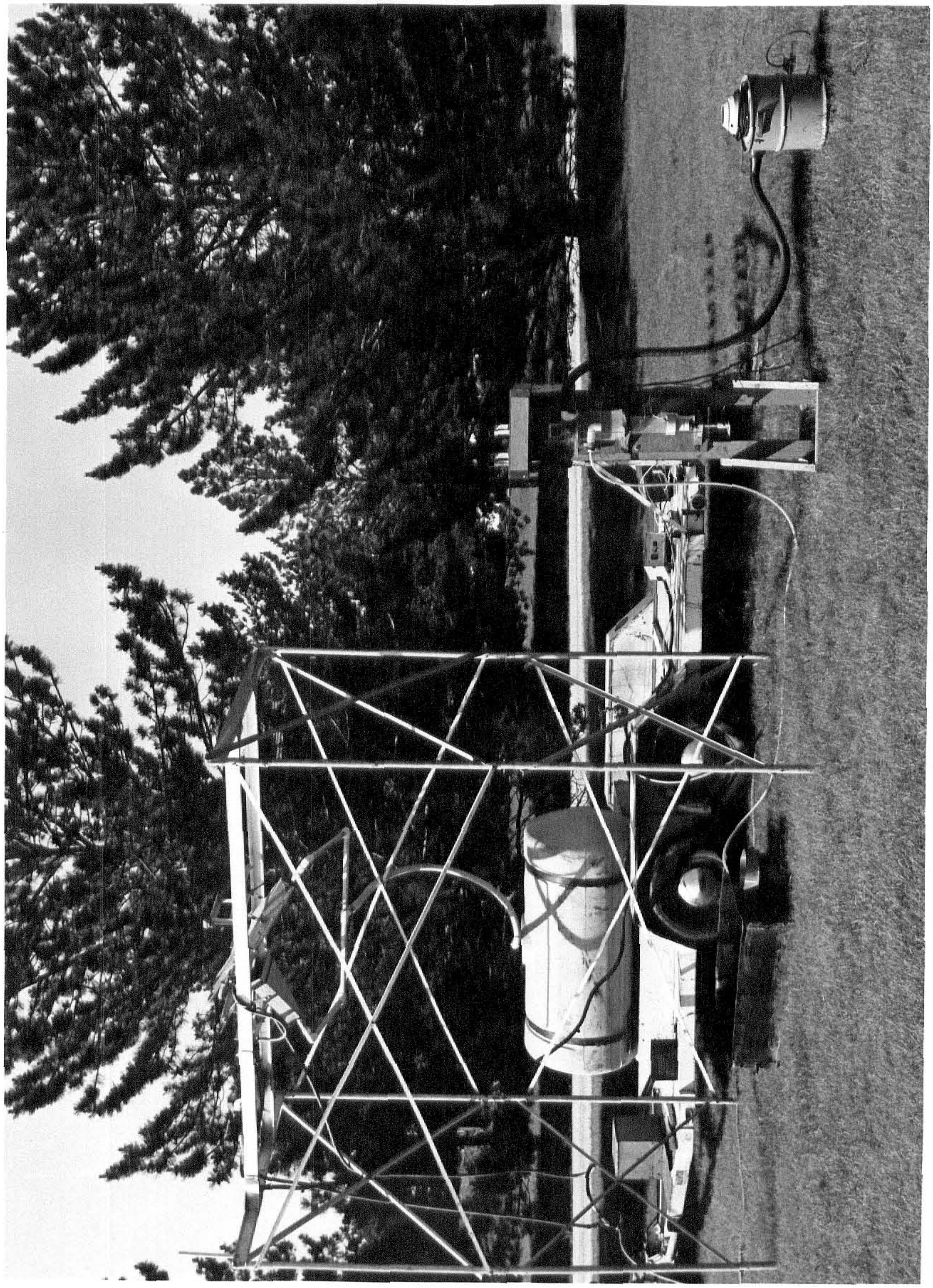


Figure 3. Schematic diagram of the rainfall simulator equipment

Figure 4. Multiple intensity rainfall simulator used for this research



The Rainfall Simulator

The simulator modeled after Meyer (1979) consists of the rainfall simulator frame, the windskirt, the base pads, and the plotframe. The rainfall simulator frame is a 1.5 by 3.0 by 3.0 meter aluminum structure built in two sections. Its main purpose is to provide the nozzles a sufficient height above the plot to allow the droplets to obtain terminal velocity before reaching the ground.

The windskirt is a 3.6 m by 10 m piece of nylon-reinforced polyethylene that is wrapped around the rainfall simulator frame to prevent wind from interfering with the experiment. A nylon rope was hemmed into the top of the windskirt, and grommets were installed along the bottom and sides. Four base pads were used to distribute the load of the rainfall simulator to prevent it from sinking into the ground when the ground became saturated. The base pads fit on the corner legs of the simulator to keep the nozzles the proper distance above the plot. Stakes were driven through the grommets to make the windskirt more rigid. Due to the windy conditions of western Kansas, the simulator frame was usually tied down.

The plotframe defines the area studied. Its dimensions are 0.9 m by 0.7 m and is made of 10 gauge plate steel. A plot frame attachment is placed over the plot frame and is used to drive the plotframe about 10 to 15 cm into the soil with a sledgehammer.

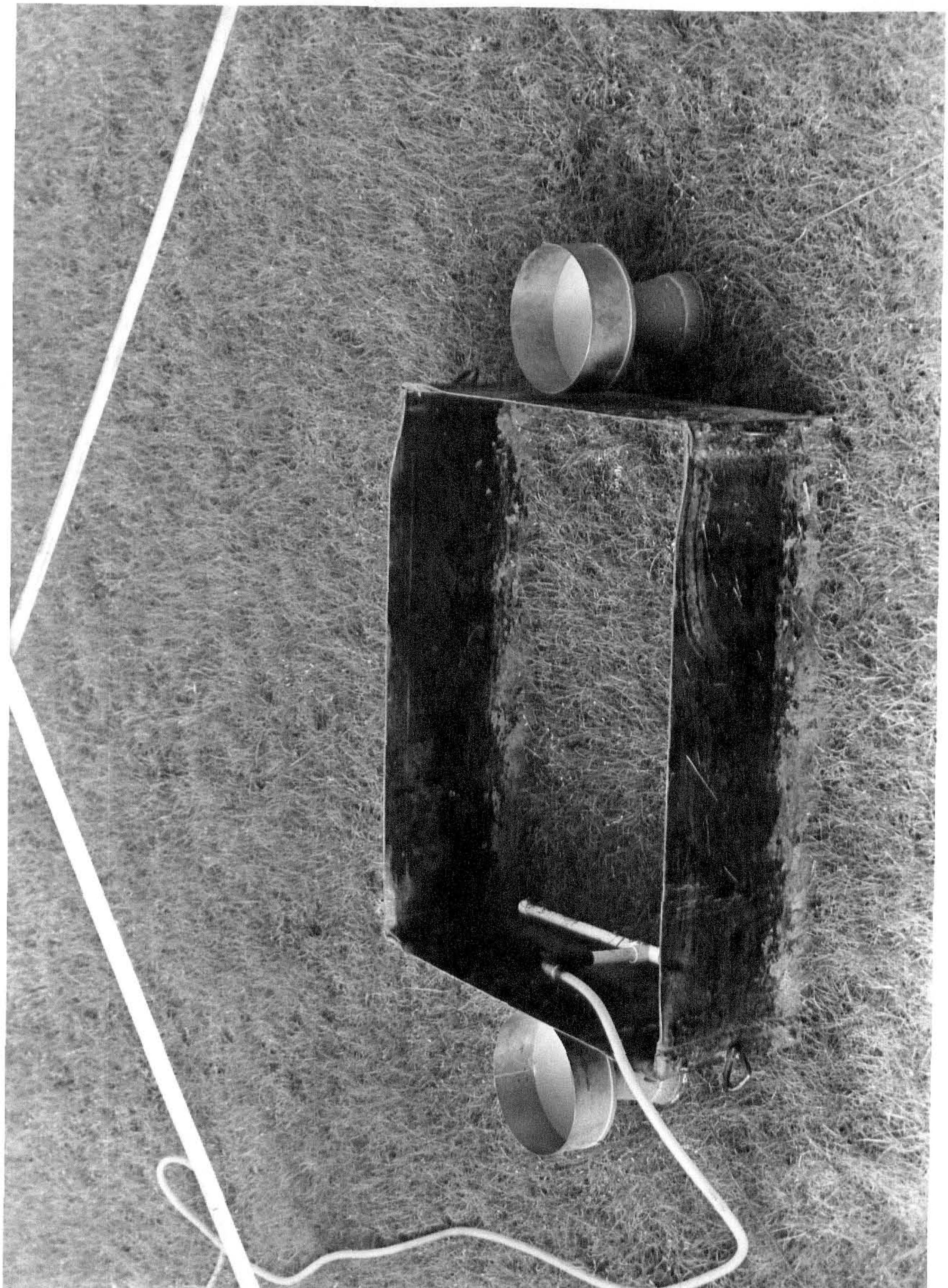
Water Supply

The water supply consists of an 850 liter tank as a water reservoir, a 0.37 kW centrifugal pump provides the flow rate and the pressure needed to simulate raindrops and two Veejet nozzles (80100 and 80150) that project a flat spray and is oscillated across the plot. The 80100 Veejet nozzle produces smaller droplets at a lower intensity than the 80150 Veejet nozzle at the same pressure. The 80100 Veejet nozzle is used to simulate a light intensity storm, where the 80150 Veejet nozzle is used to simulate high intensity storms. To conserve water, two collector funnels return water to the supply tank via plastic hoses when the nozzles where in the stop position.

The runoff was taken off the plot by placing a 60 cm long 1.5 cm diameter PVC tube with holes drilled in the tube along the lowest side of the plotframe (Figure 5). Suction from a vacuum cleaner removed the runoff adjacent to the tube and transported the runoff to the volumetric runoff meter. The plexiglass chamber has four openings, one for the vacuum line, one for the runoff inlet, a butterfly valve for the runoff outlet, and a solenoid-controlled vent at the top of the chamber. A solenoid controls the runoff outlet and the vent.

When the chamber is filling with runoff, both the vent and the outlet are closed. After the chamber is filled with one liter of runoff water, an electric current travels between two nodes through the runoff water. This engages the solenoid which opens the vent to let the outside air into the chamber. This stops runoff from the plot and opens the outlet to let the runoff in the chamber discharge.

Figure 5. Plot frame with two tipping bucket rain gages with runoff suction tube



The Data Collection Equipment

The purpose of the data collection equipment was to record on cassette tape the rainfall intensity and runoff data. Time of runoff events was also recorded by hand as a backup.

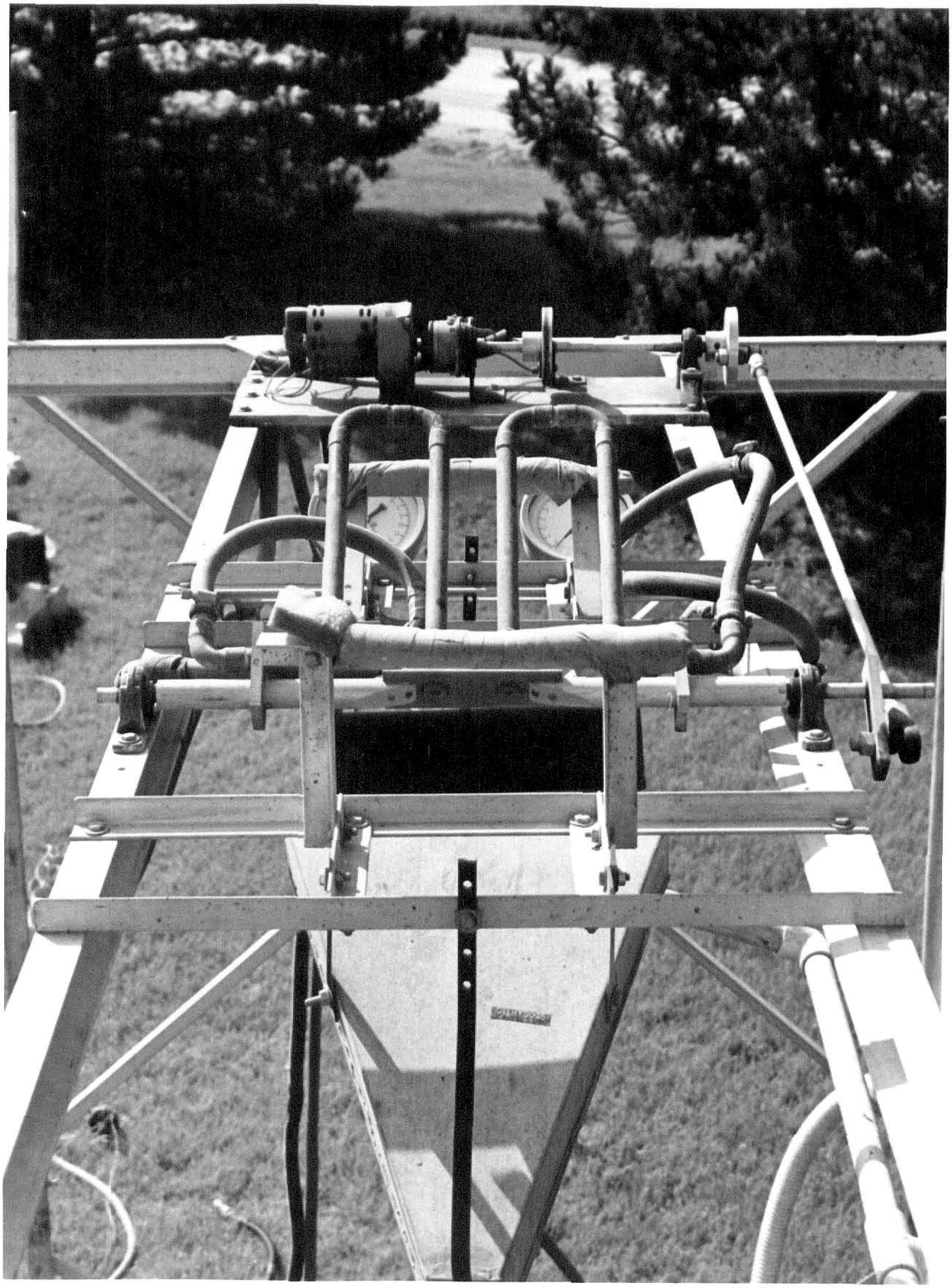
Electricity was converted from 115 volts AC to 12 volts DC and also 3.5 volts DC. The 12 VDC output was connected to the tipping bucket of rain gages. The 3.5 VDC output was connected to the SYM-1 microprocessor. A line from the top of the power supply is 115 VAC and is used to run the cassette recorder. The runoff meter is connected to the SYM-1 and no external power source is needed.

The program cassette contains the computer program that is read into the SYM-1 from the cassette recorder. The program enables the SYM-1 to run a clock, date and label the experiment, record the time when the tipping bucket rain gages tipped and the time when one unit of runoff came from the plot. The SYM-1 calculates the rates and keeps a cumulative sum of the events. The SYM-1 either automatically or manually loads the data it has collected onto the cassette tape in the cassette recorder for processing back in the laboratory.

The Electrical System

A 3.0 kW gasoline generator was used to provide power for the entire system. This was done to simplify the operation of the experiment by having only one power source instead of two or three power sources. A 0.37 kW centrifugal pump provided adequate water pressure and flow rate needed by the nozzle to simulate natural rainfall. A Martek time sequencer provided the application rate by engaging a clutch-brake system that oscillated the nozzle back and forth across the plot and by stopping the nozzle at each end for the set amount of time. The Martek time sequencer also channeled the power to a small 0.1 kW electric motor that oscillated the nozzle (Figure 6). The generator was a power supply for the data collection equipment and an industrial-type vacuum cleaner that provided the suction to remove the runoff water from the plot. The solenoid on top of the runoff meter also used power from the generator to discharge runoff from the meter.

Figure 6. Top of rainfall simulator



CALIBRATION OF THE RAINFALL SIMULATOR

The calibration of the rainfall simulator was performed in the Hydraulic Laboratory of the Civil Engineering and Agricultural Engineering Departments in Seaton Hall on the Kansas State University Campus during 1979-1980 school year. The calibration consisted of four parts: the calibration of the pressure of the spray nozzles, the rainfall distribution over the plot area, the voltage and rest interval of the Martek Time Sequencer, and the runoff meter.

Nozzle Pressure Calibration

Since pressure is very critical to the formation of droplets, the pressure gage was calibrated to the nozzle pressure of 41 kPa (6 psig) to correspond with the work of L. D. Meyer and others. Meyer (1979) found that at this pressure setting, the nozzles produced a dropsize distribution that most nearly approximated the convective thunderstorms in Mississippi with typical intensities. With data obtained from the National Severe Storms Laboratory in Norman, Oklahoma dropsize distributions of three Oklahoma storms of late May and early June in 1975 were analyzed (Figure 7). The nozzles were found to be satisfactory for artificial simulation of a Great Plains convective thunderstorm. The Veejet 80100 spray nozzle produces smaller droplets. The smaller droplets are normally associated with lower intensity storms than droplets produced from the Veejet 80150 spray nozzle.

The procedure followed in calibration of the spray nozzles was to place another pressure gage directly in front of the nozzle to be calibrated. Next, water was run through the system.

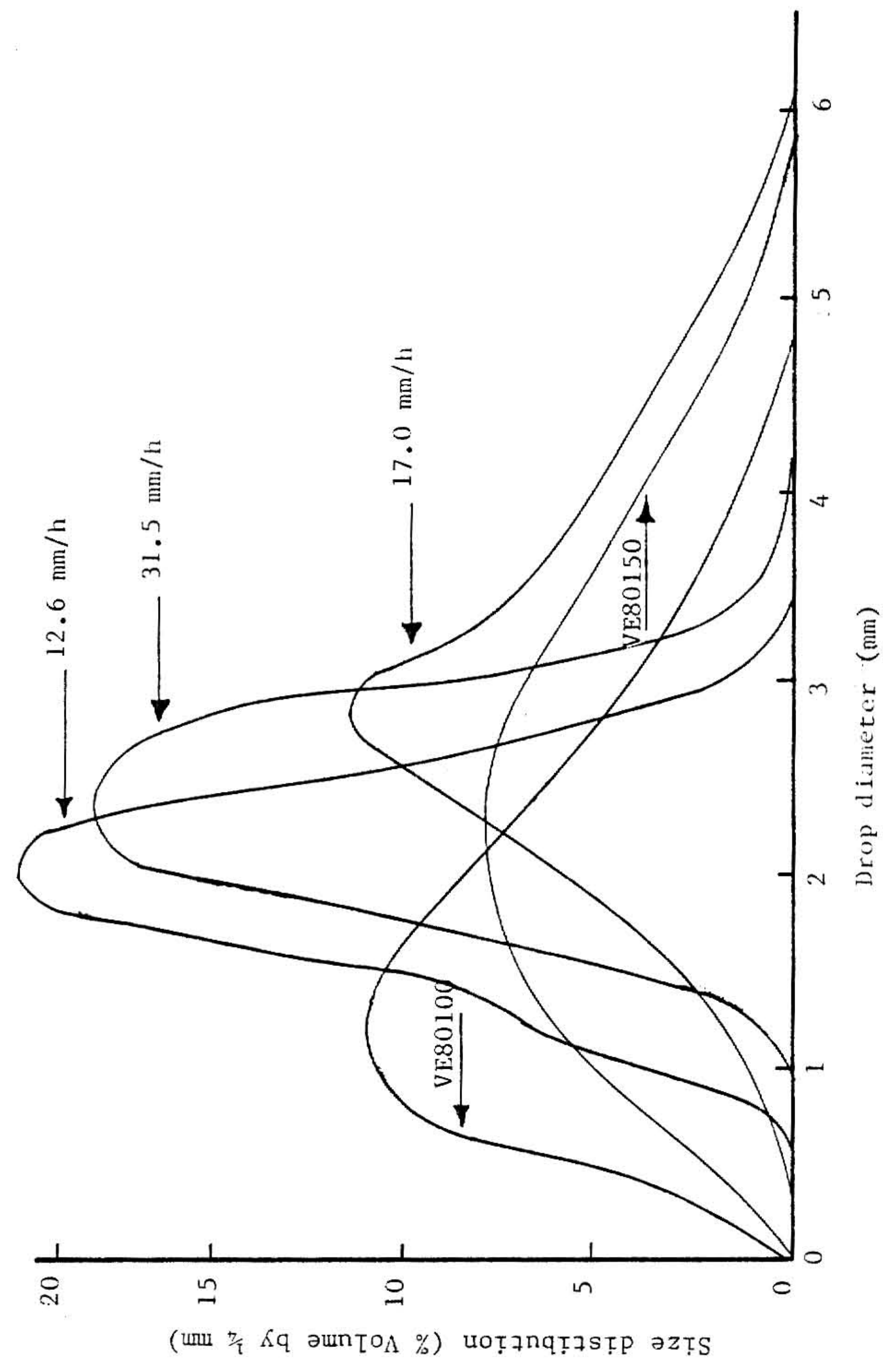


Figure 7. Drop-size distributions for Veejet 80100 and 80150 nozzles as compared with those for three Oklahoma rainfall intensities (Meyer, 1977 and National Severe Storms Laboratory, 1975)

Pressure was recorded from both gages for a range of pressures. The 1.6 cm diameter hose lengths between the gage and the nozzles were 119 cm for the VE80100 nozzle and 132 cm for the VE80150 nozzle.

For both of the nozzles, it was found that there was a linear first-order relationship between the gage pressure and the pressure at the nozzle. The pressure of the gage was higher than at the nozzle. To get the proper dropsize distribution, a pressure of 41 kPa (6 psig) is required at the nozzles. Because of pressure losses the pressure required at the gage is 45.5 kPa (6.6 psig) for the 80100 nozzle and 60 kPa (8.75 psig) for the 80150 nozzle (Figure 8).

The Rainfall Distribution Across the Plot

Because the nozzles were oscillated from one point over the plot, an analysis of the way the rainfall amount varied across the plot was made. Fifteen standard-size 500 ml beakers were placed in a three by five matrix on the plot. The locations are 5 rows on 30 cm spacing in the direction of the oscillation of the nozzle from 60 cm off center of the rainfall simulator and 3 beakers per row on a 30 cm spacing. To determine the amount of rainfall for each beaker, the beakers were individually weighed, emptied, and weighed again with the difference divided by the average open area of the beakers. Multiple graphs were made to analyze the distribution across the base of the rainfall simulator. The other data recorded during the experiment are beginning and ending tank weights, elapsed time, gage pressure, and number of oscillations.

The distribution of rainfall across the bottom of the rainfall simulator is shown in Figure 9.

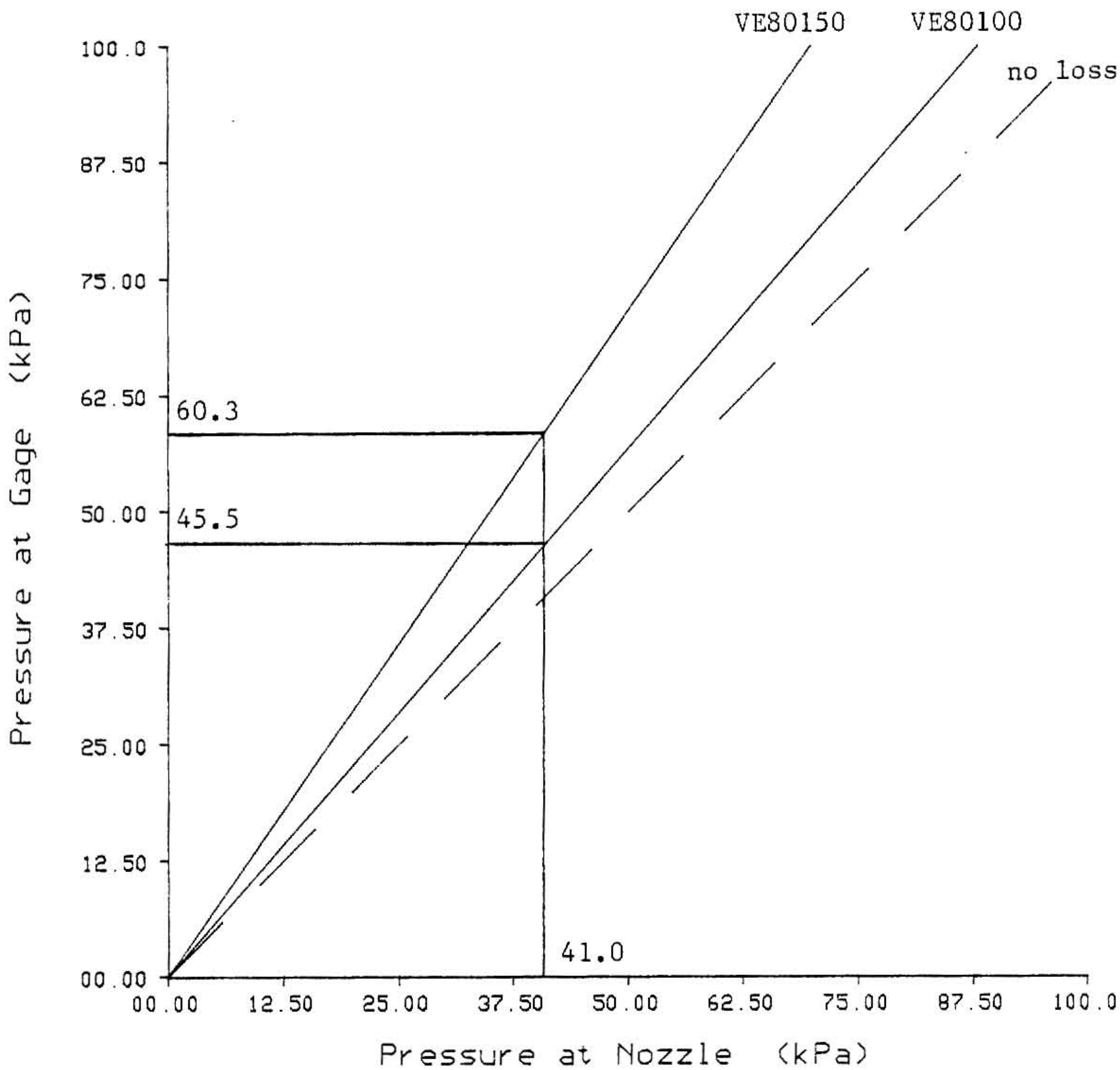


Figure 8. Nozzle pressure vs. gage pressure for the Veejet 80100 and 80150 nozzles

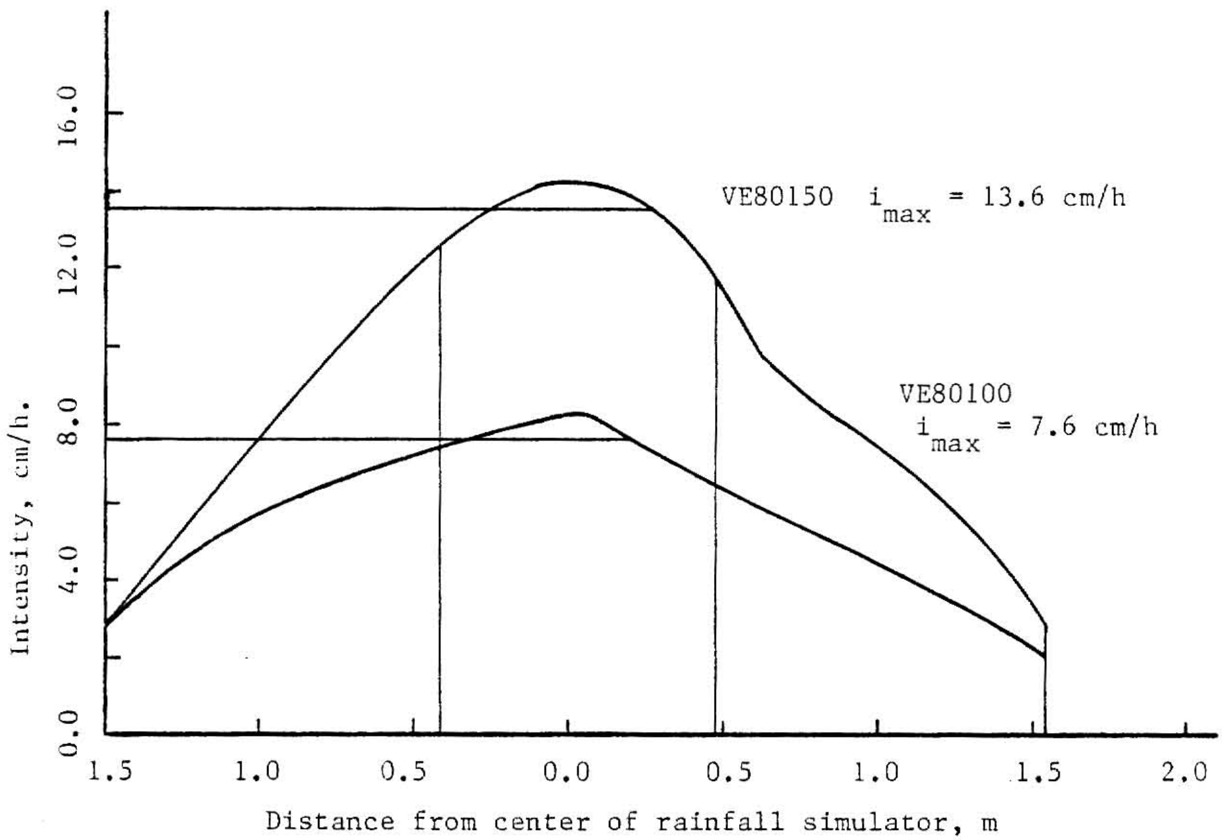


Figure 9. Average Intensity Distribution for Veejet 80100 and 80150 nozzles at nozzle pressure of 41 kPa, a height of 3 m, and a time sequencer rest interval of 0.1 s

The Runoff Meter

The runoff meter was calibrated so that one unit of runoff was equal to 1000 ml. When 1000 ml was in the runoff meter, an electric current would pass through the runoff water between the anodes. This opens the valve on top. While the meter was emptying, no runoff was entering the meter due to the open valve on top.

The Martek Time Sequencer

The Martek Time Sequencer has two factors that can change the intensity of the application. The two items are the rest interval and the voltage potentiometer.

The voltage potentiometer regulated the voltage potential that activated the clutch-brake system which oscillated the nozzles. As the potentiometer dial is turned clockwise, the voltage to the clutch-brake increased. This reduces the amount of time the clutch was disengaged. Our solution to a constant rest interval was to set the voltage potentiometer in one position. Several runs were made to calibrate the rest interval. A mark was placed on the front panel of the time sequencer that, when lined up with the mark on the dial, provided a reference location. Once this was accomplished, the rest interval was changed to a different setting and tested again.

The rest interval ranged from 0.0 seconds to 9.9 seconds at intervals of 0.1 seconds. By changing the rest interval on the time sequencer, the rainfall intensity could easily be changed. An equation was developed that determined the rest interval setting for a specified intensity. This equation is:

$$R_s = \frac{I_m(T_m + R_{max})}{I_s} - T_m \tag{9}$$

where

R_s = rest interval for the specified intensity

I_m = maximum intensity, cm/h

I_s = specified intensity, cm/h

T_m = time for nozzle to move across plot, 0.5 sec

R_{max} = rest interval for the maximum intensity, 0.1 sec.

For the VE80150 nozzle the equation is:

$$R_s = \frac{13.6(0.5 + 0.1)}{I_s} - 0.5 \tag{10}$$

For example, to find the delay required for a 5.1 cm/h intensity using VE80150 nozzle:

$$R_s = \frac{13.6}{5.1}(0.6) - 0.5 = 1.1 \text{ sec. delay} \tag{11}$$

For the VE80100 nozzle the equation is:

$$R_s = \frac{7.6}{I_s}(0.6) - 0.5 \tag{12}$$

PROCEDURE AND EXPERIMENT DESIGN

The rainfall simulator experiments were in two areas, northeastern and northwestern Kansas. The North Farm pasture experiment at Manhattan, Kansas is in the northeastern part of the state. This location marked the first time the rainfall simulator was used in the field. The equipment was monitored closely. In northwestern Kansas, the rainfall simulator was set up on wheat stubble ground and moved to different plots to study the effect of tillage treatment upon runoff from simulated rainfall. This section deals with the design of the experiments, the procedures used, and the individual plot setup.

North Farm Pasture

Part I of the rainfall simulator experiment was conducted at the Manhattan North Farm on pasture land. The soil type is Wymore silty clay loam. It is in hydrologic soil group C.

Test Procedure

At the North Farm, several successive runs were made on the same plot. The first run was at a dry antecedent moisture, AMC-I condition with the remainder of the runs at a wet antecedent moisture condition, AMC-III. The application intensity was varied between the runs but not during the runs. This was done to determine the effect of antecedent moisture condition and application rate on the ending infiltration rate and the runoff curve number.

Colby and Hays, Kansas

The rainfall simulator experiment was conducted at two locations on land that had been planted to wheat. The locations were the Colby Branch Experiment Station at Colby, Kansas and the Fort Hays Branch Experiment Station at Hays, Kansas. The soil type at Colby was Richfield silt loam. It is hydrologic soil group B. The soil type at Hays was a Harney silt loam in hydrologic soil group C. Both sites were on nearly level ground. Figures 10 and 11 are maps of the two areas showing the plot layouts.

Test Procedure

At both places, the field was divided into three parts for each tillage treatment, no-till, undercut, and either moldboard plow or clean-till. The areas were further reduced to individual plots, nine at Colby and fifteen at Hays, that were platted in rows and columns. Three plots were randomly selected from each treatment such that only one plot used was in any row or column. This was done to reduce the field effects, which could bias the experiment. The other plots are reserved for future use to study the variations in runoff at various critical times during the contemporary cropping rotations.

The rainfall simulator experiment was conducted at Colby on land in a wheat-fallow rotation and at Hays on land in a wheat sorghum fallow rotation. The experiments were conducted within five days after the wheat had been harvested.

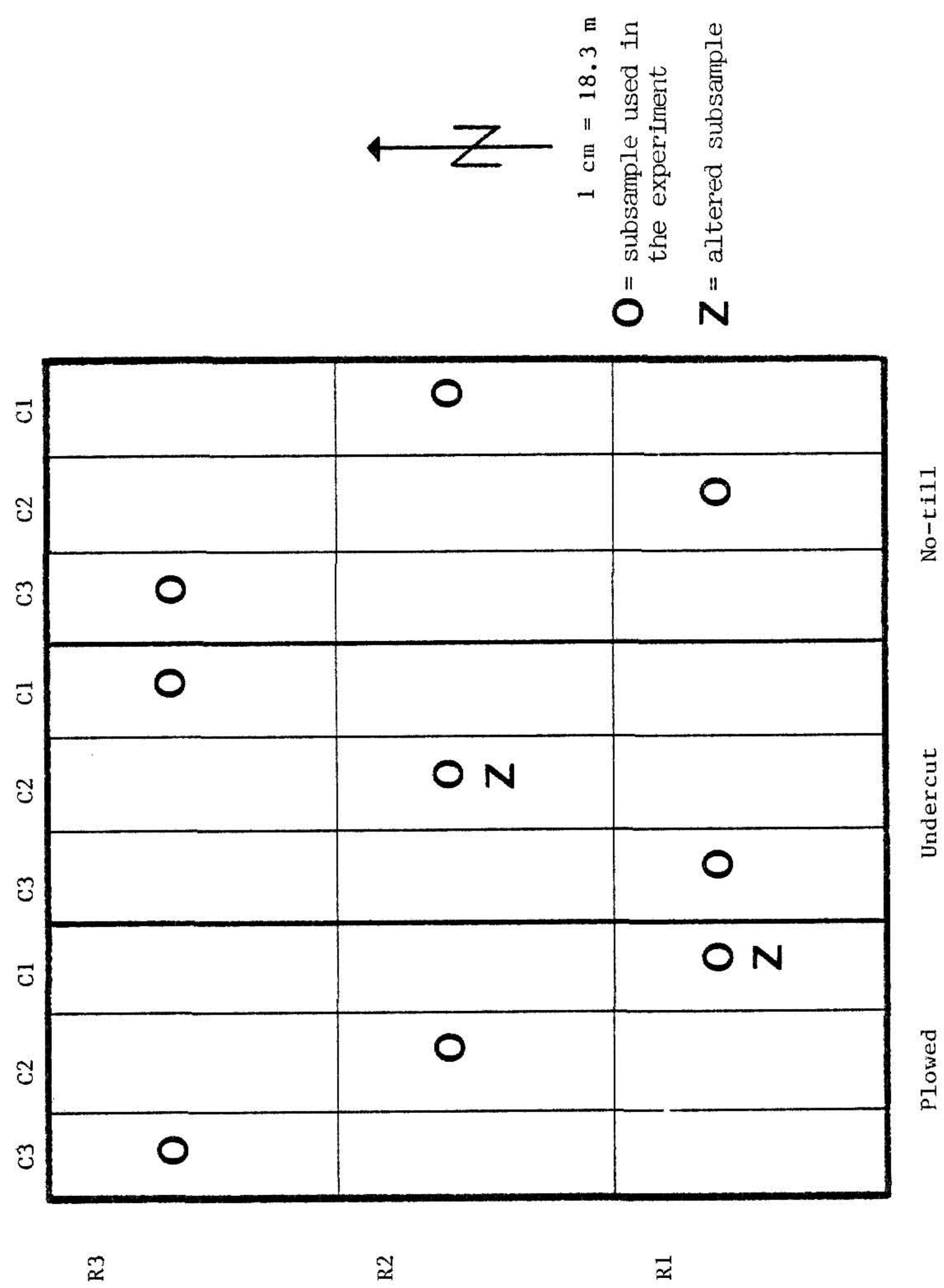


Figure 10. Treatment layout at Colby, Kansas

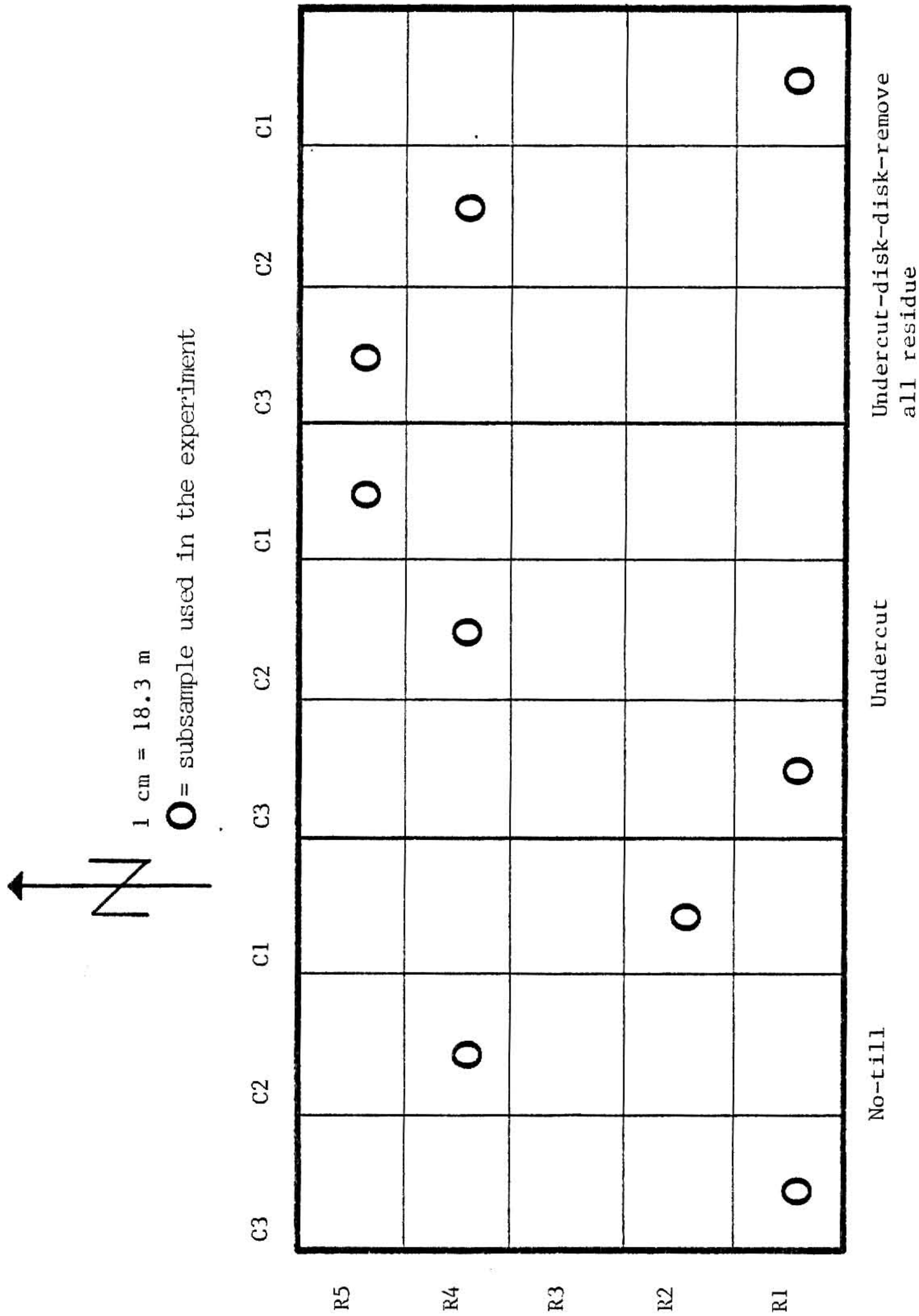


Figure 11. Treatment layout at Hays, Kansas

Individual Plot Setup

For each individual plot, the procedure was to choose a representative place in the individual area and drive in the plotframe to an approximate depth of ten centimeters. After the plotframe was leveled, the rainfall simulator was placed in a level position over the plotframe so that the nozzle was directly over the center and would oscillate back and forth parallel to the longest side of the plotframe. Two digital tipping bucket rain gages were placed adjacent to the plotframe. The windskirt was wrapped around the rainfall simulator frame and staked into the ground. If the weather was gusty, the rain simulator was tied to the trailer as a safety measure. Color slides were taken of the plot to determine percent residue cover.

Immediately prior to the application of rainfall, the generator was started, the time sequencer was set to the proper time sequence, the nozzle was directed to the collector funnels, the pump turned on and the pressure gage set to the correct pressure, and the vacuum cleaner turned on. The next step was to load the computer program into the microcomputer and record the run number, date, and time. Finally, the sequencer was started.

While the rainfall simulator was in operation, three soil samples were taken along with a residue sample. The program cassette was removed from the cassette recorder and replaced with a cassette for data storage. Water pressure had to be watched, since the decline of the water level in the supply tank caused a loss of pressure at the nozzle. Time was recorded when each liter of runoff was accumulated.

CALCULATIONS

Mathematical calculations were essential in examining the relationships between the variables of the experiment. The areas of mathematical analysis were: (1) calculation of runoff curve numbers and infiltration rates for the field data and, (2) calculation of estimated runoff curve numbers from the SCS and Rawls methods and infiltration rates from standard infiltration equations.

Field Data Calculations

Total infiltration was assumed to be the difference between rainfall and runoff. The infiltration rate was assumed to be the difference between the application rate and the runoff rate.

This is illustrated by the example below:

For Hays No-Till Plot R1C3

$$F = P - Q \qquad (13)$$

$$P = I * T \qquad (14)$$

$$Q = n * q \qquad (15)$$

$$F = I * T - n * q \qquad (16)$$

where

P = precipitation amount, 13.03 cm.

I = rainfall intensity, 3.8 cm/h.

F = infiltration amount, 11.76 cm.

T = time of application, 3.4 h.

Q = runoff amount, 1.28 cm

n = number of units of runoff, 8

q = one unit of runoff, 0.16 cm

Determining the curve number required more complex calculations. The maximum potential difference between the precipitation amount, P, and the runoff, Q, at the time of the storm beginning had to be determined then transformed to the curve number. This was done by the SCS equation (equation 1):

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (1)$$

where

$$P \geq 0.2S \qquad (2)$$

where S is the maximum potential difference between rainfall and runoff. S is found by solving the quadratic equation, with the lower value being S. The lower value is S due to the condition that P is greater than or equal to 0.2S. Equation 1 is rearranged to the form of:

$$S = 5(P + 2Q - \sqrt{(4Q^2 + 5PQ)}\ ) \qquad (17)$$

The relationship of S to the curve number is:

$$CN = \frac{1000}{10 + S} \qquad (18)$$

where

CN = curve number

S = maximum potential retention, inches

or in SI units,

$$CN = \frac{2540}{25.4 + S} \qquad (19)$$

where

CN = curve number

S = maximum potential retention, cm

The S value for the example plot was

$$S = 5(13.03 + 2(1.27) - \sqrt{4(1.27)^2 + 5(13.03)(1.27)}\ ) \qquad (20)$$

$$S = 30.63 \text{ cm}$$

The curve number for the example plot was:

$$CN = \frac{2540}{25.4 + 30.63} = 45.3 \qquad (21)$$

which is rounded off to 45.

The infiltration rate was determined by:

$$f_{tn} = i - \frac{q_n}{t_{n+1} - t_{n-1}} \qquad (22)$$

where

f_{tn} = the average infiltration rate at time n, h

I = application intensity, cm/h

q_n = one unit of runoff at time n, cm

t_{n+1} = time one unit of runoff at time n, ended, h

t_{n-1} = time one unit of runoff at time n, began, h

For the example of Hays No-Till R1C3 Plot:

$$f_{tn} = 4.03 - \frac{0.16}{3.42 - 3.37} = 0.83 \text{ cm/h} \qquad (23)$$

Calculation of Estimated Runoff Curve Numbers and Infiltration Rates

Two methods were used to estimate the curve number, Rawls and SCS. The SCS method determines an AMC-II curve number for the peak growth of the crop. The peak growth curve number is the difference between twice the average crop curve number and the fallow curve number. One needs to know the hydrologic soil group, whether the crop is straight row or contoured and terraced, and the hydrologic condition. For residue that covers 60% or more of the surface the curve levels out to a 10% reduction in the fallow curve number.

The infiltration rates were more difficult to determine. These involved using Holtan's equation modified for use in the USDA HL-70 Watershed Model, (Viessman, et al; 1977) as shown below and Hawkins (1979) differentiation of the SCS Runoff equation. (Equation 5):

$$f_{tn} = (GI)(a)(S_a)^{1.4} + f_c \tag{24}$$

where

f_{tn} = infiltration capacity in/h at time n from start of storm

GI = growth index of crop in % of maturity

a = vegetation parameter of infiltration capacity in in-h/(in)$^{1.4}$ of the available storage, 0.30 for small grains good condition

S_a = available storage remaining in the surface layer, 0-15 cm, generally in inches of water equivalent

$$S_a = \frac{(S - F)}{S}\frac{d}{2} \quad (25)$$

f_c = final infiltration capacity, iph

d = available water capacity in inches per foot of depth

For example, for the Hays No-Till Plot R1C3:

$$f_{tn} = \left| (GI)\ (a)\ \left|\frac{(S - F)}{S}\frac{d}{2}\right|^{1.4} + f_c \right| * 2.54 \quad (26)$$

$$f_{tn} = \left| 1.00\ (0.30)\ \left|\frac{(12.06 - 4.63)}{12.06}\frac{2.5}{2}\right|^{1.4} + 0.1 \right| * 2.54 \quad (27)$$

f_{tn} = 0.78 cm/h (0.31 iph)

where

GI = 1.00

a = 0.30 in-h/(in)$^{1.4}$

S = 30.63 cm = 12.06 in

F = 11.76 cm = 4.63 in

f_c = 0.25 cm/h = 0.1 iph

$$S_a = \frac{(S - F)}{S}\frac{d}{2} \quad (28)$$

f_{tn} = 0.78 cm/h

To solve for infiltration rate, f_c, a and GI have to be known. The term f_c can be obtained from ring infiltrometer tests or other methods. The growth index is visually estimated. S_a was calculated by multiplying the fraction of potential maximum retention left available at time n to the absolute total moisture storage capacities available in 15 cm of soil.

The SCS infiltration rate equation, equation 5 is shown again below.

$$f_{tn} = i_{tn} * \left(\frac{S}{P_t + 0.8S}\right)^2 \qquad (5)$$

For Hays No-Till Plot R1C3:

i_{tn} = 4.0 cm/h

P_t = 13.8 cm

S = 33.2 cm

$$f_{tn} = 4.0 * \left(\frac{33.2}{13.8 + 0.8 * 33.2}\right)^2 \qquad (29)$$

f_{tn} = 2.7 cm/h

DISCUSSION

The results of the experiments are presented by location; North Farm, Colby, and Hays. The runoff curve numbers and ending infiltration rates were analyzed. Background information and infiltration curves are located in the appendix.

North Farm

Simulated rainfall analysis of the pasture showed the average of curve numbers to be 78.8 as compared to the SCS prediction of 75. Table 1 contains data and calculations of the North Farm plot. The standard deviation of the curve numbers was 4.1. The SCS estimate was within one standard deviation of the average and was determined to be not significantly different from the average. A correlation coefficient of -0.31 was calculated between the application intensity and the runoff curve number. The results indicate that a higher rainfall intensity lowers the curve number with a 69% degree of uncertainty. The estimated curve number varies from 80 at an application rate of 1.3 cm/h to 77 at an application rate of 13.6 cm/h. Varying the application rate did not change the curve number much. The curve number is more sensitive to the amount of application than the application rate.

The ending infiltration rates were compared to Holtan's and the SCS predicted infiltration rates. The actual ending infiltration rate for Run 1 was 12.6 cm/hr as compared to Holtan's estimate of 0.6 cm/hr and the SCS estimate of 8.2 cm/h.

TABLE 1. Rainfall-runoff data and calculations from the North Farm test plot

1 Run Number	2 Application Intensity (cm/h)	3 Length of Duration (hrs)	4 Rainfall Amount (cm)	5 Runoff Amount (cm)	6 Infiltrated Potential (cm)	7 Maximum Potential Retention (cm)	8 AMC-II (CN) Observed	9 AMC-II (CN) Predicted	10 Numerical ftn (cm/h)	11 Holtan's ftn (cm/h)	12 SCS ftn (cm/h)
1	13.6	0.57	7.76	1.01	6.75	16.04	79	75	12.6	0.6	8.2
2	13.6	0.26	3.63	1.32	2.31	3.55	75	75	2.4	0.4	4.1
3	5.4	0.41	2.23	0.68	1.54	2.57	80	75	0.2	0.5	1.9
4	2.7	1.05	2.84	1.43	1.42	1.82	85	75	0.4	0.3	0.5
5	1.3	1.36	1.77	0.24	1.53	3.59	75	75	0.7	0.6	0.8

The soil type is Wymore silty-clay loam.
The pasture was 6 cm high dense grass.
The AMC conditions was AMC-I for run number 1 and AMC-III for the rest of the runs.
The rainfall simulator did not move between runs.

The 12.6 cm/hr rate was higher than expected and was possibly due to cover on the plot, the dry condition of the soil and to sampling error. Run 2 started 3.5 hours after Run 1 ended. The ending infiltration rate for Run 2 was below the SCS estimate and above Holtan's estimate. Run 2 did not reach equilibrium with the soil profile but was much closer than Run 1. The ending infiltration rates for Runs 3, 4, and 5 were close to Holtan's estimates and are near the final infiltration capacity of the soil. The ending infiltration rates for Runs 4 and 5 were close to the SCS estimates. The SCS infiltration rate tended to over estimate the ending infiltration rate and Holtan's equation underestimated the ending infiltration except when the application rate was low and the soil profile saturated.

Colby, Kansas

Table 2 shows the results of the curve number calculations. A one-way analysis of variance on the treatment means indicated a significant difference between the treatment means at the 5% error level. Using the "F" test (Snedecor and Cochran, 1967), analyses of variance were performed on individual pairs of treatment means. The no-till cropping practice was found to produce more runoff with less rainfall than either undercut or moldboard plowed with a 95% level of confidence. No significant difference was noted between the undercut treatment mean and the moldboard plowed treatment mean. No-till produced more runoff because residue cover does not reduce runoff more than freshly tilled soil when the soil surface has previously been exposed during the growing season. The runoff was straw-colored and was not as silty as from undercut or moldboard plow. The smooth soil surface covered by residue in no-till retarded the infiltration amount.

TABLE 2. SCS curve numbers from Colby, Kansas

	No-Till	Stubblemulch	Plowed
Percent Cover	90	90	1
1	76	72	69
2	77	71	60
3	77		
Average	76.7	71.5	64.5
Rawls Est.	77	77	86
SCS Est.	54	54	86

The curve numbers are AMC-II converted from AMC-I.

The soil type is Richfield silt loam in hydrologic group B.

The application intensity for all the plots was 4.0 cm/h except for the first run on no-till, which was 2.7 cm/h for the first two hours, then 4.0 cm/h, thereafter.

The moldboard plow tillage treatment had the lowest potential for runoff of the three tillage treatments. Normally, the opposite case is expected. The highest runoff curve number for any soil cover complex is for unprotected bare soil lying fallow (USDA, 1964). Moldboard plowing inverts the soil to a depth of 15-25 cm and buries the residue. The better-textured soil is brought up and the bulk density is reduced. The soil is in a loose, unstable state and can absorb much of the first major storm's raindrop kinetic energy and momentum while the soil surface is sealing over. Undercutting, while leaving most of the surface covered with residue, works the soil to a depth of 5-10 cm, breaking the surface crust. The breaking of the surface crust by undercutting increased the storage capacity of the soil profile. The soil type at Colby was a Richfield silt loam with a low clay content and was noticeably granular. Rawls' estimate of the runoff curve number (Table 3) was close for no-till and undercut and high for moldboard plowed. The SCS estimate was very low for no-till and undercut and high for moldboard plowed.

Table 4 shows the results of the ending infiltration rate calculations. The ending infiltration rates are 1.6 cm/h for no-till, 1.4 cm/h for undercut and 2.4 cm/h for moldboard plowed. Holtan's estimates were 1.7, 1.7, and 1.8 cm/h, respectively. The SCS estimates were 2.4, 2.5, and 2.8 cm/h respectively. The no-till treatment and the undercut treatment had a slightly lower ending infiltration rate than what was predicted by Holtan's equation. The moldboard plowed treatment had an ending infiltration rate that was approximately halfway between Holtan's estimate and the SCS estimate. The deep tillage operation of moldboard plowing opened the soil profile for greater penetration by the rainfall.

TABLE 3. Comparison of observed runoff curve number with estimated curve numbers by Rawls and SCS

Tillage Treatment	Percent Cover	Rawls Est.	Obs. CN	Diff. CN	SCS Est.	Obs. CN	Diff. CN
				Colby			
No-till	90	77	77	0	54	77	-23
Undercut	90	77	72	5	54	72	-18
Moldboard plowed	1	86	65	21	86	65	21
				Hays			
No-till	99	82	68	14	65	68	-3
Undercut	92	82	57	25	65	57	8
Clean-till	2	91	79	12	91	79	12

TABLE 4. Comparison of ending infiltration rate calculations for Colby, Kansas

	Num.	Hol.	SCS
	All in cm/h		
No-till	1.6	1.7	2.4
Undercut	1.4	1.7	2.5
Plowed	2.4	1.8	2.8

Hays, Kansas

Table 5 shows the results of the curve number calculations. A two-way analysis of variance performed on the treatment means and the application intensity means indicated no significant difference between the application rate means but a significant difference was found between the treatment means at the 10 % error level. A one-way analysis was then performed between the treatment means alone and showed a significant difference at the 5 % error level. By not separating out the application intensity means, the significant difference between treatments increased. The results indicated that the intensity of rainfall from 4.0 to 6.7 cm/h was not a major factor in determining the amount of runoff. Further one-way analyses of variance between individual treatment means indicated that the clean-till treatment produced the same amount of runoff with significantly less rainfall than either no-till or undercut. As at Colby, the undercut treatment mean was less than the no-till treatment mean curve number. This time the difference was not significant.

Since the clean-till treatment produced the same amount of runoff with less rainfall than either no-till or undercut, some reasons are set forth. The clean-till treatment was tilled 3 times, first by undercutting to a depth of 5-10 cm and twice by disking by a tandem disk harrow to a depth of 10-15 cm. Disking does not invert the soil but throws the soil to one side. By subjecting the soil to 3 tillage operations with 5 sets of tools, 1 undercut and 2 disk gangs for each disking operation, the clods were broken up more than from moldboard plowing alone. No measurements of clod size were taken.

TABLE 5. SCS curve numbers from Hays, Kansas

Application Rate cm/h Percent Cover	No-Till 99	Undercut 92	Clean-Till 2	Application Rate Average
4.0	63	56	79	66
5.4	70	69	74	71
6.7	71	46	85	67.3
Average	68	57	79.3	69.8
Predicted Rawls	82	82	91	
Predicted SCS	65	65	91	

The curve numbers are AMC-II converted from AMC-I.
The soil type is Harney silt loam in hydrologic soil group C.

Comparison of the observed runoff curve numbers with Rawls' estimate and the SCS estimate showed that Rawls' estimate indicated more runoff potential than actually came from the plots (Table 3). The SCS estimate was low for the no-till treatment and high for the other two. Some explanations for this condition are as follows: undercut and clean-till fields were freshly tilled and had not been exposed to very much weathering and the soil moisture content was at or below the wilting point causing the high clay content, approx. 40 %, to shrink causing numerous large cracks. Some of the cracks were 2-3 cm wide and at least 60 cm deep. While locating the no-till plots, one could see the cracks and avoid them. Undercutting hid the cracks from view, permitting large amounts of rainfall to infiltrate before runoff is produced. Disking the clean-till plots made a thick seal for the cracks producing the opposite effect. Water applied to the clean-till plots dispersed the soil enough to plug the cracks.

Table 6 shows the results of the ending infiltration rate calculations. The ending infiltration rates at Hays were higher than at Colby, 2.2 cm/h for no-till, 2.3 cm/h for undercut, and 2.6 cm/h for clean-till. Holtan's estimates were 1.2, 1.2, and 1.1 cm/h respectively. The SCS estimates were 3.5, 3.8, and 3.8 cm/h respectively. Holtan's equation underestimated the infiltration rate and the SCS equation over estimated the infiltration rate. The high infiltration rates suggest some available storage is still remaining. The clean-till infiltration rate is higher than no-till and undercut due to the lower bulk density of the disked layer which increased porosity.

TABLE 6. Comparison of ending infiltration rate calculations for Hays, Kansas

	Num.	Hol.	SCS
	All in cm/h		
No-till	2.2	1.2	3.5
Undercut	2.3	1.2	3.8
Clean-till*	2.6	1.1	3.0

*Undercut-Disk-Disk-Remove All Residue

CONCLUSIONS

The use of a rainfall simulator to determine the rainfall-runoff properties of a soil cover complex is practical. The rainfall simulator was used as a field testing unit on pasture at the North Farm in Manhattan, Kansas, and on wheat ground at Colby and Hays, Kansas. The runoff curve numbers were not affected by the application intensity. To calculate the curve number, 1.27 cm of runoff was obtained from the plots at Colby and Hays with the condition that the infiltrated amount was greater than or equal to one-fifth of the maximum potential retention.

In conclusion, the findings of this study are as follows:

1. The maximum application rates of the Veejet 80100 and 80150 nozzles at a pressure of 41 kPa were 7.6 and 13.6 cm/hr respectively. The application rate is determined from the maximum application rate by lengthening the rest interval of the time sequencer from 0.1 seconds to the necessary rest interval.

2. The SCS curve numbers measured at the North Farm plot were 79, 75, 80, 85, and 75 for AMC-II conditions. This compares to predicted value of 75 for the AMC-II condition.

3. The average SCS curve numbers for AMC-II conditions on wheat stubble ground for several tillage and surface residue treatments at Colby and Hays, Kansas are as follows: at Colby, no-till, 76.7; undercut, 71.5, and clean-till, 64.5; at Hays, no-till, 68, undercut 57, and clean-till, 79.3. The predicted values are: at Colby, no-till 77, undercut 77 and clean-till, 86; at Hays, no-till, 82,

undercut, 82, and clean-till, 91.

All curve numbers were determined for the first rainfall event following tillage at the beginning of the fallow period. Different results would be expected later in the fallow period and if rainfall had occurred since tillage had been done.

SUGGESTIONS FOR FUTURE RESEARCH

Rainfall simulation has proven to be a useful tool in research. Procedures and equipment should be reviewed periodically to keep current with the "State of the Art".

As this thesis is concerned about dryland practices, future research is needed on irrigated land, before and after irrigations. Simulation could be carried out on various soil-cover complexes. Determinations of optimal depths of tillage operations as related to runoff rates is an area that could be extensively studied. One such soil-cover complex is a no-till treatment with all residue removed to determine the effect of cover on the soil.

One of our difficulties was collecting residue from the plot. Criteria should be standardized as to what residue is and by what means should residue density be measured. The residue samples collected from the undercut plots were heavier than the no-till plots after drying. It was felt that roots and some dirt sticking to the roots that made the undercut residue samples heavier. Tillage operations reduce the amount of residue left on the ground.

Some of the equipment needs improvement. The water pressure needs to be regulated so that when the water level in the water supply tank is lowered, the pressure does not decrease. The runoff collection tube has a tendency to become clogged with straw. The solenoid on the runoff meter will occasionally refuse to engage to permit the runoff water to exit from the runoff meter.

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APPENDIX A: Background Information per Location

BACKGROUND INFORMATION FOR MANHATTAN, KANSAS

Latitude: 39 degrees 12 minutes

Longitude: 96 degrees 35 minutes

Elevation: 329 m (1080 ft)

Climate: Continental

Average annual precipitation: 800 mm (31.6 inches)

Average growing season precipitation: 600 mm (23.7 inches)

Average length of growing season: 178 days

Average temperature 13^{o}C (55.3^{o}F)

Thunderstorms occurr on about 55 days each year

Soil subclassification:

1. Wymore silty clay loam

    Family; Fine, montmorillonitic, mesic

    Subgroup; Aquic Argiudolls

    Order; Mollisols

    High water capacity

    Soils are well drained to moderately well drained

    Subsoils are slowly permeable

    Irrigation design group 1

    Hydrologic soil group C

BACKGROUND INFORMATION FOR COLBY, KANSAS

Latitude: 39 degrees 25 minutes

Longitude: 101 degrees 4 minutes

Elevation: 966 meters (3170 feet)

Climate: Continental semi-arid

Average annual precipitation: 468 mm (18.43 inches)

Precipitation exceeds 25 mm on an average of three days per year

Average annual temperature: 10.6°C (51°F)

Average temperature during growing season: 18.9°C (66°F)

Average annual windspeed: 9.7 kilometers per hour (6 mph)

Average growing season pan evaporation: 1636 mm (64.4 in)

Average length of growing season: 160 days

Major soil type: Eolian silt (loess)

Wisconsin loess more than 670 cm (22 ft) thick 67-100% of land covered

Soil subclassification:

1. Richfield silty loam. Aridic Arguistolls; fine, montorillonitic, mesic deep well-drained, moderately slowly permeable soils on uplands.

   0-2% slopes.

   Irrigation design group 5.

   Hydrologic soil group B

BACKGROUND INFORMATION FOR HAYS, KANSAS

Latitude: 38 degrees 52 minutes

Longitude: 99 degrees 20 minutes

Elevation: 613 meters (2010 feet)

Climate: Continental semi-arid

Average annual precipitation: 582 mm (22.9 inches)

Precipitation averages greater than 76 mm (3 inches) in May, June, and July.

Average temperature during growing season: 21^{o}C (69^{o}F)

Number of weeks with normal rainfall of greater than 2.5 cm (1 inch): 1

Average growing season pan evaporation: 1776 mm (70 in)

Average length of growing season: 170 days

Major soil classifications:

1. Harney silt loam, 0-1% slopes

   Runoff is slow

   Soil is calcareous

   Moderately slow permeability

   High available water capacity

   Deep well-drained soils

   Irrigation design group 3

   Hydrologic soil group C

APPENDIX B: Infiltration Curves

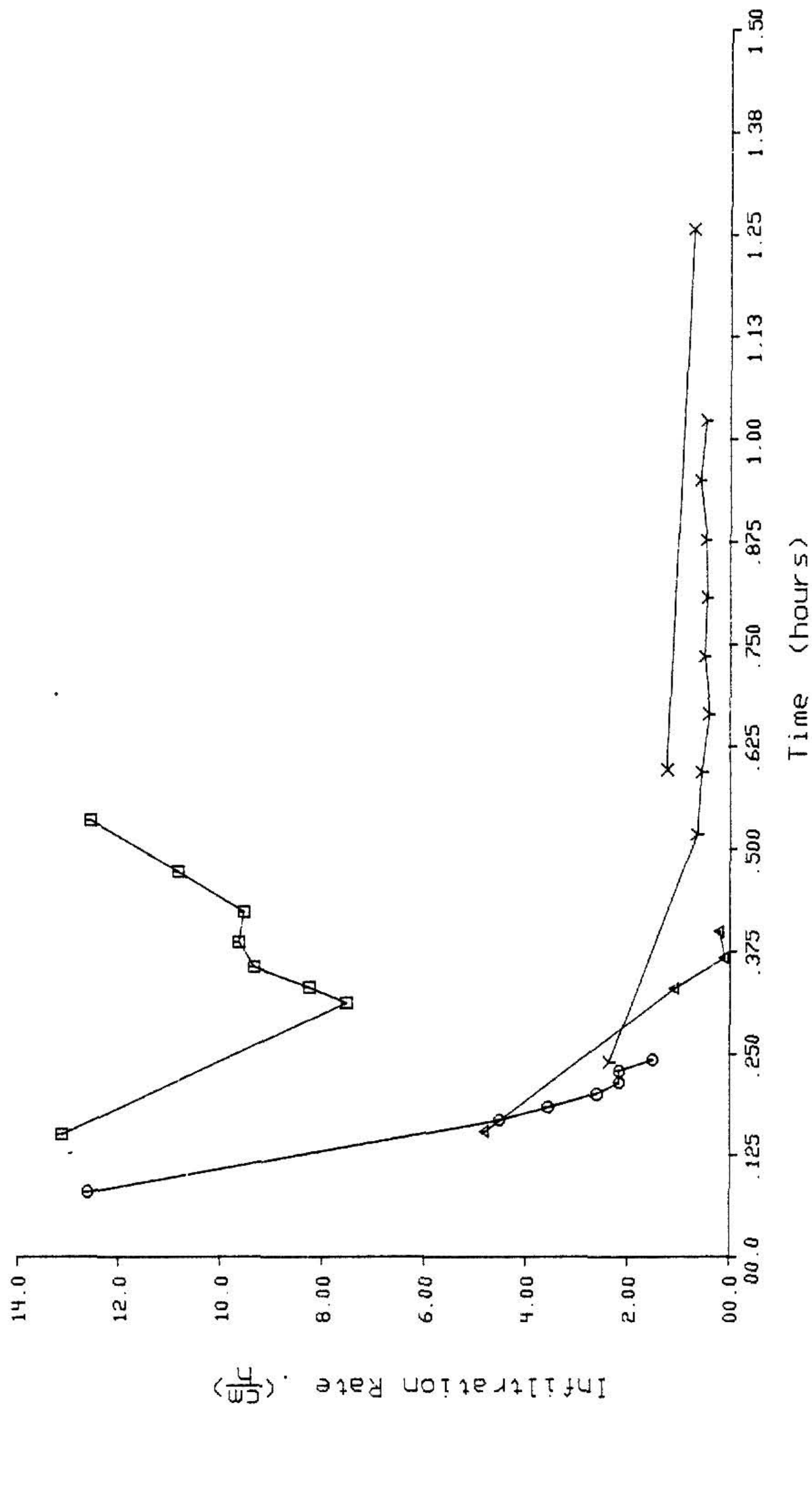

Figure 12. Infiltration rates vs. time for pasture at Manhattan, KS during June, 1980.

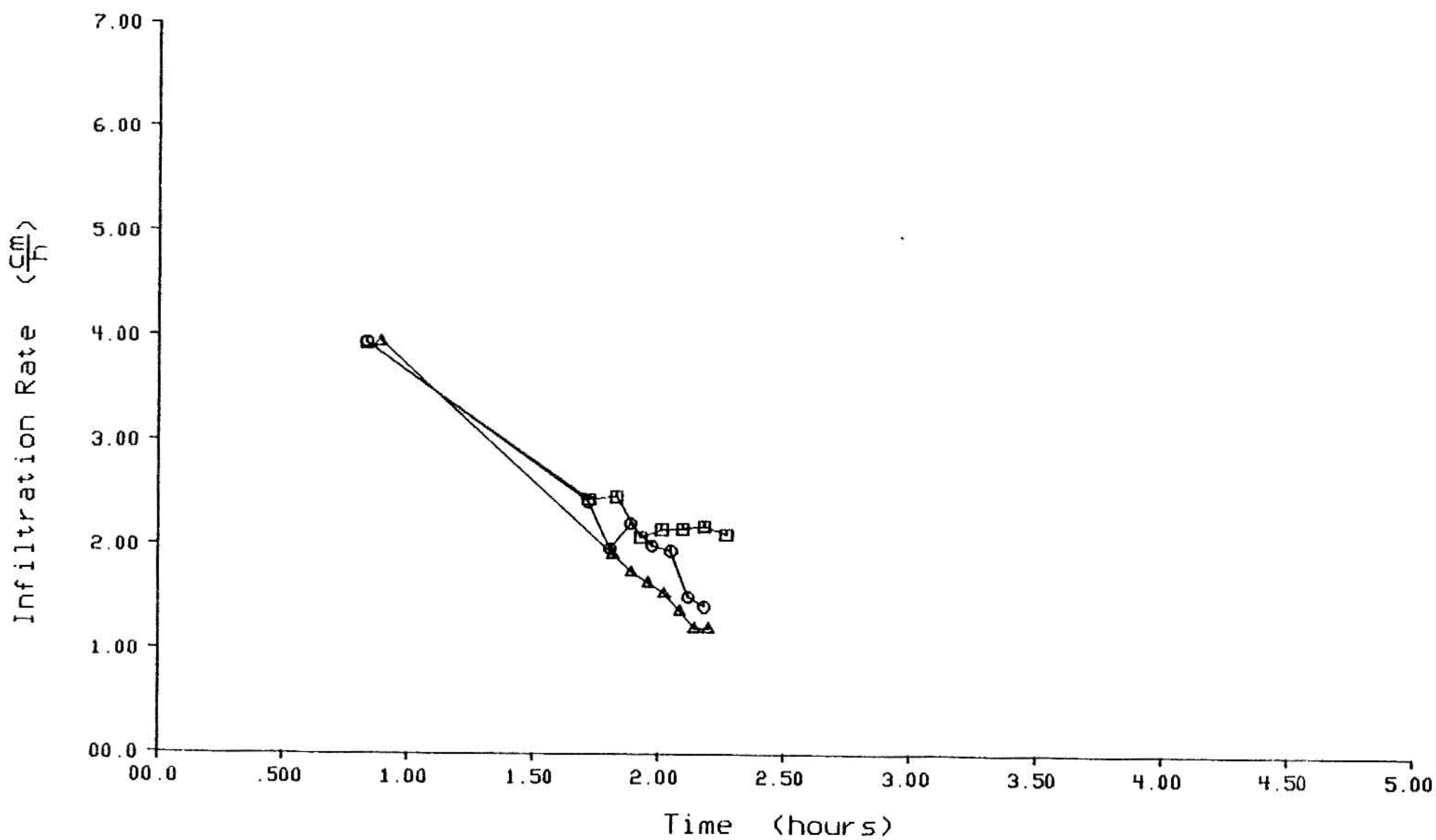

Figure 13. Infiltration rates vs. time for no-till at Colby, KS during July, 1980.

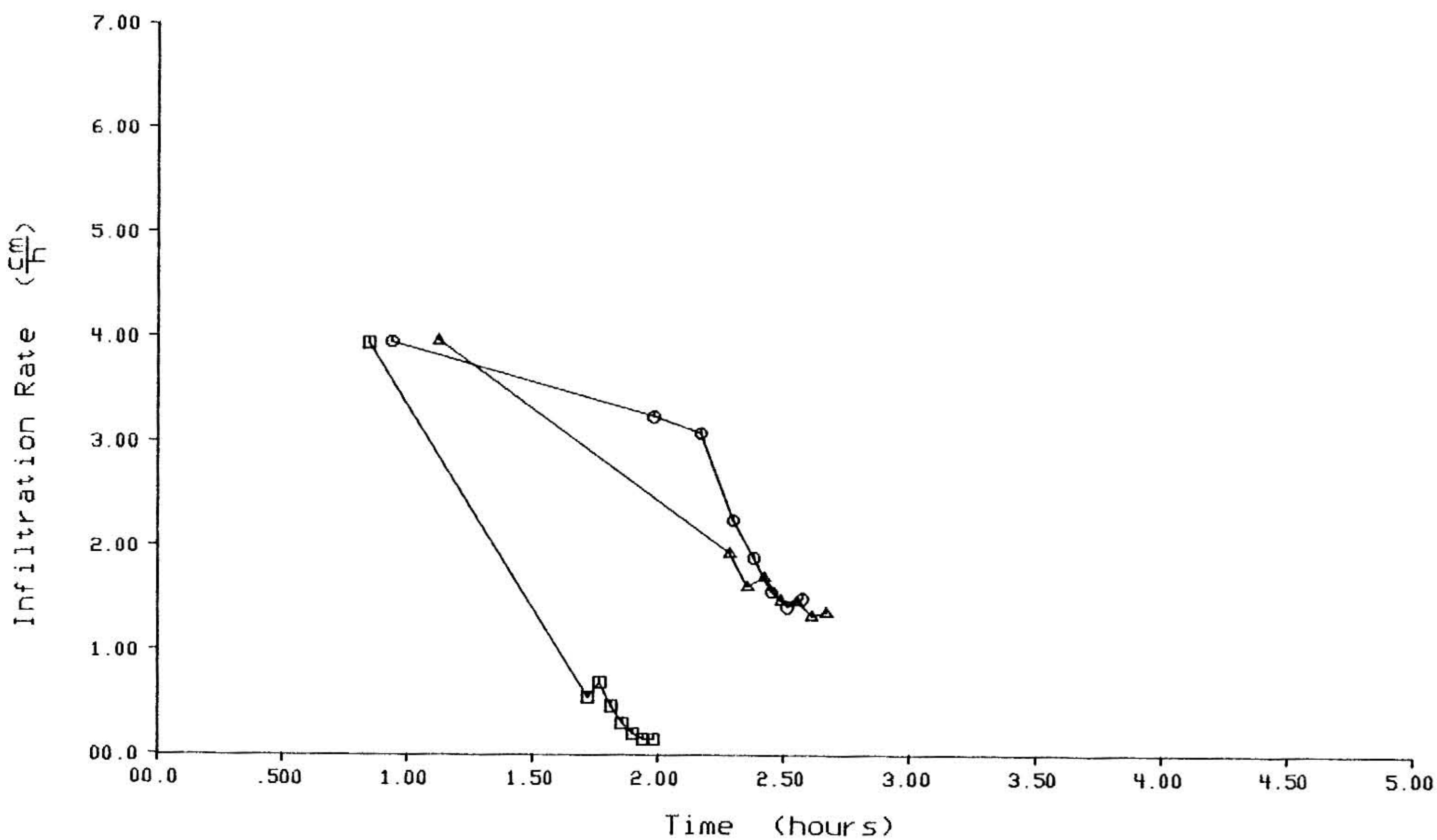

Figure 14. Infiltration rates vs. time for undercut at Colby, KS during July, 1980.

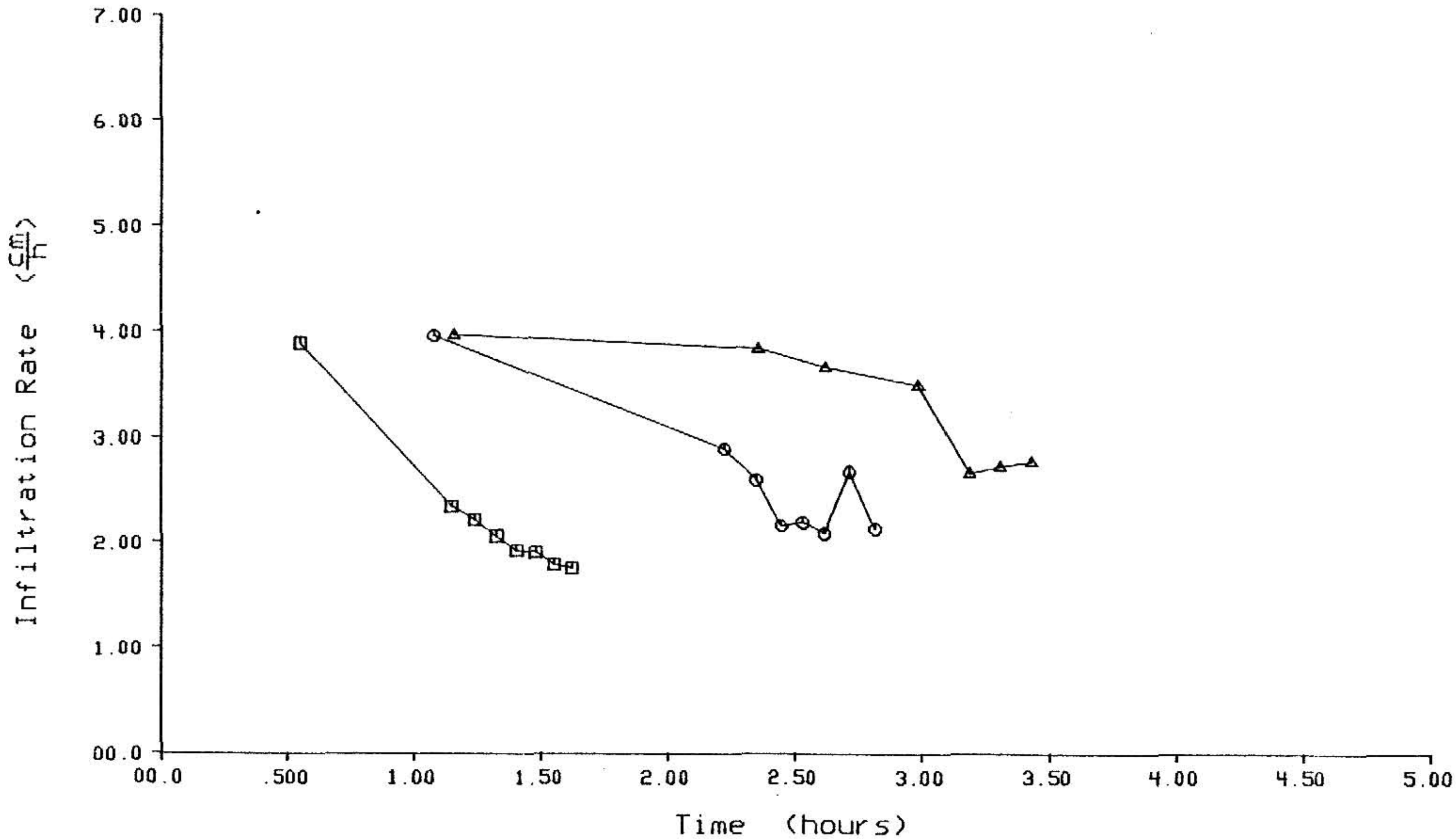

Figure 15. Infiltration rates vs. time for clean till at Colby, KS during July, 1980.

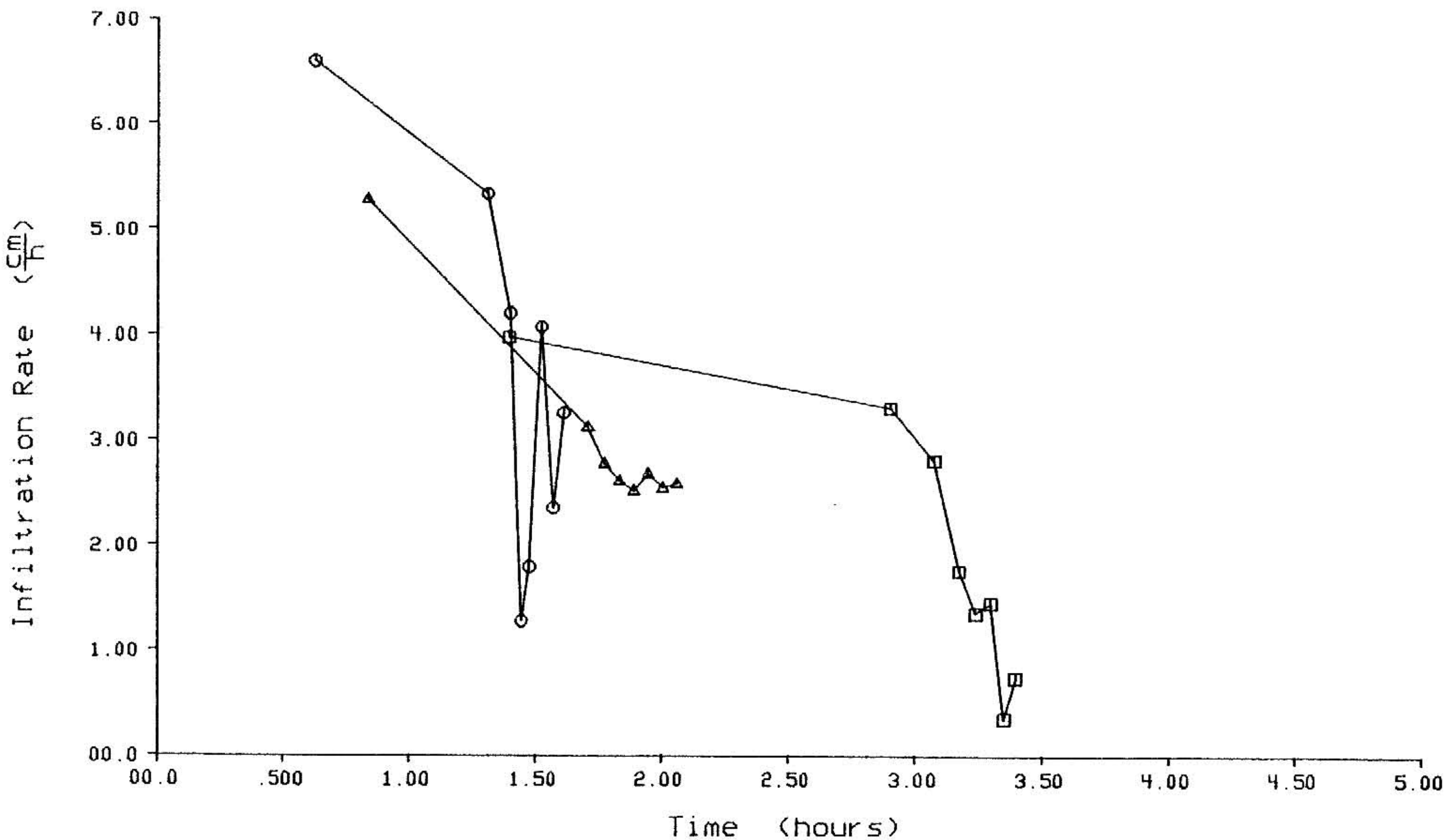

Figure 16. Infiltration rates vs. time for no-till at Hays, KS during July, 1980.

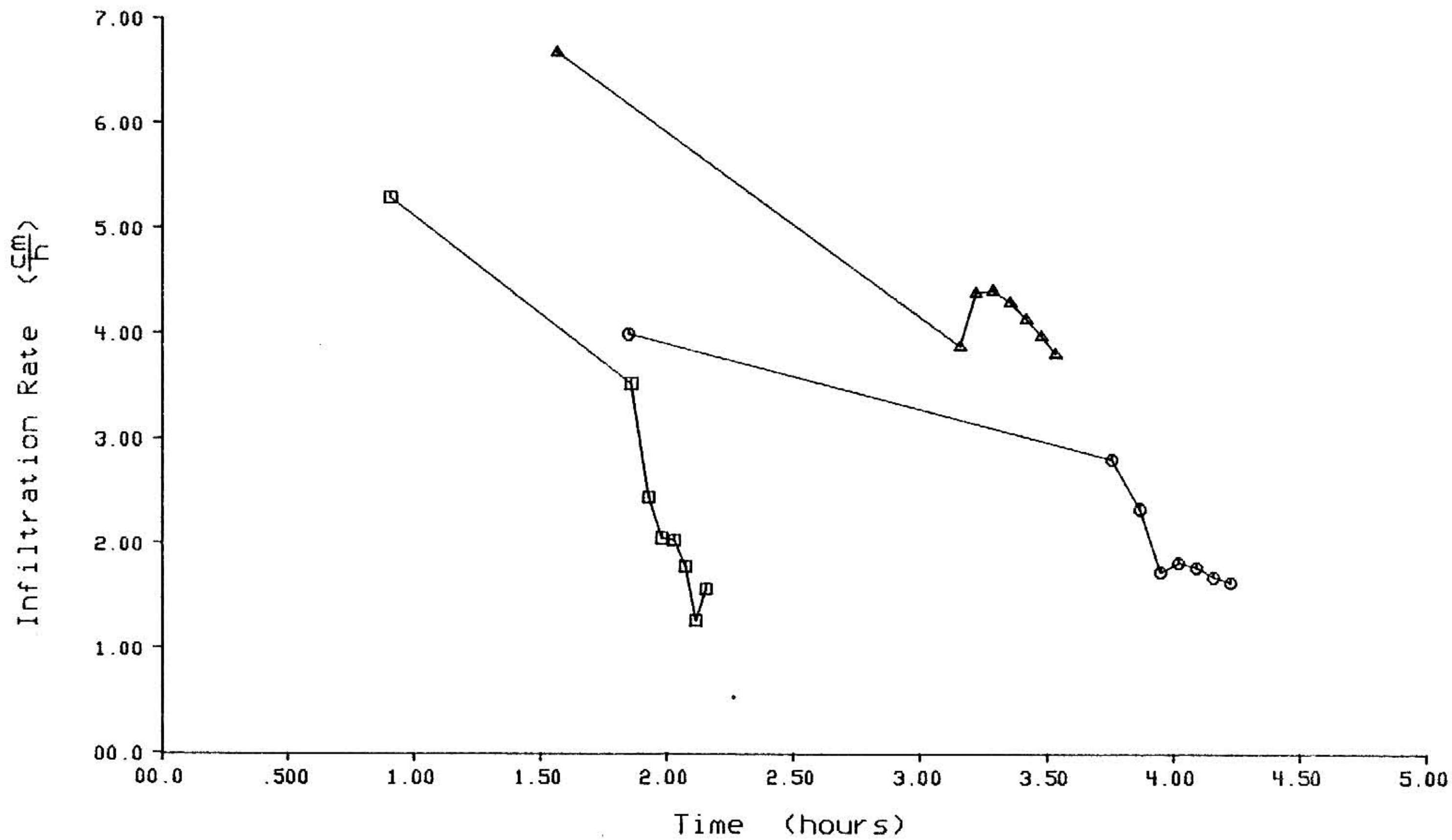

Figure 17. Infiltration rates vs. time for undercut at Hays, KS during July, 1980.

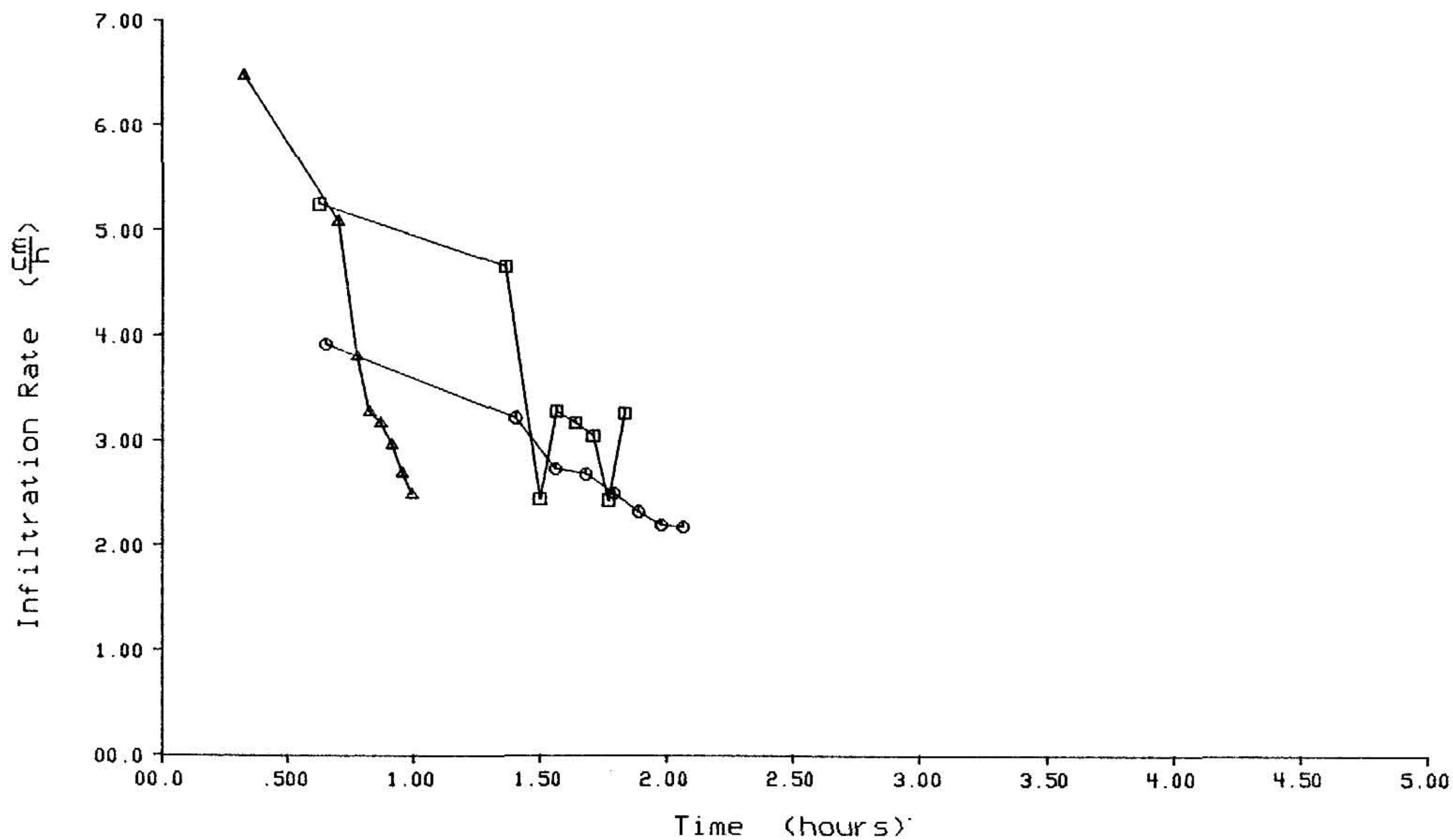

Figure 18. Infiltration rates vs. time for clean till at Hays, KS during July, 1980.

APPENDIX C: Rainfall Simulator Data

Definitions

time,	time, h from start of application to half-way between unit of runoff began and the next unit began
rain,	rainfall amount, cm from start to time
rainr,	rainfall rate, cm/h
run,	runoff amount, cm of one unit collected during time the unit began to runoff and the time the next unit began to runoff
prun,	runoff rate percentage of the rainfall rate
runr,	momentary runoff rate, cm/h
xinf,	momentary infiltration rate, cm/h
pxinf,	infiltration rate percentage of the rainfall rate
infilt,	total infiltration amount, cm
Ftn,	ending infiltration rate

Manhattan, KS first run 6/13/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	13.60	0.00	0.00	0.00	0.00	0.00
0.15	4.11	13.60	0.14	3.47	0.47	13.12	96.53
0.31	4.36	13.60	0.11	44.58	6.06	7.53	55.42
0.33	4.65	13.60	0.11	39.23	5.33	8.26	60.77
0.36	5.03	13.60	0.12	31.32	4.26	9.34	68.68
0.39	5.46	13.60	0.13	29.13	3.96	9.64	70.87
0.42	6.03	13.60	0.17	29.86	4.06	9.54	70.14
0.47	6.80	13.60	0.16	20.39	2.77	10.82	79.61
0.54	7.76	13.60	0.07	7.58	1.03	12.56	92.42

total runoff	rain	infilt
1.011	7.761	6.750

The average rainfall rate is 13.595 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 79.

The Potential Maximum Difference is 16.004 cm

Numerical Ftn =12.564 Holtan's Ftn = 0.600 SCS Ftn = 8.234 cm/h

Manhattan, KS second run 6/13/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	13.60	0.00	0.00	0.00	0.00	0.00
0.08	2.18	13.60	0.16	7.30	0.99	12.60	92.70
0.17	2.41	13.60	0.16	66.72	9.07	4.53	33.28
0.19	2.63	13.60	0.16	73.74	10.03	3.57	26.26
0.20	2.82	13.60	0.16	80.83	10.99	2.61	19.17
0.21	3.01	13.60	0.16	84.06	11.43	2.17	15.94
0.23	3.20	13.60	0.16	84.06	11.43	2.17	15.94
0.24	3.40	13.60	0.17	88.91	12.09	1.51	11.09
0.26	3.63	13.60	0.19	82.68	11.24	2.35	17.32

total runoff	rain	infilt
1.317	3.629	2.312

The average rainfall rate is 13.595 cm/h.

The initial soil moisture condition was AMC 3

The RUNOFF CURVE NUMBER IS 75.

The Potential Maximum Difference is 3.549 cm

Numerical Ftn = 2.354 Holtan's Ftn = 0.424 SCS Ftn = 4.093 cm/h

Manhattan, KS third run 6/17/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	5.37	0.00	0.00	0.00	0.00	0.00
0.15	1.66	5.37	0.17	10.49	0.56	4.81	89.51
0.33	1.88	5.37	0.17	80.10	4.31	1.07	19.90
0.37	2.06	5.37	0.17	98.28	5.28	0.09	1.72
0.40	2.22	5.37	0.16	96.65	5.19	0.18	3.35

total runoff	rain	infilt
0.683	2.225	1.542

The average rainfall rate is 5.375 cm/h.

The initial soil moisture condition was AMC 3

The RUNOFF CURVE NUMBER IS 80.

The Potential Maximum Difference is 2.573 cm

Numerical Ftn = 0.180 Holtan's Ftn = 0.461 SCS Ftn = 1.940 cm/h

Manhattan, KS fourth run 6/17/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	2.69	0.00	0.00	0.00	0.00	0.00
0.24	1.29	2.69	0.16	12.31	0.33	2.36	87.69
0.52	1.50	2.69	0.16	76.49	2.06	0.63	23.51
0.59	1.69	2.69	0.16	80.24	2.16	0.53	19.76
0.67	1.88	2.69	0.16	85.74	2.30	0.38	14.26
0.74	2.07	2.69	0.16	82.10	2.21	0.48	17.90
0.81	2.26	2.69	0.16	84.05	2.26	0.43	15.95
0.88	2.45	2.69	0.16	83.39	2.24	0.45	16.61
0.95	2.65	2.69	0.16	78.76	2.12	0.57	21.24
1.02	2.84	2.69	0.16	83.39	2.24	0.45	16.61

total runoff	rain	infilt
1.429	2.844	1.416

The average rainfall rate is 2.687 cm/h.

The initial soil moisture condition was AMC 3

The RUNOFF CURVE NUMBER IS 85.

The Potential Maximum Difference is 1.824 cm

Numerical Ftn = 0.446 Holtan's Ftn = 0.346 SCS Ftn = 0.483 cm/h

Manhattan, KS fifth run 6/19/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	1.34	0.00	0.00	0.00	0.00	0.00
0.60	1.60	1.34	0.16	9.89	0.13	1.21	90.11
1.26	1.77	1.34	0.08	48.33	0.65	0.69	51.67

total runoff	rain	infilt
0.238	1.769	1.531

The average rainfall rate is 1.344 cm/h.

The initial soil moisture condition was AMC 3

The RUNOFF CURVE NUMBER IS 75.

The Potential Maximum Difference is 3.590 cm

Numerical Ftn = 0.694 Holtan's Ftn = 0.596 SCS Ftn = 0.804 cm/h

Colby, KS R1C2 NO-TIll 7/15/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
0.84	6.74	4.03	0.17	2.59	0.10	3.93	97.41
1.72	7.14	4.03	0.16	39.38	1.59	2.44	60.62
1.83	7.61	4.03	0.18	38.82	1.56	2.47	61.18
1.93	7.94	4.03	0.16	48.55	1.96	2.07	51.45
2.01	8.28	4.03	0.16	46.63	1.88	2.15	53.37
2.10	8.62	4.03	0.16	46.48	1.87	2.16	53.52
2.18	8.97	4.03	0.16	45.88	1.85	2.18	54.12
2.27	9.33	4.03	0.17	47.83	1.93	2.10	52.17

total runoff	rain	infilt
1.325	9.334	8.009

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 76.

The Potential Maximum Difference is 18.426 cm

Numerical Ftn = 2.103 Holtan's Ftn = 1.697 SCS Ftn = 2.361 cm/h

Colby, KS R2C1 NO-TILL 7/15/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
0.83	6.72	4.03	0.16	2.36	0.10	3.94	97.64
1.72	7.12	4.03	0.16	39.93	1.61	2.42	60.07
1.81	7.43	4.03	0.16	51.18	2.06	1.97	48.82
1.89	7.79	4.03	0.16	45.20	1.82	2.21	54.80
1.97	8.11	4.03	0.16	50.45	2.03	2.00	49.55
2.05	8.41	4.03	0.16	51.74	2.09	1.95	48.26
2.12	8.67	4.03	0.16	62.73	2.53	1.50	37.27
2.18	8.91	4.03	0.16	65.03	2.62	1.41	34.97

total runoff	rain	infilt
1.275	8.912	7.637

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 77.

The Potential Maximum Difference is 17.527 cm

Numerical Ftn = 1.410 Holtan's Ftn = 1.696 SCS Ftn = 2.354 cm/h

Colby, KS R3C3 NO-TILL 7/17/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
0.89	7.18	4.03	0.16	2.21	0.09	3.94	97.79
1.82	7.48	4.03	0.16	52.50	2.12	1.91	47.50
1.89	7.76	4.03	0.16	56.70	2.29	1.75	43.30
1.96	8.03	4.03	0.16	59.31	2.39	1.64	40.69
2.02	8.28	4.03	0.16	61.90	2.50	1.54	38.10
2.08	8.52	4.03	0.16	65.93	2.66	1.37	34.07
2.14	8.75	4.03	0.16	70.18	2.83	1.20	29.82
2.20	8.98	4.03	0.16	70.18	2.83	1.20	29.82

total runoff	rain	infilt
1.270	8.977	7.707

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 77.

The Potential Maximum Difference is 17.756 cm

Numerical Ftn = 1.202 Holtan's Ftn = 1.698 SCS Ftn = 2.365 cm/h

Colby, KS R1C3 UNDERCUT 7/16/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
0.94	7.56	4.03	0.16	2.16	0.09	3.94	97.84
1.98	8.39	4.03	0.16	19.76	0.80	3.23	80.24
2.17	9.08	4.03	0.16	23.70	0.96	3.08	76.30
2.30	9.44	4.03	0.16	44.30	1.79	2.25	55.70
2.38	9.75	4.03	0.16	53.29	2.15	1.88	46.71
2.45	10.00	4.03	0.16	61.37	2.47	1.56	38.63
2.51	10.25	4.03	0.16	65.03	2.62	1.41	34.97
2.57	10.50	4.03	0.16	63.00	2.54	1.49	37.00

total runoff	rain	infilt
1.289	10.501	9.212

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 72.

The Potential Maximum Difference is 22.289 cm

Numerical Ftn = 1.491 Holtan's Ftn = 1.720 SCS Ftn = 2.495 cm/h

Colby, KS R2C2 UNDERCUT 7/16/80 * ALTERED *

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
0.85	6.84	4.03	0.16	2.32	0.09	3.94	97.68
1.72	7.02	4.03	0.16	86.44	3.48	0.55	13.56
1.77	7.22	4.03	0.16	82.90	3.34	0.69	17.10
1.81	7.39	4.03	0.16	88.60	3.57	0.46	11.40
1.86	7.57	4.03	0.16	92.65	3.73	0.30	7.35
1.90	7.73	4.03	0.16	95.14	3.84	0.20	4.86
1.94	7.90	4.03	0.16	96.43	3.89	0.14	3.57
1.98	8.06	4.03	0.16	96.44	3.89	0.14	3.56

total runoff	rain	infilt
1.270	8.062	6.792

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 80.

The Potential Maximum Difference is 15.049 cm

Numerical Ftn = 0.144 Holtan's Ftn = 1.680 SCS Ftn = 2.259 cm/h

Colby, KS R3C1 UNDERCUT 7/17/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
1.12	9.06	4.03	0.16	1.75	0.07	3.96	98.25
2.28	9.36	4.03	0.16	52.12	2.10	1.93	47.88
2.35	9.62	4.03	0.16	60.07	2.42	1.61	39.93
2.42	9.90	4.03	0.16	57.86	2.33	1.70	42.14
2.49	10.15	4.03	0.16	63.29	2.55	1.48	36.71
2.55	10.40	4.03	0.16	63.57	2.56	1.47	36.43
2.61	10.64	4.03	0.16	67.18	2.71	1.32	32.82
2.67	10.87	4.03	0.16	66.24	2.67	1.36	33.76

total runoff	rain	infilt
1.270	10.875	9.605

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 71.

The Potential Maximum Difference is 23.628 cm

Numerical Ftn = 1.361 Holtan's Ftn = 1.727 SCS Ftn = 2.538 cm/h

Colby, KS R1C1 PLOWED 7/16/80 * ALTERED *

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
0.55	4.45	4.03	0.16	3.57	0.14	3.89	96.43
1.15	4.83	4.03	0.16	41.82	1.69	2.35	58.18
1.24	5.18	4.03	0.16	45.00	1.81	2.22	55.00
1.33	5.51	4.03	0.16	48.88	1.97	2.06	51.12
1.40	5.81	4.03	0.16	52.31	2.11	1.92	47.69
1.48	6.11	4.03	0.16	52.70	2.12	1.91	47.30
1.55	6.40	4.03	0.16	55.59	2.24	1.79	44.41
1.62	6.68	4.03	0.16	56.48	2.28	1.75	43.52

total runoff	rain	infilt
1.270	6.679	5.409

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 86.

The Potential Maximum Difference is 11.145 cm

Numerical Ftn = 1.754 Holtan's Ftn = 1.645 SCS Ftn = 2.059 cm/h

Colby, KS R2C2 PLOWED 7/17/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
1.08	8.68	4.03	0.16	1.83	0.07	3.96	98.17
2.22	9.24	4.03	0.16	28.30	1.14	2.89	71.70
2.35	9.69	4.03	0.16	35.71	1.44	2.59	64.29
2.45	10.03	4.03	0.16	46.48	1.87	2.16	53.52
2.53	10.38	4.03	0.16	45.73	1.84	2.19	54.27
2.61	10.70	4.03	0.16	48.38	1.95	2.08	51.62
2.71	11.17	4.03	0.16	33.75	1.36	2.67	66.25
2.81	11.51	4.03	0.16	47.25	1.90	2.13	52.75

total runoff	rain	infilt
1.270	11.511	10.241

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 69.

The Potential Maximum Difference is 25.661 cm

Numerical Ftn = 2.126 Holtan's Ftn = 1.735 SCS Ftn = 2.586 cm/h

Colby, KS R3C3 PLOWED 7/17/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
1.16	9.32	4.03	0.16	1.70	0.07	3.96	98.30
2.35	9.65	4.03	0.02	4.73	0.19	3.84	95.27
2.62	11.44	4.03	0.16	9.14	0.37	3.66	90.86
2.98	12.62	4.03	0.16	13.46	0.54	3.49	86.54
3.19	13.09	4.03	0.16	34.00	1.37	2.66	66.00
3.31	13.58	4.03	0.16	32.51	1.31	2.72	67.49
3.43	14.08	4.03	0.16	31.36	1.26	2.77	68.64

total runoff	rain	infilt
0.973	14.082	13.109

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 60.

The Potential Maximum Difference is 37.625 cm

Numerical Ftn = 2.767 Holtan's Ftn = 1.791 SCS Ftn = 2.923 cm/h

Hays, KS R1C3 NO-TILL 7/21/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
1.40	11.25	4.03	0.16	1.41	0.06	3.97	98.59
2.90	12.13	4.03	0.16	18.08	0.73	3.30	81.92
3.07	12.65	4.03	0.16	30.55	1.23	2.80	69.45
3.17	12.93	4.03	0.16	56.48	2.28	1.75	43.52
3.24	13.17	4.03	0.16	66.55	2.68	1.35	33.45
3.30	13.42	4.03	0.16	64.14	2.59	1.45	35.86
3.35	13.59	4.03	0.16	91.46	3.69	0.34	8.54
3.40	13.79	4.03	0.16	81.94	3.30	0.73	18.06

total runoff	rain	infilt
1.270	13.786	12.516

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 63.

The Potential Maximum Difference is 33.157 cm

Numerical Ftn = 0.728 Holtan's Ftn = 1.188 SCS Ftn = 2.727 cm/h

Hays, KS R2C1 NO-TILL 7/22/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	6.72	0.00	0.00	0.00	0.00	0.00
0.63	8.41	6.72	0.16	1.89	0.13	6.59	98.11
1.31	9.18	6.72	0.16	20.64	1.39	5.33	79.36
1.40	9.61	6.72	0.16	37.47	2.52	4.20	62.53
1.44	9.80	6.72	0.16	81.01	5.44	1.28	18.99
1.48	10.02	6.72	0.16	73.32	4.93	1.79	26.68
1.52	10.42	6.72	0.16	39.38	2.65	4.07	60.62
1.57	10.67	6.72	0.16	64.93	4.36	2.36	35.07
1.61	10.97	6.72	0.16	51.55	3.46	3.26	48.45

total runoff	rain	infilt
1.270	10.973	9.703

The average rainfall rate is 6.718 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 71.

The Potential Maximum Difference is 23.941 cm

Numerical Ftn = 3.255 Holtan's Ftn = 1.161 SCS Ftn = 4.243 cm/h

Hays, KS R4C2 NO-TILL 7/23/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	5.37	0.00	0.00	0.00	0.00	0.00
0.84	8.98	5.37	0.16	1.77	0.10	5.28	98.23
1.71	9.36	5.37	0.16	41.86	2.25	3.12	58.14
1.77	9.69	5.37	0.16	48.33	2.60	2.78	51.67
1.83	10.00	5.37	0.16	51.36	2.76	2.61	48.64
1.89	10.30	5.37	0.16	53.16	2.86	2.52	46.84
1.95	10.61	5.37	0.16	50.15	2.70	2.68	49.85
2.00	10.91	5.37	0.16	52.63	2.83	2.55	47.37
2.06	11.22	5.37	0.16	51.86	2.79	2.59	48.14

total runoff	rain	infilt
1.270	11.220	9.950

The average rainfall rate is 5.375 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 70.

The Potential Maximum Difference is 24.727 cm

Numerical Ftn = 2.587 Holtan's Ftn = 1.164 SCS Ftn = 3.419 cm/h

Hays, KS R1C3 UNDERCUT 7/22/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	5.37	0.00	0.00	0.00	0.00	0.00
0.91	9.76	5.37	0.16	1.63	0.09	5.29	98.37
1.86	10.22	5.37	0.16	34.52	1.86	3.52	65.48
1.93	10.51	5.37	0.16	54.52	2.93	2.44	45.48
1.98	10.77	5.37	0.16	61.81	3.32	2.05	38.19
2.03	11.03	5.37	0.16	62.17	3.34	2.03	37.83
2.07	11.26	5.37	0.16	66.87	3.59	1.78	33.13
2.12	11.47	5.37	0.16	76.49	4.11	1.26	23.51
2.16	11.70	5.37	0.16	70.88	3.81	1.57	29.12

total runoff	rain	infilt
1.270	11.696	10.426

The average rainfall rate is 5.375 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 69.

The Potential Maximum Difference is 26.258 cm

Numerical Ftn = 1.565 Holtan's Ftn = 1.169 SCS Ftn = 3.465 cm/h

Hays, KS R4C2 UNDERCUT 7/22/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
1.85	14.88	4.03	0.16	1.07	0.04	3.99	98.93
3.76	15.40	4.03	0.16	30.55	1.23	2.80	69.45
3.87	15.78	4.03	0.16	42.19	1.70	2.33	57.81
3.95	16.05	4.03	0.16	57.16	2.30	1.73	42.84
4.02	16.34	4.03	0.16	54.95	2.21	1.82	45.05
4.09	16.63	4.03	0.16	56.03	2.26	1.77	43.97
4.16	16.90	4.03	0.16	58.34	2.35	1.68	41.66
4.23	17.17	4.03	0.16	59.56	2.40	1.63	40.44

total runoff	rain	infilt
1.270	17.165	15.895

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 56.

The Potential Maximum Difference is 44.804 cm

Numerical Ftn = 1.630 Holtan's Ftn = 1.210 SCS Ftn = 2.880 cm/h

Hays, KS R5C1 UNDERCUT 7/23/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	6.72	0.00	0.00	0.00	0.00	0.00
1.56	21.02	6.72	0.16	0.76	0.05	6.67	99.24
3.16	21.39	6.72	0.16	42.32	2.84	3.88	57.68
3.22	21.85	6.72	0.16	34.72	2.33	4.39	65.28
3.29	22.31	6.72	0.16	34.44	2.31	4.40	65.56
3.35	22.75	6.72	0.16	36.04	2.42	4.30	63.96
3.42	23.16	6.72	0.16	38.49	2.59	4.13	61.51
3.48	23.55	6.72	0.16	40.89	2.75	3.97	59.11
3.53	23.92	6.72	0.16	43.40	2.92	3.80	56.60

total runoff	rain	infilt
1.270	23.917	22.647

The average rainfall rate is 6.718 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 46.

The Potential Maximum Difference is 69.375 cm

Numerical Ftn = 3.803 Holtan's Ftn = 1.237 SCS Ftn = 5.127 cm/h

Hays, KS R1C1 CLEAN-TILL 7/24/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	6.72	0.00	0.00	0.00	0.00	0.00
0.33	4.38	6.72	0.16	3.63	0.24	6.47	96.37
0.70	5.03	6.72	0.16	24.37	1.64	5.08	75.63
0.78	5.39	6.72	0.16	43.40	2.92	3.80	56.60
0.83	5.70	6.72	0.16	51.24	3.44	3.28	48.76
0.87	6.00	6.72	0.16	52.83	3.55	3.17	47.17
0.91	6.29	6.72	0.16	55.96	3.76	2.96	44.04
0.96	6.55	6.72	0.16	59.90	4.02	2.69	40.10
0.99	6.80	6.72	0.16	63.00	4.23	2.49	37.00

total runoff	rain	infilt
1.270	6.804	5.534

The average rainfall rate is 6.718 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 85.

The Potential Maximum Difference is 11.487 cm

Numerical Ftn = 2.486 Holtan's Ftn = 1.091 SCS Ftn = 3.466 cm/h

Hays, KS R4C2 CLEAN-TILL 7/24/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	4.03	0.00	0.00	0.00	0.00	0.00
0.65	5.25	4.03	0.16	3.02	0.12	3.91	96.98
1.40	6.04	4.03	0.16	20.25	0.82	3.21	79.75
1.56	6.53	4.03	0.16	32.29	1.30	2.73	67.71
1.68	7.00	4.03	0.16	33.51	1.35	2.68	66.49
1.79	7.42	4.03	0.16	38.11	1.54	2.49	61.89
1.89	7.79	4.03	0.16	42.44	1.71	2.32	57.56
1.98	8.14	4.03	0.16	45.58	1.84	2.19	54.42
2.06	8.49	4.03	0.16	46.03	1.86	2.18	53.97

total runoff	rain	infilt
1.270	8.487	7.218

The average rainfall rate is 4.031 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 79.

The Potential Maximum Difference is 16.297 cm

Numerical Ftn = 2.176 Holtan's Ftn = 1.127 SCS Ftn = 2.311 cm/h

Hays, KS R5C3 CLEAN-TILL 7/23/80

time	rain	rainr	run	prun	runr	xinf	pxinf
0.00	0.00	5.37	0.00	0.00	0.00	0.00	0.00
0.63	6.72	5.37	0.16	2.36	0.13	5.25	97.64
1.36	7.91	5.37	0.16	13.41	0.72	4.65	86.59
1.50	8.20	5.37	0.16	54.52	2.93	2.44	45.48
1.56	8.60	5.37	0.16	39.09	2.10	3.27	60.91
1.64	8.99	5.37	0.16	41.05	2.21	3.17	58.95
1.71	9.35	5.37	0.16	43.40	2.33	3.04	56.60
1.77	9.64	5.37	0.16	54.80	2.95	2.43	45.20
1.83	10.05	5.37	0.16	39.38	2.12	3.26	60.62

total runoff	rain	infilt
1.270	10.048	8.778

The average rainfall rate is 5.375 cm/h.

The initial soil moisture condition was AMC 1

The RUNOFF CURVE NUMBER IS 74.

The Potential Maximum Difference is 21.030 cm

Numerical Ftn = 3.258 Holtan's Ftn = 1.150 SCS Ftn = 3.292 cm/h

CALIBRATION OF A RAINFALL SIMULATOR FOR DETERMINATION OF SOIL CONSERVATION SERVICE RUNOFF CURVE NUMBERS

by

Russell Wayne LaForce

B.S., Kansas State University, 1979

AN ABSTRACT OF A MASTERS THESIS

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ABSTRACT

Tillage practices can have a major effect on runoff from cropland. Long term effects of reduced runoff can be partially responsible for low water levels in reservoirs even though rainfall is near normal. This is occurring in northwestern and northcentral Kansas in the Solomon River basin.

As natural rainfall is very unpredictable, a portable rainfall simulator was built and calibrated to determine the effects of tillage practices on wheat stubble ground on runoff for two major soil types in the Solomon River basin. The rainfall simulator can vary the application rate between 0.5 and 13.6 cm/h at a nozzle pressure of 41 kPa. Two fan type spray nozzles are used. The smaller one models low intensity storms and the larger one is used to model high intensity storms. The nozzles are 3 meters above the plot and oscillate back and forth to wet the entire 1.5 m by 3.0 m base of the rainfall simulator. Runoff is collected by a suction tube from the edge of a 0.7 m by 0.9 m plot located directly underneath the nozzles.

Field calibration of five runs, one at AMC-I condition and the remainder at AMC-III condition, on a single plot of pasture land produced an average curve number of 79. The SCS estimated curve number was 75 for a difference of 4. The application rate between the runs varied from 13.6 cm/h to 1.3 cm/h.

Nine plots were chosen at Colby, KS to represent the soil in the western half of the basin. Three tillage treatments, no-till, undercut, and moldboard plow, had three replications each on wheat stubble ground. The observed curve numbers using 1.27 cm of runoff were 78, 74, and 65 respectively. Statistical analysis indicated that no-till was signficantly higher in producing runoff at the five percent error level than the undercut and moldboard plow tillage treatments.

Nine plots were chosen at Hays, KS to represent the eastern half of the basin also on wheat stubble ground. Three tillage treatments, no-till, undercut, and undercut- disk-disk-remove all residue, had three replications each. The observed curve numbers using 1.27 cm of runoff were 68, 57, and 79 respectively. Statistical analysis indicated that undercut-disk-disk-remove all residue treatment required signficantly less rainfall to produce runoff at the five percent error level compared with the other two treatments.

The soil at Colby and Hays was at an extremely dry AMC-I condition.