OPTIMUM SPRINKLER APPLICATION RATES ON SOILS OF LOW INFILTRATION RATE

by

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The author would also like to express his conviction that there is a higher realm revealed in the person of Jesus Christ, which has had an important bearing upon the author's initiative and enjoyment in pursuing this thesis problem.

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INTRODUCTION

Many sprinkler irrigation systems cause runoff of irrigation water and puddling of the soil when operating during their normal period. Runoff and puddling occur when the application rate exceeds the soil infiltration rate (29, p. 21). This is frequently the case on some of the sandy soils and especially noticeable on the clay soils that are prevalent in the Willamette Valley.

Runoff and puddling are generally recognized to be the result of an improperly designed sprinkler system although Stippler felt that they might occur on any soil after a period of several hours of sprinkler irrigation (45, p. 22). American Society of Agricultural Engineers (ASAE) has recommended, with the approval of the Sprinkler Irrigation Association (SIA), that a sprinkler irrigation system, when properly designed and operated shall:

> Apply water at a rate which does not cause runoff during the normal operating period nor cause water to stand on the surface of the ground after the sprinkler line is shut off. (1, p. 157)

Runoff and puddling of water result in a waste of both power and water (29, p. 21). As water becomes more scarce it will become increasingly important that an end be brought to this waste.

Free said that soil splash, aggregate destruction, crusting and sealing occur without erosion and natural rainfall where sprinkler irrigation is practiced (19, p. 494). These conditions are responsible for low infiltration rates and high runoff (2, p. 450).

One of the major problems in designing a sprinkler irrigation system is the determination of the rate of application. Soil infiltration rate, although relatively high at first, diminishes until it reaches a more or less constant rate. The selected design application rate is usually intended to be slightly less than the soil infiltration rate when it has reached a fairly constant value.

This procedure for selecting a design application rate has worked fairly well with all soils except the clay soils found in the Willamette Valley. Examples of these clay soils are the Willamette, Amity and Dayton soil series. Recommended application rates for clay soils range from 0.20 to 0.35 inches per hour (50, p. 75). It has been observed, on the typical clay soils which are found on the Oregon State Dairy Farm, by the foreman, Mr. George Hannay, Dr. John W. Wolfe and the author that puddling and runoff occur after 6 to 8 hours of sprinkler irrigation at rates close to 0.33 inches per hour.

Slower application rates would be the most apparent answer, but application problems become more difficult at lower rates. Applying water at low rates with conventional equipment increases the cost of labor, requires more equipment and often decreases the uniformity of water distribution.

It soon becomes evident that a rate must be determined that will put water on the field with a minimum of puddling and runoff yet with a minimum amount of equipment. This rate shall be called an optimum rate.

The objectives of this thesis are:

1. To explore the possibilities that time-to-puddle (defined as that time from the start of irrigation until one can detect water standing on the surface) is the criterion to find optimum application rate.

2. To find relationships between soil-water puddling, lateral water translocation and irrigation efficiency.

LITERATURE REVIEW

Infiltration

The committee on terminology of the Soil Science Society of America defines infiltration as the downward entry of water into the soil (44, p. 434). Infiltration rate is defined as:

> The maximum rate at which a soil, on a given condition at a given time, can absorb water. Also, the maximum rate at which a soil will absorb water impounded on the surface at a shallow depth when adequate precautions are taken regarding border or fringe effects. Defined as the volume of water passing into the soil per unit of area per unit of time, it has the dimensions of velocity, (LT^{-1}). (44, p. 434)

In general the rate of infiltration decreases with time of application. Most soils when dry will absorb water rather rapidly. Then the rate of infiltration declines more or less quickly, depending on the texture of the soil. After water has been applied for several hours, the infiltration rate may be only a small fraction of that at the start and usually approaches a constant value (45, p. 22).

Horton (43, p. 259) derived an equation empirically and his equation took the following form:

$$I_t = I_f + (I_i - I_f)e^{-Bt} \qquad (1)$$

where

I_t = infiltration rate at time t

I_f = final infiltration rate

I_i = initial infiltration rate

B = constant

e = the base for natural logarithms

t = time

His equation may also be derived from the assumption that the processes which reduce the high, initial infiltration rate to a lower, constant rate are of the nature of exhaustion processes. Linsley, et al. said that some of these processes are rain packing, inwashing, swelling of colloids, closing of sun checks and breaking down of the crumb structure of the soil. Infiltration rates also are reduced because of increasing resistance to flow as the moisture front moves downward through the soil profile. They also said that this increased resistance resulted from increasing friction with increased channel length and decreased permeability with depth (34, p. 310-311).

Kostiakov (43, p. 259) proposed the following equation in 1931:

$$I = aKt^{a-1} \qquad (2)$$

where

I = infiltration rate

t = time

$a = 1/2$, $K = S$ as $t \rightarrow 0$

$a = 1,\ K = K_o$ as $t \rightarrow \infty$

S = Sorptivity (function of moisture content).

This equation has been used rather widely and describes the infiltration process moderately well (42, p. 135).

Criddle, *et al.* (12, p. 6) showed how Kostiakov's equation could be derived experimentally. They plotted infiltration rate during a normal irrigation on log-log paper on the vertical axis and time on the horizontal axis. The resulting equation was:

$$I = At^b \qquad (3)$$

where

I = infiltration rate

t = time that water is on the soil surface

A = infiltration rate intercept at unit time

b = slope of the line (vertical scaled distance divided by horizontal scaled distance).

The value for b has been determined experimentally by Criddle, *et al.* as -0.5 (12, p. 9) and also theoretically by Philip as -0.5 (43, p. 261).

Many methods have been proposed to measure infiltration capacity. Most of the existing methods are too cumbersome and slow, and often too inaccurate for use in evaluating the range of relative infiltration rates found on farms. Also each method was developed to meet a specific need and in many cases the method was and is not widely adaptable (41, p. 311-312).

There are three general categories of methods of measuring infiltration capacity.

1. Horton first suggested that infiltration could be determined as the difference between water applied and runoff (27, p. 453). Since then many investigators have tried various techniques of applying this principle. Parr and Bertrand summarize these techniques very well (41, p. 321-336).

2. Water is impounded in a confined area. Infiltration is measured as the amount of water that enters the soil in a given amount of time. The limitation in this method is the manner of placement of impounding rings into soil. Another problem is that of entrapped air inside a soil column caused when a constant head of water is applied upon the soil (41, p. 338-346).

3. Another method characterizes infiltration by means of hydrographs from watershed drainage areas. Bertoni, et al. (3, p. 572), after analyzing many years of data, developed an equation for infiltration capacity. The equation is:

$$I = 0.211 + 1.019e^{-0.056t} \qquad (4)$$

where

I = infiltration rate in inches per hour

t = time in minutes

e = the base for natural logarithms.

Parr and Bertrand's opinion of this method is that:

> Infiltration rates obtained by means of watershed hydrographs are of limited value from the agronomic standpoint since a direct interpretation of data is virtually impossible. (41, p. 348)

Soil-water puddling

Buehrer and Rose define soil puddling as:

> ....the destruction of the aggregate condition of the soil by mechanical manipulation within a narrow range of moisture contents, above or below the moisture equivalent, so that the aggregates lose their identity and the soil is converted into a structurally homogeneous mass of ultimate particles. (7, p. 212)

Baver thought puddling was the reduction in the apparent specific volume of a soil by performing mechanical work on it. Puddling is caused by normal stress associated with compression and tangential stress causing shear (2, p. 117).

Bodman and Rubon showed how the change in volume per unit work was related to the air-filled pore space (6, p. 117).

Maximum puddling occurs in the "wet" range of soil consistency (2, p. 119).

McGeorge said that puddling develops not only from careless tillage but is even difficult to avoid in agricultural irrigation. He found that penetration of irrigation would decrease because puddling reduces the volume of the capillary pore space (38, p. 128).

Ellison and Slater found that raindrops affect surface sealing. Their equation

$$E = KV^{4.33}d^{1.07}I^{0.65} \qquad (5)$$

where

E = amount of soil carried by a raindrop

K = a constant

V = velocity of raindrop in feet per second

d = diameter of drop in millimeters

I = rainfall intensity in inches per hour

has a relationship to infiltration rates. They found that low infiltration rates are associated with high values of E. They also found that soil properties play an important role in the sealing process which reduces infiltration capacity (18, p. 156).

When falling raindrops strike the ground surface or the thin films of water covering it, they splash small bits of soil into the air. These particles reach varying heights ranging up to more than 2 feet vertically, and more than 5 feet horizontally on level surfaces (15, p. 197).

Hendrikson found that water on the ground surface became puddled immediately by the small particles thrown into suspension. He said that these small particles tended to clog the soil pores thereby appreciably increasing runoff (25, p. 501).

Lowdermilk felt that fine particles were filtered at the soil surface where they formed layers of fine-textured material which determined the infiltration rate quite independently of the percolation capacity of the soil (35, p. 490).

Duley noted that raindrops formed a thin, compacted layer at the soil surface. He believed that this layer was the result of severe structural disturbance due in part to the beating effect of raindrops and partially to an assorting action that fitted fine particles between the large ones (13, p. 61).

Gray thought that in clay soils, when water was applied too fast, the minute silt particles were disturbed and dislodged. They then settle out and pack on the surface, which becomes slick, causing runoff and preventing further water penetration (23, p. 8).

Linsley, et al. stated that the effect of drop size on infiltration capacity is due to its effect on the rate of rainpacking and breaking down of soil structure (34, p. 314).

Levine found that increasing the drop size resulted in a statistically significant decrease in infiltration capacity for the soils (33, p. 559).

Christiansen felt that the rate at which soils absorbed water depended on how the water was applied. Large drops resulting from low pressures tended to puddle and seal the soil surface sooner than a fine atomized spray (10, p. 119).

Gray proposed that puddling be eliminated by determining the soil infiltration rate and then applying water at half that rate or less (24, p. 7). He believed that water applied at very slow rates improved the soil surface structure and gave increased yields (22, p. 20).

Other investigators have thought that lower application rates were the answer to soil puddling and loss of water due to runoff. It was also regarded that puddling (used from now on to denote water ponded on the soil surface) was the criterion for determining when rates became excessive.

Strong said excessive application rates caused puddling and runoff and made succeeding applications more difficult. He felt that over-application as evidenced by puddling was more common than under-application (46, p. 9-10).

Wolfe stated that to obtain the most benefit from a sprinkler irrigation system and to prevent erosion it was necessary that each drop of water be absorbed when it fell. This meant there should be no free water standing or running on the surface during an irrigation (49, p. 3).

McCulloch and Schrunk said that the application of water to soil with sprinkler irrigation is based on the principle of "no runoff". They thought a properly designed sprinkler system should apply water without movement from one part of the field to another (37, p. 103).

Almost all authors as shown in reviewing their literature believe that puddling is some sort of a criterion for determining when application rates become excessive. They have implied that there is a connection between puddling and irrigation efficiency. Irrigation efficiency as used in this thesis is defined as the ratio of soil moisture increase in the root zone at any point to the water applied at that point. Although they believe that puddling will give poor irrigation efficiency, there is little experimental evidence to back their theory.

It is also assumed in the literature that soil-water puddling is almost entirely a surface phenomenon. It should be recognized that most of the results in the literature review on soil-water puddling were obtained on bare soil. Lowdermilk (35, p. 490) recognized the importance of litter on top of the soil and felt that litter would keep the infiltration rate from being decreased by soil surface sealing. The author could find no literature directly relating soil-water puddling and infiltration capacity of the soil. Linsley, et al.

implies that infiltration capacity could be the limiting factor in soil-water puddling (34, p. 314).

The objectives of this thesis are again set forth as:

1. To explore the possibilities that time-to-puddle is the criterion to find optimum application rate.

2. To find relationships between soil-water puddling, lateral water translocation and irrigation efficiency.

PROCEDURE

Certain pasture sites on the Oregon State University Dairy Farm (Figure 1) of low infiltration rate soils were selected. Clark L. Mitchell, an employee of the Farm Service Department of Oregon State University, also observed that these sites showed runoff and puddling after a short time of sprinkler irrigation.

Borings were made with a soil auger in each plot. The water table occurred from 3.5 to 5.0 feet below the surface of each plot during the summer and about 18 inches during the winter.

Since prepared-plot no. 5 and plot no. 7 were considered to be permanent for the duration of the project, each site was surveyed in order to determine the best place for its location. The remaining sites were picked at random to provide temporary sampling plots.

The first plot (prepared plot no. 5) was laid out in July, 1959. The remaining plots were laid out during the summer of 1960. The layout of individual plots and accompanying sprinkler irrigation systems are shown in Figures 2, 3, 4 and 5.

A single lateral was used because of the decreasing application rate toward the edge of the wetted pattern. This allowed observations at varying application rates.

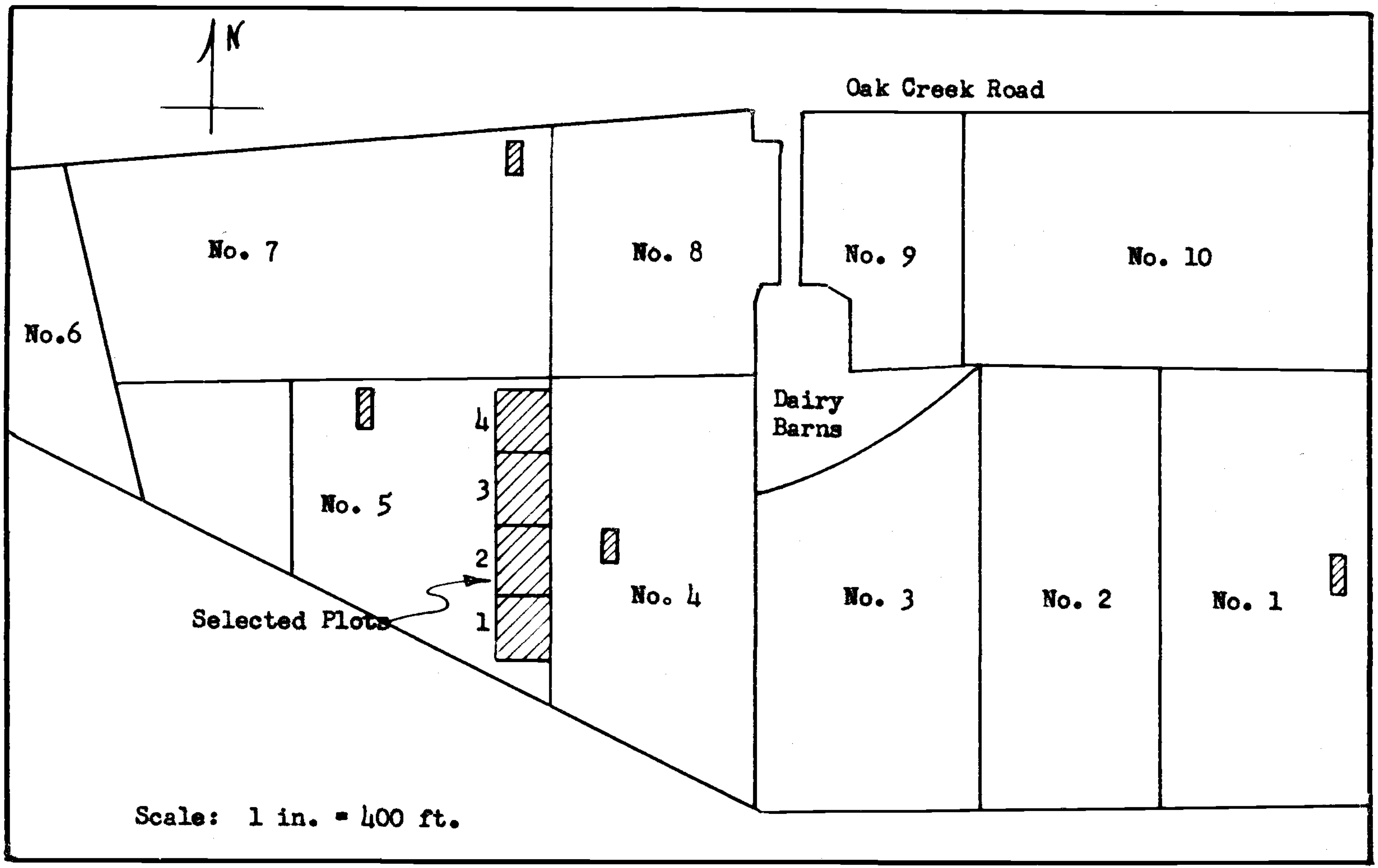

Figure 1. Map of Dairy Farm

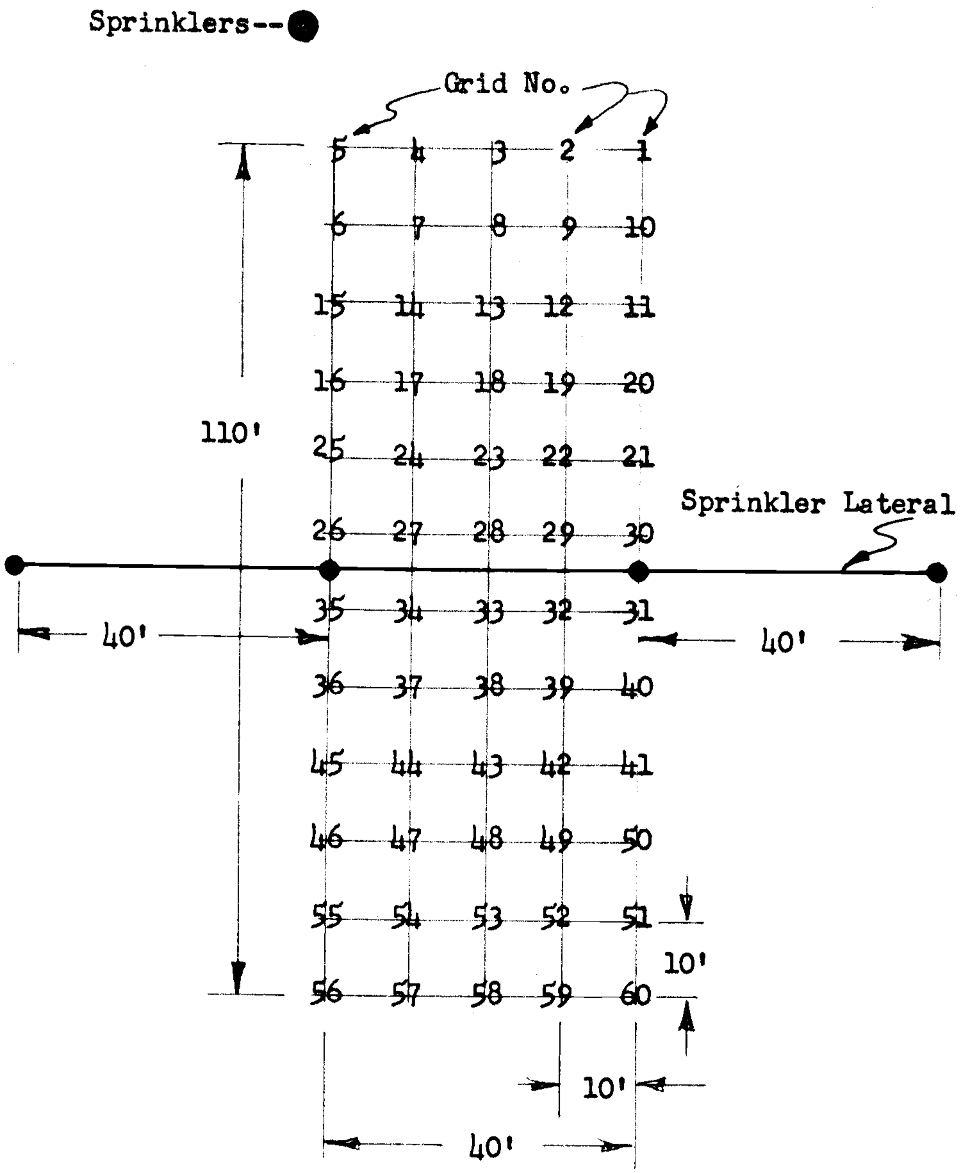

Figure 2. Layout of plot no. 1, plot no. 4, and prepared plot no.5

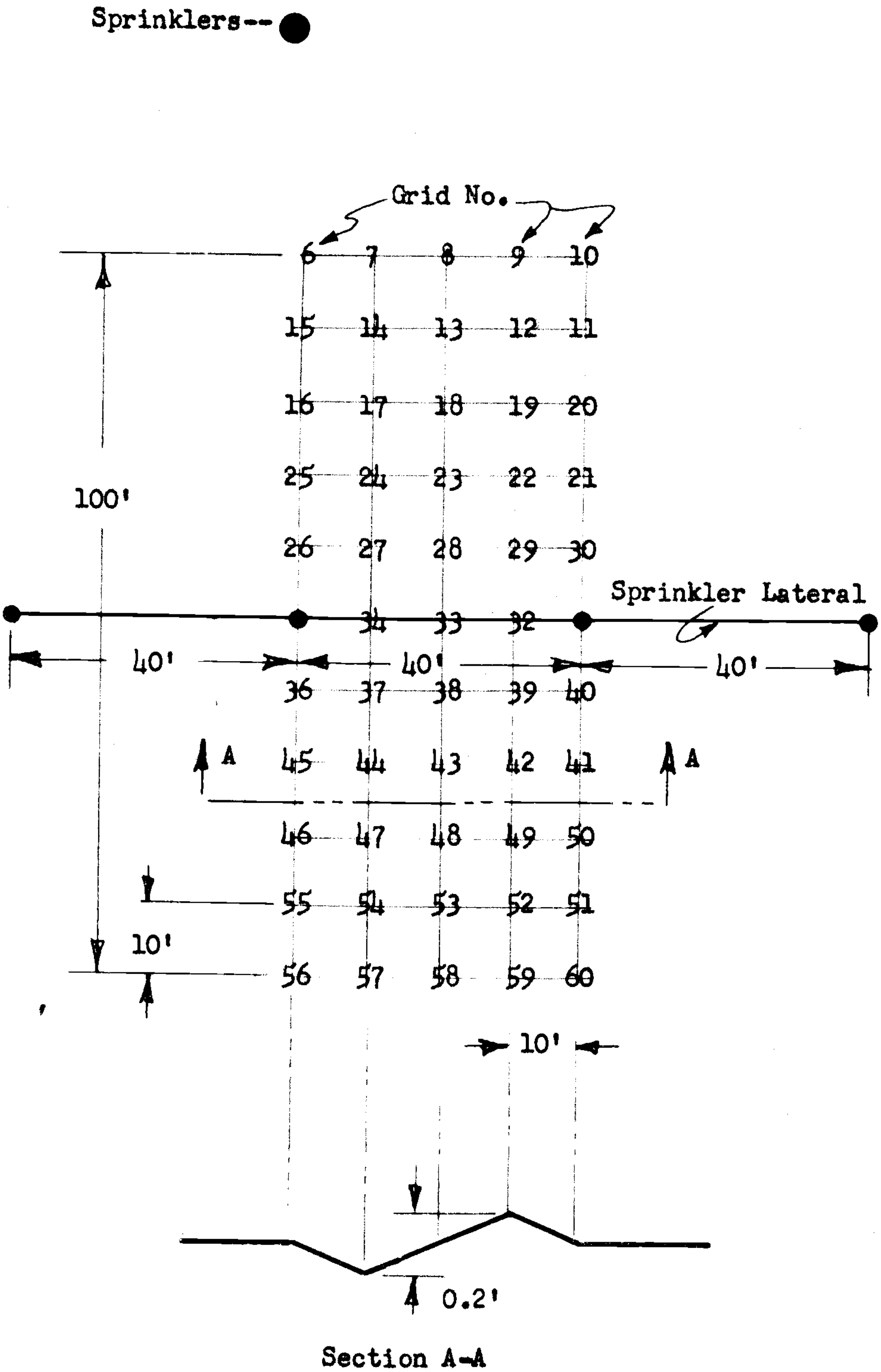

Figure 3. Layout of plot no. 7

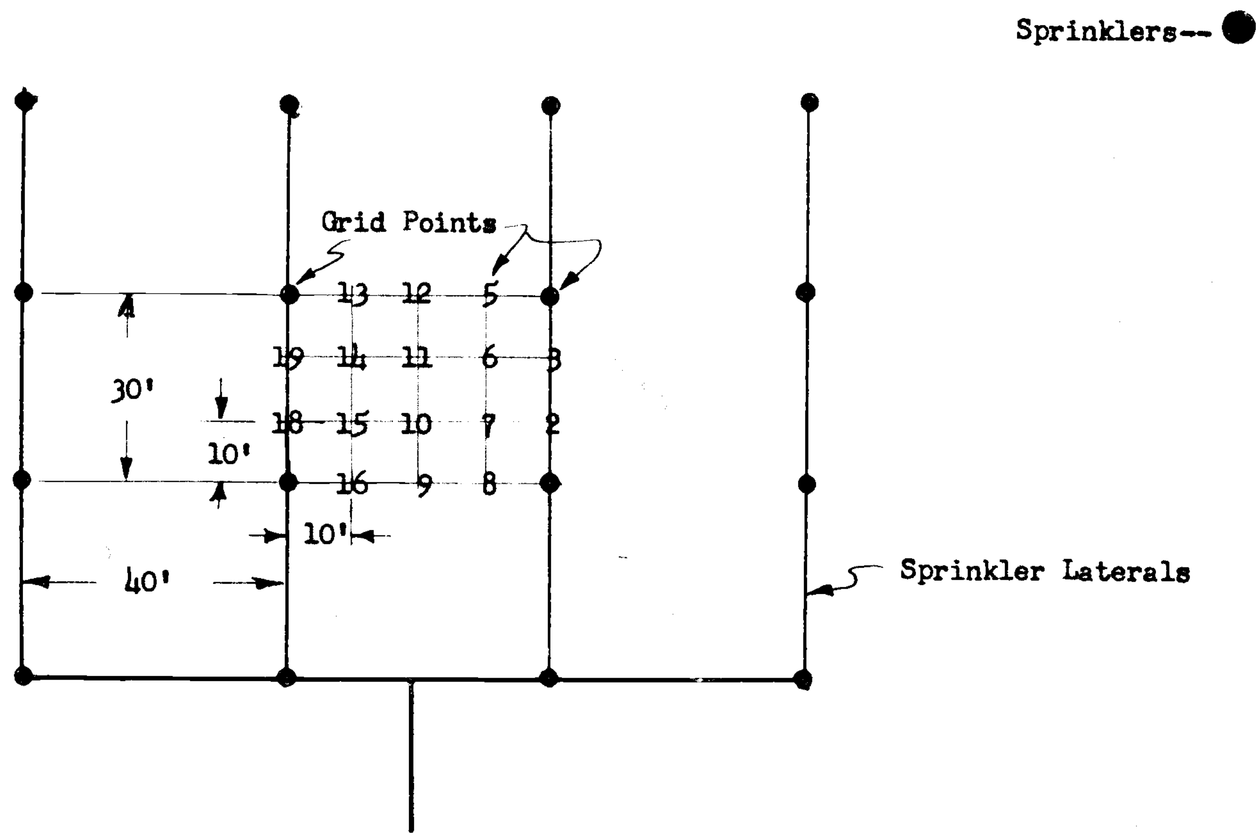

Figure 4. Layout of selected plots 1, 2, 3 and 4

Solid sets were used (Figure 4) with Rainbird no. 12-D sprinklers. These sprinklers applied water at rates of 0.080 inch per hour when used in solid sets. The purpose of the use of these sprinklers was to find out how uniformly they applied water and to observe soil-water puddling at very low application rates.

Plot no. 7 was precisely graded (Figure 7) to form a slight ridge and swale so that one could both control the direction of lateral water movement on the soil surface and easily predict when and where puddling would occur. Ridge top is 0.2 feet above the swale bottom and the down slope is 1 percent. It was seeded to a pasture mix in July, 1960, and one experiment was completed during September, 1960.

A 10-foot grid was laid out over each plot, and during each irrigation a tall, slender, water-collecting can was placed at each grid point to measure the water applied (Figure 6). The cans were made from 2-inch aluminum tubing, each 12 inches long with an aluminum disc inserted in one end to form the bottom and welded with a tungsten inert gas welder. The open ends of the cans were filed in accordance with U. S. Weather Bureau recommendations (28, p. 2) so that each can recorded only the amount of water that fell through the opening. To obtain the accuracy of the 2-inch aluminum cans, tests

Figure 5. Typical arrangement of four sprinklers during experiments

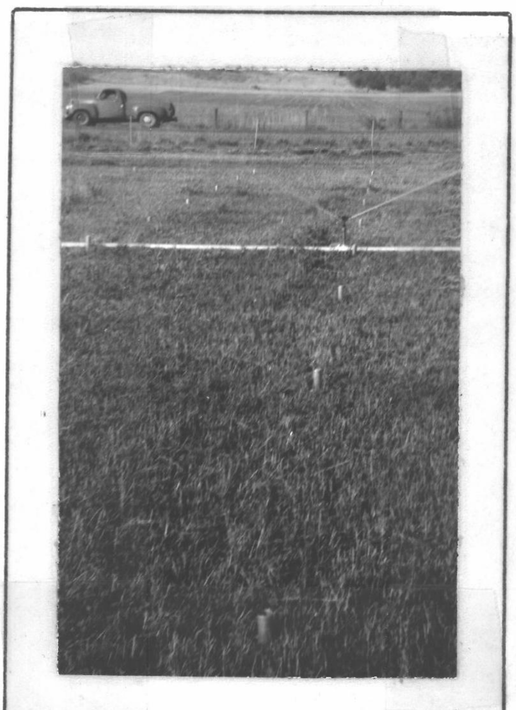

Figure 6. Grid pattern of collecting cans on plot no. 7

were made comparing them with others of different diameters. The results are shown in Table 4 in Appendix.

The cans were filled one-third full of diesel oil, as recommended by Frost and Schwalen (21, p. 527), to prevent evaporation once water had fallen in the cans. Then they were weighed by a torsion balance in the laboratory. They were then transported to one of the plots. In prepared plot no. 5 there is a 2-inch (inside diameter) steel conduit placed to a depth of 4 feet at each grid point. These conduits were placed in this plot under the assumption that a neutron-scattering instrument would be used to measure the soil moisture at each point. Unfortunately, the neutron-scattering instrument could not be properly calibrated and therefore was not used on any measurements reported here.

In prepared plot no. 5 several rubber bands were slipped around the outside of each collecting can. The collecting can was then placed inside of the conduit. The rubber bands acted as O-rings thereby keeping the collecting can securely in place during sprinkler trial. In the other plots, holes were drilled with a 2-inch auger to a depth of 6 inches. These holes were reamed out by using a short piece of 2-inch conduit and then driving the conduit into the hole into which the cans were placed.

All vegetative obstructions were cleared from each grid point so that nothing would keep water from entering the can. At the end of the sprinkler trial, the cans were carefully collected, brought into the laboratory and again weighed carefully.

The depth of water in each can was calculated by the following equation:

$$D = \frac{W_2 - W_1}{CA} \quad (6)$$

where

D = depth of water caught in can, inches

W_2 = weight of collecting, diesel oil, and water, grams

W_1 = weight of collecting can and diesel oil, grams

C = conversion constant (16.39 grams of water $\approx$ one cubic inch of water)

A = inside can area, square inches (Table 5 in Appendix).

Soil moisture samples were taken before and after irrigation at each grid point. They were taken as close to irrigation as possible; usually the day before and 3 days after. Samples were taken 3 days after irrigation because Marsh, et al. (36, p. 10-11) found that it takes 3 days for water to stop relocating itself in the soil and to come to equilibrium. During the period between soil samples, the amount of water taken out of the soil was estimated by consumptive-use measurements. These measurements were obtained from a portion of Oregon

Agricultural Experiment Station Project 179: "Evaporation Versus Consumptive Use of Pastures".

Soil samples were taken with a Veihmeyer soil sampling tube (Figure 8). The variability of soil moisture sampling is shown in Table 6 in Appendix. Samples were taken in 6-inch increments to a depth of 36 inches. The soil samples were then taken into the laboratory in moisture cans, weighed and put into a drying oven. After drying thoroughly, they were re-weighed. Moisture content on a weight basis was found by using the following equation:

$$M_W = \frac{W_2 - W_1}{W_1} 100 \qquad (7)$$

where

M_W = moisture content on a weight basis, percent

W_2 = weight of wet soil, grams

W_1 = weight of dry soil, grams.

To find the soil moisture increase in a 6-inch soil layer due to the irrigation the following equation was used:

$$M_V = \frac{(M_2 - M_1)}{100} (B.D.)6 \qquad (8)$$

where

M_V = soil moisture increase, inches

M_2 = moisture content after irrigation, percent

M_1 = moisture content before irrigation, percent

B.D. = bulk density of soil.

Bulk density of the soil of each plot was obtained (Figure 9) by using a Pomona Sampler, and is shown in Table 7 in Appendix.

Other data obtained during each test were wind velocity and direction by the use of an anemometer. Readings were taken every 2 hours and averaged. Temperature and relative humidity were obtained by the use of a hygrothermograph. Time-to-puddle data was obtained by noting when water appeared on the surface and the grid point to which it was closest (Figures 10, 11, 12). Pressure measurements were made by a pressure gauge connected to a pitot tube. The amount of water flowing into the sprinkler lateral was measured by a calibrated nutating meter.

Figure 7.

Preparation of plot no. 7 to control water movement

Figure 8.

Typical view of Veihmeyer soil sampling tube

Figure 9.

Bulk density samples being prepared through the use of a Pomona soil sampler

Figure 10.

Soil-water puddling
just about to start

Figure 11.

Moderate soil-water puddling

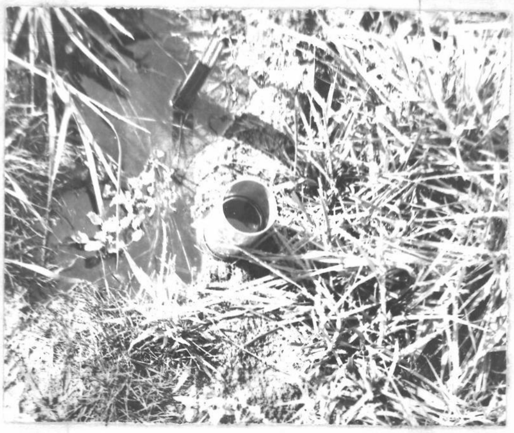

Figure 12.

Extreme soil-water puddling

RESULTS AND DISCUSSION

Time-to-puddle and application rate

Time-to-puddle was plotted against application rate (Figure 13). Time-to-puddle, as used in making observations this past summer, is as previously defined, the time from the start of irrigation until one can detect water standing on the surface. A regression analysis was made of the log of application rate on the log of time-to-puddle and the regression coefficient was found to be statistically significant.

The general equation of a straight line is:

$$y = bx + a \qquad (9)$$

where

b = slope of line

a = y intercept of the straight line.

Using the log application rate versus log time-to-puddle curve (Figure 14), an equation can be written using the values obtained in the regression analysis.

$$\text{log time-to-puddle} = -0.95 \text{ log application rate} + \text{log constant}$$

$$\log t = -\log A^{0.95} + \log \text{constant}$$

$$\log t = \log \frac{\text{const.}}{A^{0.95}}$$

$$t = \frac{\text{const.}}{A^{0.95}} \qquad (10)$$

and similarly

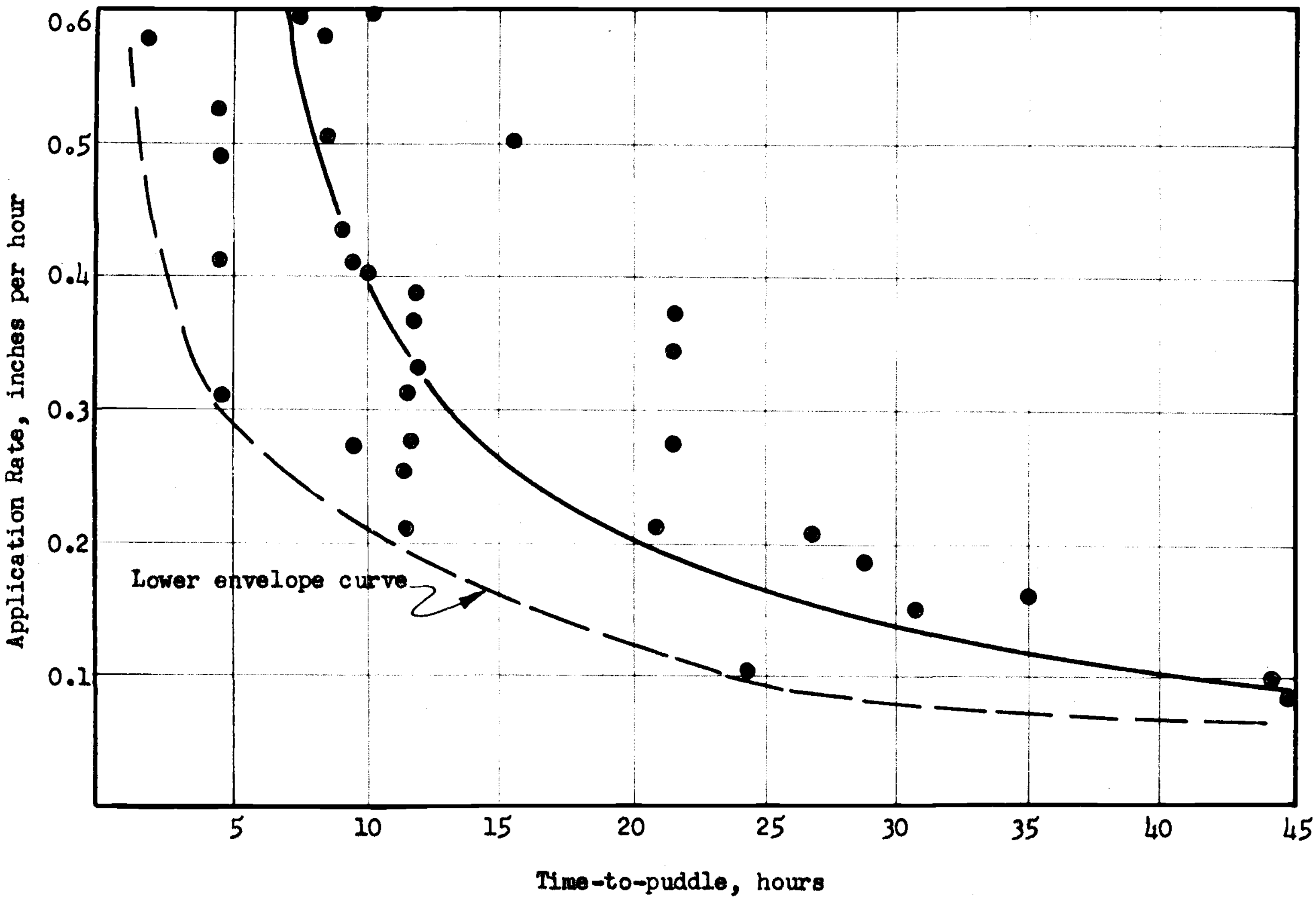

Figure 13. Application rate versus time-to-puddle

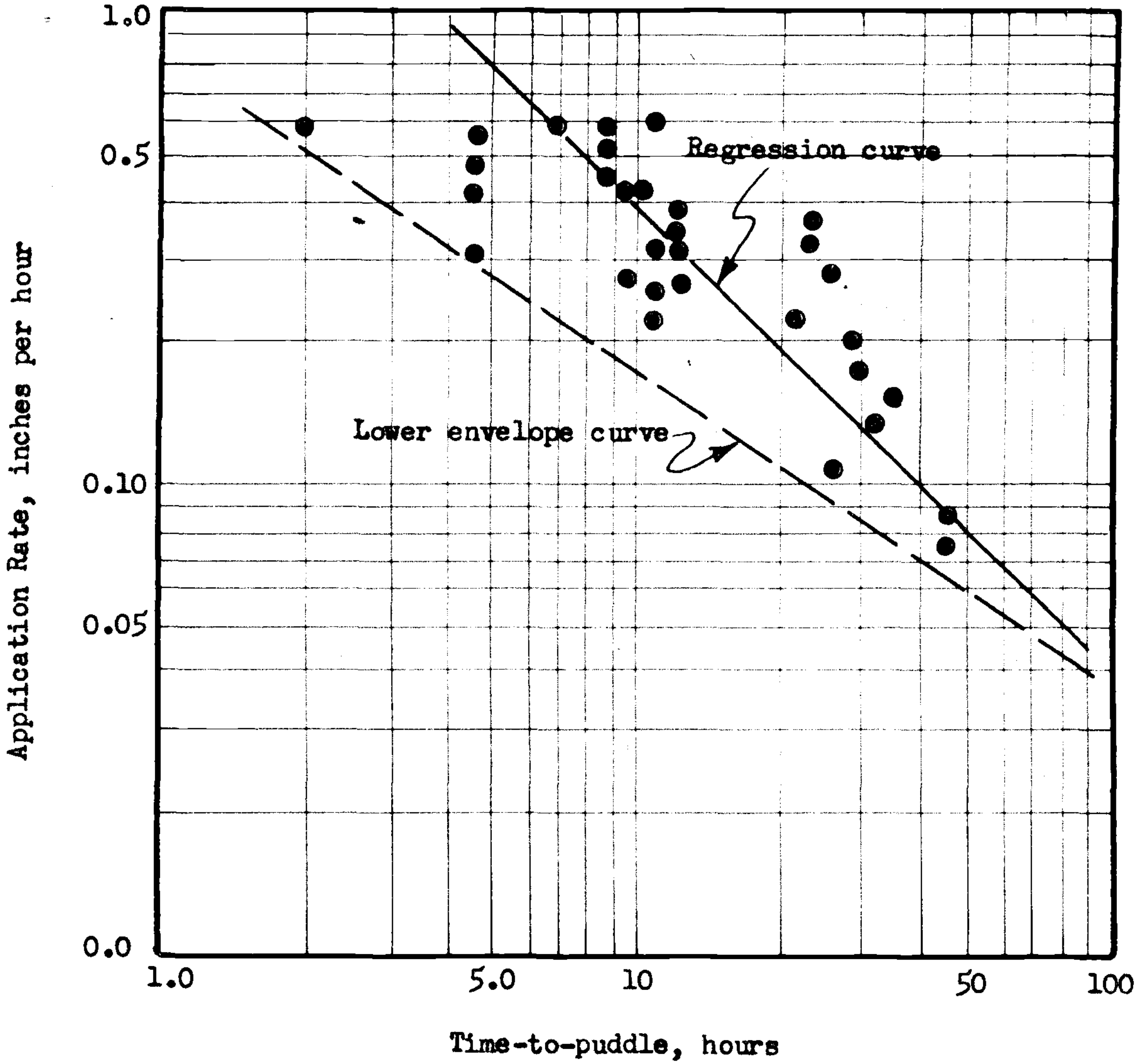

Figure 14. Log application rate versus log time-to-puddle

$$A = \frac{\text{const.}}{t^{0.736}} \qquad (11)$$

These two equations are different due to the regression analysis. The regression was first calculated with time-to-puddle as a function of application rate, and then application rate as a function of time-to-puddle. This gives the smallest possible deviation from regression in each equation.

Initial moisture content of soil influences the amount of water that soil can absorb. If initial moisture content were higher then time-to-puddle should be less; so runoff should occur. Infiltration capacity must also be a function of initial moisture content of soil (34, p. 312).

Since infiltration is a function of initial moisture content, time-to-puddle (t) versus application rate curve was adjusted for initial moisture content. The initial moisture content was calculated from previous data and divided by each individual application rate to give a time (t'). This time (t') was added to time-to-puddle (t) in order to give a corrected time-to-puddle (t").

$$t'' = t' + t \qquad (12)$$

The corrected data is plotted in Figures 15 and 16. Comparison with the uncorrected data shows that the dispersion of points has been reduced when initial

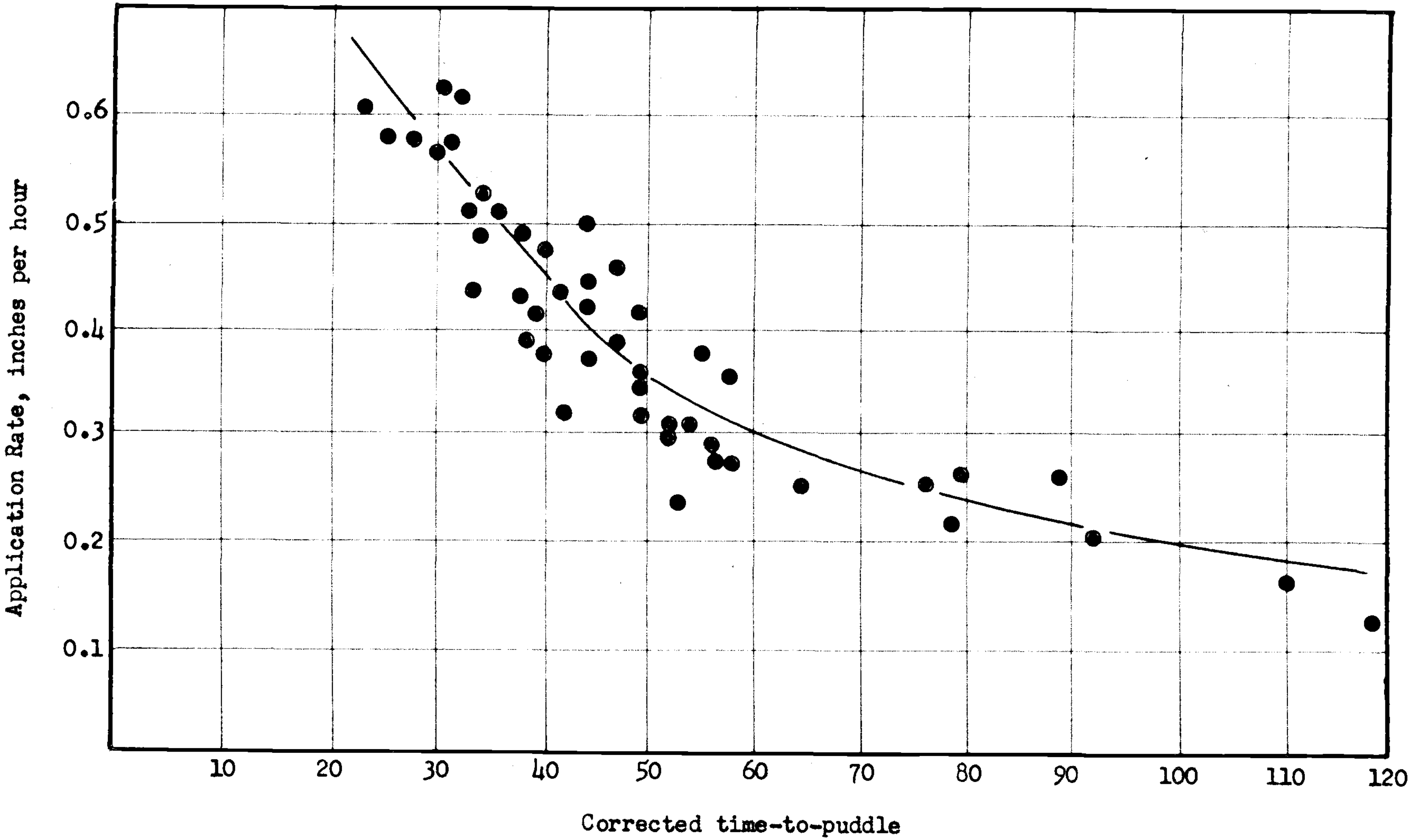

Figure 15. Corrected time-to-puddle versus application rate

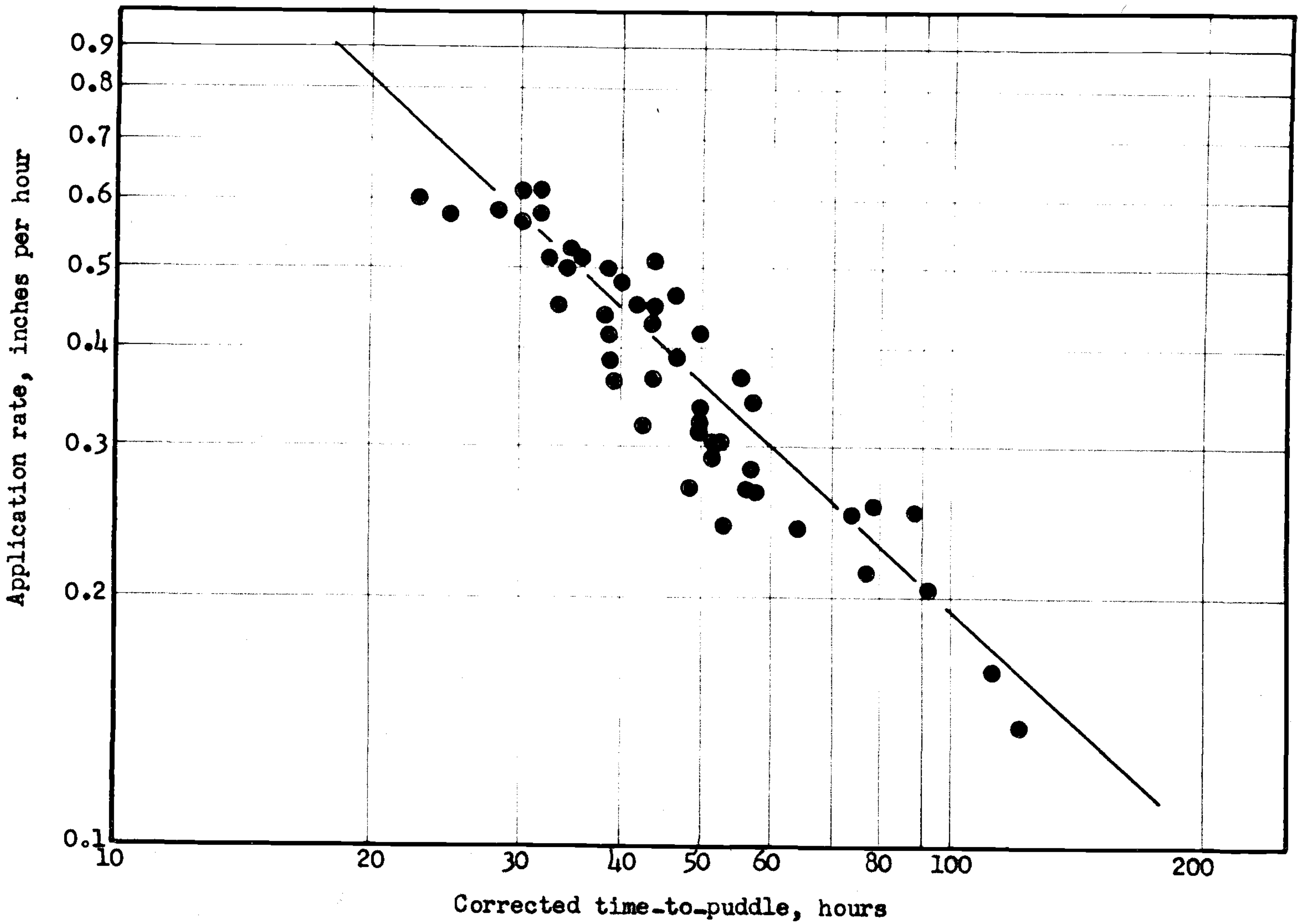

Figure 16. Log corrected time-to-puddle versus log application rate

moisture content is taken into consideration. The correlation coefficient is increased from 0.750 for the uncorrected data to 0.935 for the corrected data. This shows that initial moisture content affects time-to-puddle.

This fact was also observed last summer. Field test no. 10 was run when the soil moisture content was extremely low. Puddling did not occur on the plot until the irrigation set was about to be turned off after 12 hours. The area showed only slight puddling at the end of the application.

It was also noticed on the dairy farm that when the frequency of irrigation was high (meaning that moisture content is kept at a high level) puddling occurred from 4 to 6 hours after the start of irrigation at application rates of 0.33 inches per hour.

When time-to-puddle is corrected for initial moisture content, the two equations are as follows:

$$T = \frac{\text{const.}}{A^{0.968}} \qquad (13)$$

and

$$A = \frac{\text{const.}}{T^{0.903}} \qquad (14)$$

where

T = corrected time-to-puddle

A = application rate.

Again each equation gives the smallest variation in each regression analysis.

Kostiakov's equation,

$$I = \text{const. } t^{a-1} \qquad (15)$$

chosen because it is of the same form as the obtained regression equation and because it represents the infiltration process moderately well, can be made to look like equations (11) and (14) by letting a = 0.264 and 0.097 respectively. Since equation 14 fits the regression line with the smallest variation, it shall be used in the following analysis.

The obtained regression equation

$$A = \frac{\text{const.}}{T^{0.903}} \qquad (16)$$

and Kostiakov's equation with "a" chosen as 0.097

$$I = \frac{\text{const.}}{t^{0.903}} \qquad (17)$$

are seen to be very similar. Since the two equations are very similar, one can say that the corrected time-to-puddle versus application rate curve is representative of the infiltration process.

The following procedure is suggested as a possible way for obtaining an infiltration curve for clay soils in the Willamette Valley, such as Dayton, Willamette and Amity soil series.

1. Find initial moisture content of soil.

2. Set out collection cans in a definite grid

pattern around sprinklers.

3. Use one or more sprinklers and apply water with a Rainbird no. 30 at about 45 pounds per square inch. Apply water until it is observed standing on the soil surface at increasing distances away from sprinklers. Note the time-to-puddle at two or more grid points located where application rates are different.
4. Corrected time-to-puddle may be found by dividing initial moisture content (inches) by the application rate (inches per hour) at each grid point, and then adding the quotient (hours) to observed time-to-puddle (hours) at that grid point.
5. Plot two or more points on log-log graph paper and draw a straight line through the points.
6. Obtain an equation from the line.
7. By using constant values (obtain from curve in this thesis) calculate infiltration curve for the soil being tested.

Discussion

The area obtained by multiplying the ordinate by the abscissa, at various application rates corresponding to points on the lower envelope curve in Figure 13, is the amount of water in inches that may be put on the field without any puddling. Using the bottom-envelope curve, one can adhere to the "no runoff" principle in design of sprinkler irrigation systems. It should also be noticed that when adhering to the "no runoff" principle more water can be infiltrated into soil by using lower, rather than higher, application rates as shown in Table 1. Table 1 values are calculated from the envelope curve in Figure 13.

Table 1

Application rate, inches per hour	Amount of water taken into soil before puddling occurs, inches
0.05	2.25
0.10	2.25
0.20	2.20
0.30	1.20
0.40	1.20
0.50	1.00

Time-to-puddle can also be defined as shown in Figure 17 in which total accumulated water in inches is plotted against time. An ordinate of curve 1 at any time is the area under the infiltration rate versus time curve at that same time. The ordinate of curve 2 at any time is the area under the application rate versus time curve at that time. When the accumulated application becomes greater than the accumulated infiltration, water will start standing on the soil surface and puddling will occur. When the curves in Figure 17 were drawn, it was assumed that surface sealing does not restrict the infiltration of water into the soil. Therefore the limiting physical factor is the percolation capacity of the soil.

However, if it were true that surface sealing does restrict the infiltration of water into the soil, then the ordinates of curve 1 would be decreased. This would mean that curves 1 and 2 would cross each other at a point to the left of point 0. It is most probable that different rates cause different decreases in time-to-puddle (18, p. 157). Higher rates would more greatly decrease time-to-puddle due to their more destructive effect on the soil surface; whereas lower rates would have less of an effect on surface breakdown. It should be noted that the accumulated infiltration and application curves have equal ordinates where they cross (Point 0.). Since the ordinates of the accumulated curves are equal and quantitatively represent the areas under the rate curves, then the areas under the rate curves must be equal. This fact gives point A in Figure 18.

Point A is obtained due to the fact that the complete infiltration capacity is not being utilized when water is first applied; therefore the soil still

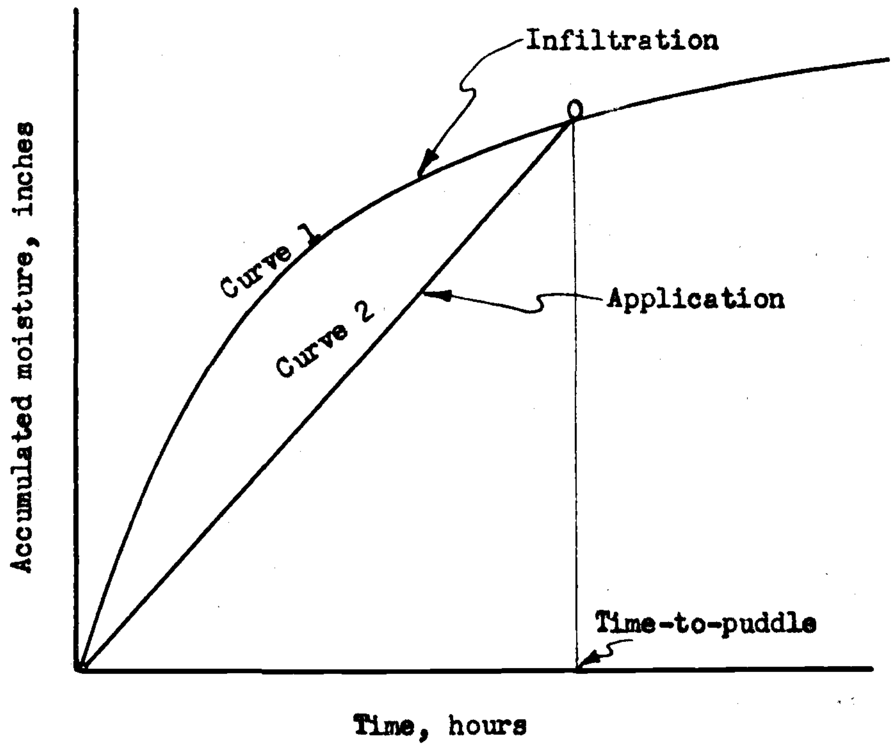

Figure 17. Second definition of time-to-puddle

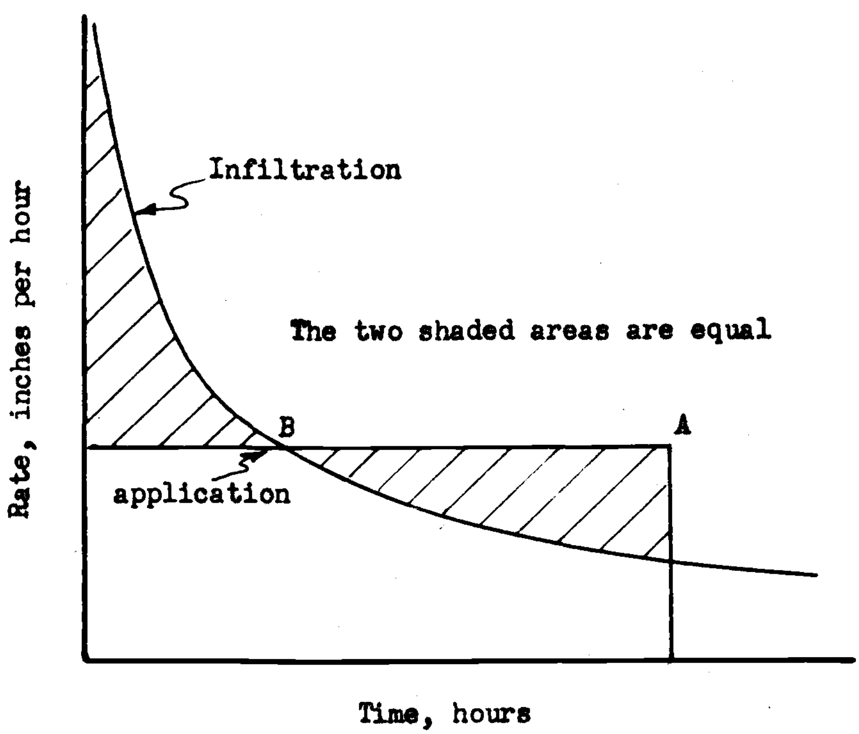

Figure 18. Application rate and infiltration rate versus time

has potential for infiltration remaining during the later stages of application. As previously noted, A is also the point where puddling would occur if the percolation capacity of the soil is the limiting physical factor.

As surface sealing becomes more of a factor it would appear that time-to-puddle will move from point A towards point B. It is reasoned that the points obtained from the application rate versus corrected time-to-puddle curve will fall somewhere in between A and B, depending upon the proportions of the two controlling factors.

It should be noted that the slope of the application rate versus corrected time-to-puddle curve (Figure 15) is nearly minus 1. This means that the area obtained by multiplying the ordinate by the abscissa at any point on the curve has the same value. Physically this means that the amount of water that is in the soil (initial moisture plus amount infiltrated into the soil from sprinkler irrigation) is the same when puddling occurs regardless of application rate. This suggests that capacity of the soil to hold water is the governing factor and that either before reaching field capacity surface breakdown does not affect the infiltration process or is constant at the application rates used in the experiment. The obtained data, although relatively complete in the low and middle application rates, are very incomplete at higher rates (above 0.60 inches per hour) and also at time approaching zero.

Plotting soil depth versus moisture content (Figure 19) and referring to Figure 24 in Appendix, one can see that field capacity occurs near a moisture content of 33 percent by weight. Field capacity for these soils is only slightly less than saturation. Using typical bulk densities, this means that at field capacity there is about 6 inches of water in the soil per foot of soil depth. This also means that about 18 inches of water is in the soil per 3 feet of soil depth. The area obtained by multiplying the ordinate by the abscissa at any point on the curve (Figure 16) ranges from 17.5 to 19 inches. Therefore it can be concluded that the top 3 feet of soil is at or near to field capacity when puddling occurs. This observation gives more evidence that puddling occurs when the soil reaches field capacity.

The area above the curve in Figure 19 that represents the unfilled portion of field capacity and therefore available to be filled by sprinkler irrigation is a little more than 4 inches. This plot is an actual soil moisture profile obtained from soil sampling data. It is also very typical of the initial moisture content of all the plots before irrigation. The area obtained by multiplying the ordinate by the abscissa (Figure 13) at any point on the curve is slightly greater than 4 inches. This also

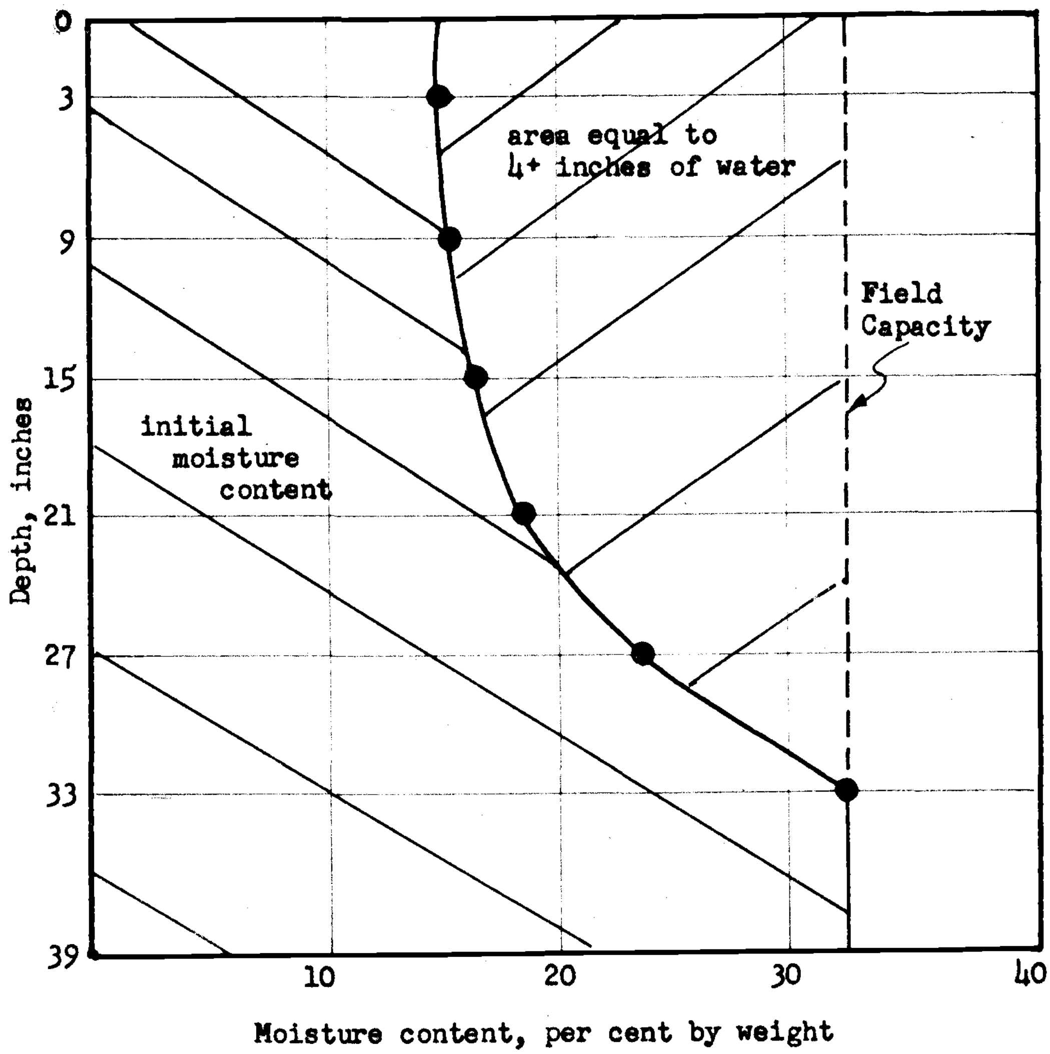

Figure 19. Depth versus moisture content curve

shows that puddling occurs when field capacity has been reached.

This evidence leads one to conclude that puddling occurs when the field capacity of the 3-foot zone has been reached.

A more technical explanation of the observed phenomenon is as follows: as the wetting front moves down in the soil, it reaches soil that is near saturation or at least field capacity. The pressure gradient drops from a high value of tension (1 to 5 atmospheres) to a very low value of tension (0.1 atmosphere) as the front reaches the zone of saturation. This means that there is a sharp drop in the magnitude of the hydraulic gradient. This sharp decrease in the hydraulic gradient causes a sharp decline in the soil infiltration rate. The infiltration becomes much less than the rate at which water is being applied and water starts to pond on the surface and puddling occurs.

Soil-water puddling, translocation and irrigation efficiency

Three experiments were carried out during the summer of 1959. An attempt was made to compare the water caught in each collecting can from sprinkler irrigation with which showed up as soil moisture increase due to irrigation at each grid point in prepared plot no. 5. The proposed hypothesis was that water moves away from grid points receiving the highest application rate to grid points receiving the lowest application rate. Elevations were obtained at each of the grid points on the plot, and contours interpolated. Six "high" points and six "low" points were selected, based on the shape of the contours. It was desired to determine if the assumption that high points lost water and low points gained water was valid. Data from the first experiment (Field Test no. 1) are in Table 2.

The majority of the low points did gain water as expected, but the gain made by the majority of high points was very unexpected. This fact gave reason to wonder whether elevation did control surface water runoff or whether the elevation differential was significant. This fact also led to the idea of precise grading of an experimental plot to further study surface water movement. Plot no. 7 was the result of such thinking and is described on page 19.

The data from the one experiment on plot no. 7 are shown in Table 3. The columns of data are oriented in the same manner as the plot is laid out.

The plot is set up in such a manner that an analysis of variance (randomized block) can be performed on the data obtained. The analysis performed on the columns

Table 2

"High" Points versus "Low" Points

From Field Test No. 1

Grid no.	Application Rate, inches per hour	Moisture Difference, inches
"High" points		
19	0.1173	-0.235
27	0.2690	1.045
32	0.4320	0.429
38	0.2437	0.420
42	0.2490	0.255
48	0.0597	-0.029
"Low" points		
14	0.0297	0.363
23	0.2668	-0.110
24	0.2500	1.545
25	0.2980	0.617
34	0.1876	0.714
47	0.0557	0.677

Table 3
Results from Plot No. 7

Row 1	Row 2	Row 3	Row 4	Row 5	
0.857	0.550	0.546	0.570	0.602	
-0.559	0.730	1.029	0.344	0.270	Column 3
-1.416	0.180	0.483	-0.226	-0.332	
1.886	1.570	1.996	1.479	1.593	
1.748	2.109	1.880	1.803	1.457	Column 4
-0.138	0.539	-0.116	0.324	-0.136	
3.056	3.144	3.084	2.596	2.872	
3.545	2.091	3.163	2.506	3.102	Column 5
0.489	-1.051	0.079	-0.090	0.230	
3.859	3.939	3.526	3.087	4.027	
4.009	3.069	4.030	4.713	3.375	Column 6
0.150	-0.870	0.506	1.626	-0.652	
7.379	3.774	3.485	3.219	6.931	
3.518	4.086	3.099	3.888	2.771	Column 7
-3.865	0.312	-0.386	0.669	-4.160	
3.686	3.625	3.431	3.100	3.194	
3.784	2.949	2.858	3.347	3.089	Column 8
0.098	-0.676	-0.573	0.247	-0.105	
3.113	2.938	3.035	2.892	2.898	
3.491	2.806	4.187	2.874	3.294	Column 9
0.378	-0.132	1.152	-0.018	0.394	
1.793	2.291	1.904	2.188	1.717	
2.461	2.505	3.086	2.502	2.408	Column 10
0.668	0.214	1.186	0.314	0.691	
0.756	0.700	0.622	0.837	0.634	
2.449	0.784	0.487	0.771	0.834	Column 11
1.693	0.084	-0.135	-0.066	0.200	

Top number--water caught in can
Middle number--soil moisture increase
Bottom number--moisture difference

(water caught in cans, soil moisture increase and moisture difference) showed that the population means were different due to the decreasing application rate as one moves away from the sprinkler lateral. The row analysis showed that the population means of the soil moisture increase and moisture differences were not different. The population means of the water caught in cans were different on the 2.5% level. It appeared that errors were in measurement of water caught in cans or that one or more of the sprinklers were not working properly.

Per amount of water applied, the ridge had a greater soil moisture increase than did the swale. A t-test performed on data from the region of puddling in the swale versus the corresponding region on the ridge indicated a significant difference in favor of the ridge at the 2.5% level.

This result was contrary to the proposed hypothesis that extra water would be absorbed in the low places. After much deliberation, it was concluded that the infiltration capacity of the soil surface was different in the swale and on the ridge. The swale was a cut and the ridge was a fill which suggests that the soil surface in the cut has a less permeable surface than does the ridge. The water that ran down into the cut probably moved on down the swale toward the lower end of the plot.

Puddled versus non-puddled points

All puddled points from data of summer, 1960 for a constant duration of sprinkler irrigation (Rainbird no. 30 with 12 hours duration) were grouped together. Non-puddled points were chosen far enough away so that the puddled points would not affect them. About an equal number of points of both groups were obtained. The data for both groups of points are given in Tables 8 and 9 in the Appendix. The points are plotted in Figure 20 for comparison and examination. From Figure 20 one finds that puddling begins at 0.2 inches per hour, that half of the field becomes puddled at 0.22 inches per hour, and that at 0.48 inches per hour the whole field is puddled after 12 hours. The sharp upturn of the curve shows that there is an application rate near 0.2 inches per hour above which puddling effect is almost immediate; therefore in designing a "no runoff" situation, application rate should be kept below 0.20 inches per hour for a 12-hour set. This recommendation is for soils that have similar characteristics as those soils on the Dairy Farm. A description of these soils is given in Table 7 and Figure 24 in the Appendix.

By plotting percentage of total observations against

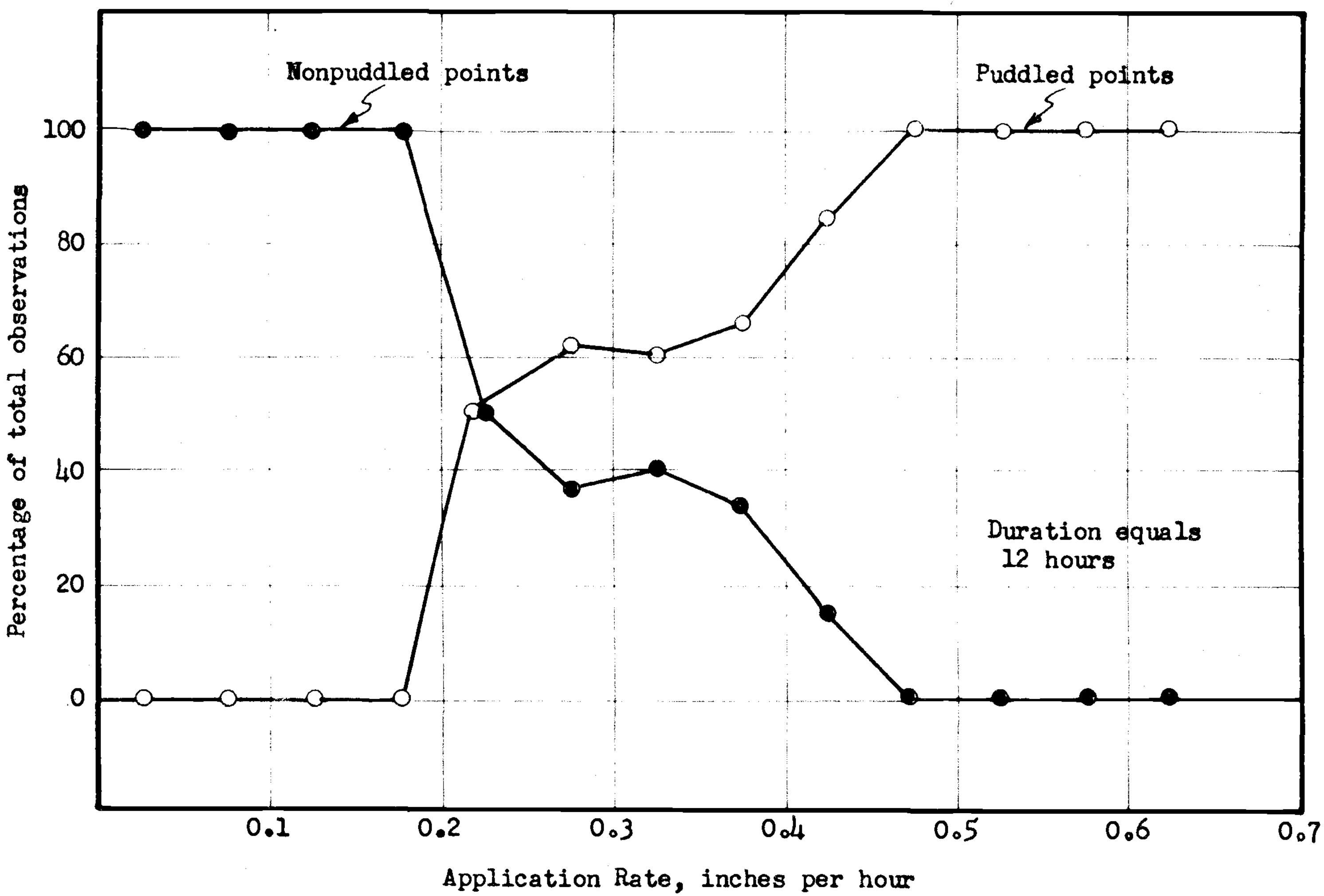

Figure 20. Percentage of total observation versus application rate

moisture difference (soil moisture increase minus water caught in can) in Figure 21, one can see the general trend is similar to Figure 20. Figure 21 has a long transition zone showing that some of the puddled points have positive moisture differences.

A t-test was run on the moisture differences (soil moisture increase minus water caught in cans) in the two groups (previously described) and showed that the population means were significantly different. Taking the t-test results and looking at Figure 21, one can see that non-puddled points show more positive moisture differences than puddled points, proving that some water moves from the puddled to the non-puddled points.

Combining the puddled points from Figures 20 and 21 by plotting application rate versus moisture difference (Figure 22), a relationship can be seen between the two variables. A regression analysis shows that the correlation is significant at the 0.5 percent level.

This would suggest that puddling helps distribute applied water by sprinkler evenly. Where a high application rate occurs, this water translocates to areas of low application rate. For example: 6 inches of water is applied with the moisture difference of -2 inches at that rate; meaning a soil moisture increase of only 4 inches. Elsewhere 2 inches of water is applied

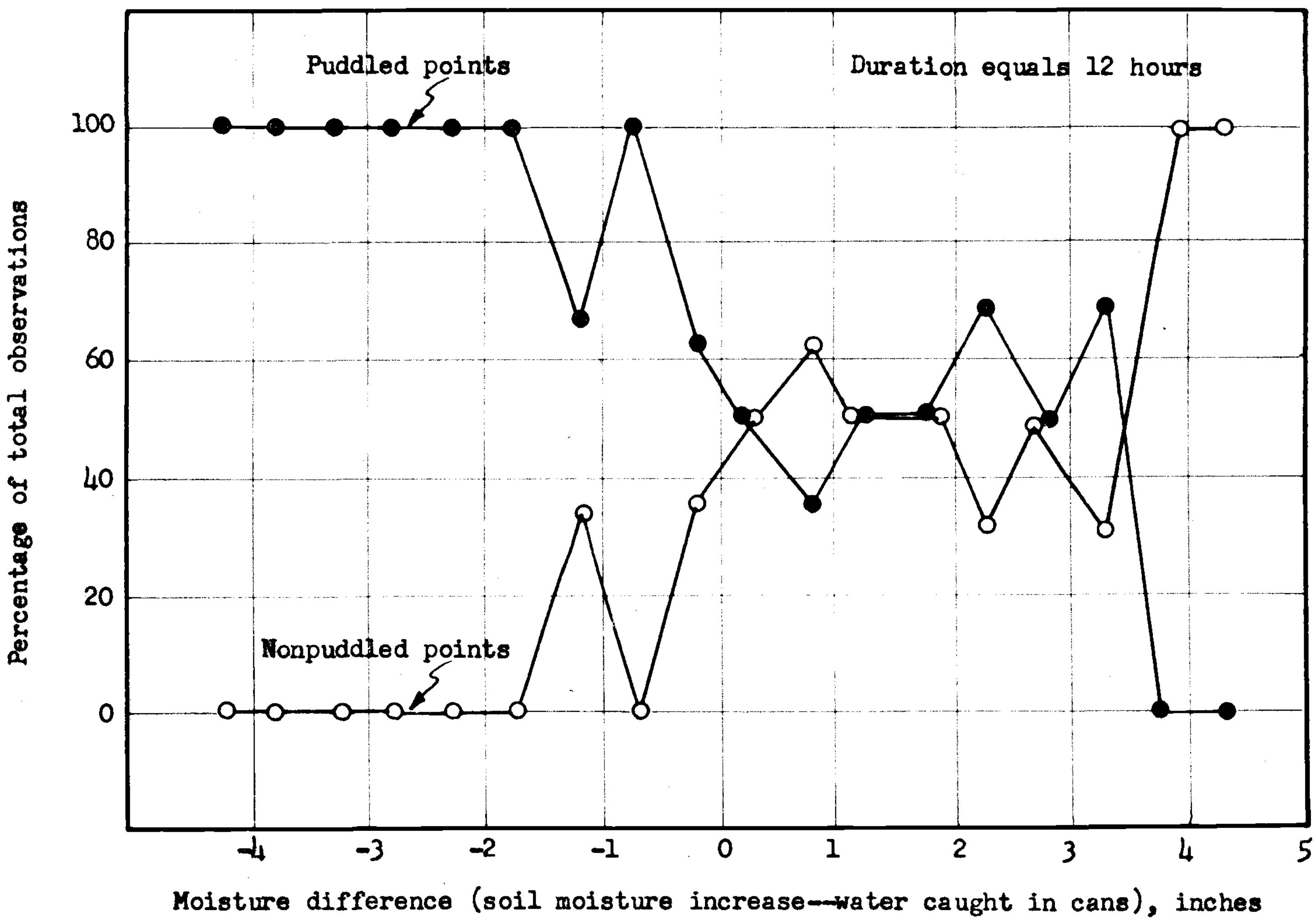

Figure 21. Percentage of total observations versus moisture difference

with moisture difference at that rate being 2; meaning a soil moisture increase of 4 inches. In other words, 2 inches of water moves from one point to the other. This suggests that there are three kinds of points:

1. Those of negative difference
2. Those of zero difference
3. Those of positive difference.

Negative points occur near the sprinkler where high application rates occur and positive points further out. Water moves toward the second grouping. In the second group of points, the application rate is an average of the two extremes. Here it is thought that water moves away from this point to regions of lower application rates and also moves toward it from the zone of high application rates; thereby giving a difference of zero or else no movement occurs at all.

Slope of the ground surface affects the difference at grid points. Application rate will exceed intake rate at certain points on a steep slope and all water will run off, leaving a large negative difference. Points on level ground when puddling occurs will probably show zero difference due to no chance of runoff. Points where puddling occurs and to which water runs should show increase. Water will gradually infiltrate into the ground if left standing at a point, even if puddling has occurred.

It is believed that the only reason for positive differences is that excessive rates produce negative differences. To get a positive difference, one must have runoff from another part of the plot or field. Runoff comes when application rate exceeds intake rate. It is also believed that puddling is caused by either of two different situations; when application rate exceeds intake rate and when runon plus application rate exceeds intake rate.

From the data obtained, one finds that puddling starts at 0.20 inches per hour for a 12-hour set. As the application rate is increased, more of the field becomes puddled. No conclusion can be drawn from the points in Figure 22 as far as an optimum application rate is concerned. All points are probably interdependent. Application rate at zero moisture difference is exactly the average of all application rates plotted in Figure 22; therefore the rate at zero difference has little significance. But the data shows that negative moisture differences, on the average are not found until the application rate reaches a rate of 0.415 inches per hour. This was obtained by regression analysis. This raises a question: does one obtain negative moisture differences if, and only if, the maximum application rate is greater

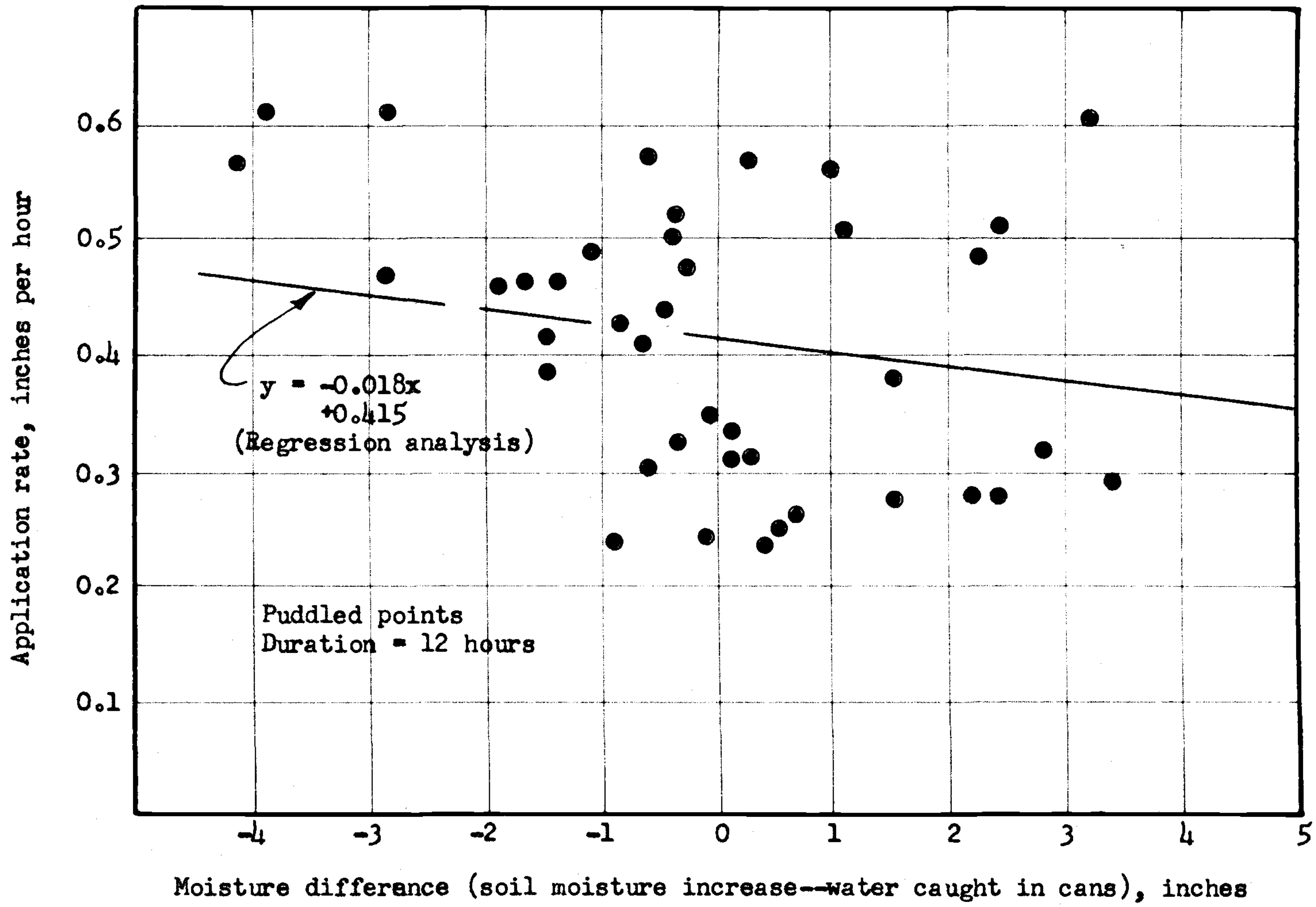

Figure 22. Application rate versus moisture difference

than 0.415 inches per hour? By plotting application rate versus moisture difference for non-puddled points in Figure 23, it is found that 30 out of 32 points are grouped around a moisture difference of zero or greater. It should be noticed that the application rates range up to 0.36 inches per hour. This brings up another question: does one obtain only positive moisture differences if the application is kept under 0.36 inches per hour? Only experimental tests for these rates will be able to answer the questions posed.

At very low application rates, the points of application rate-moisture difference curve (Figure 22) should form a vertical line close to zero moisture difference since no water movement occurs. As the application rates are increased, the points should slowly move counterclockwise to form a horizontal line at extremely high rates. This line becomes horizontal due to water movement as described previously.

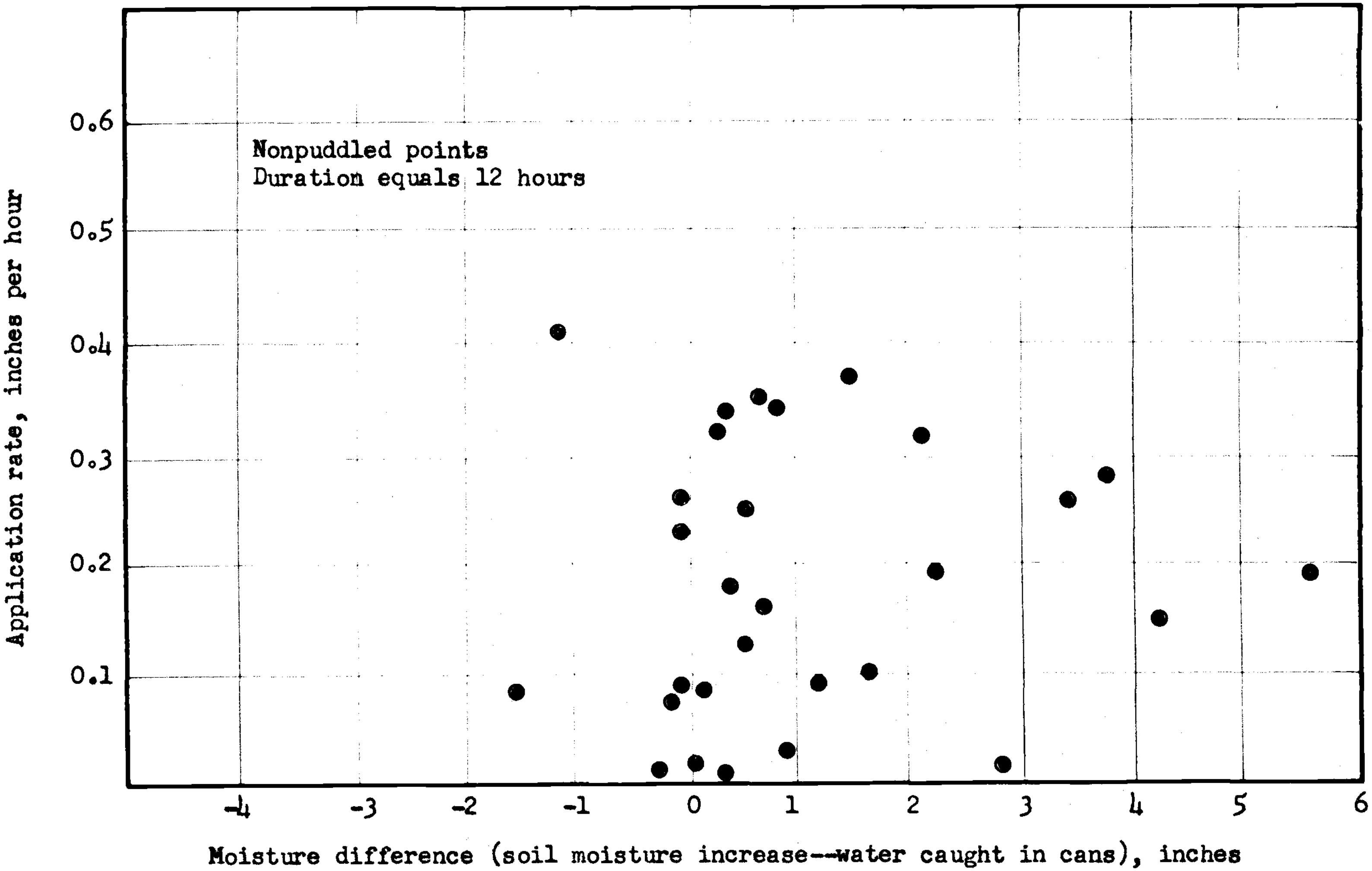

Figure 23. Application rate versus moisture difference

SUMMARY

Experiments were run to determine the relationship between puddling and optimum application rate. It was found that the time-to-puddle (corrected for initial moisture content) versus application rate curve is representative of the infiltration process. A procedure for obtaining an infiltration curve for clay soils in the Willamette Valley has been set forth.

It was found that soil-water puddling began at rates of 0.2 inches per hour for a 12 hour irrigation set. Although puddling began at 0.2 inches per hour, there is evidence that moisture differences did not become negative until application rates of 0.3 to 0.4 inches per hour were reached. This suggests that some puddling may not be detrimental to irrigation efficiency.

It was found that water moves from points of excessive application rates to points of lower application rates. This gives the positive and negative moisture differences as the data showed. It is thought that water movement will diminish entirely when the application is below a certain value depending on length of irrigation set.

Since the results of this thesis were obtained only from established pasture sites on lakebed soils in the Willamette Valley, it can not be assumed that the conclusions apply to other conditions.

RECOMMENDATIONS FOR FURTHER STUDY

The proposed procedure for obtaining an infiltration curve should be carefully checked. Data can be obtained and the procedure followed as suggested in this thesis. Initial moisture content should be carefully measured since it is an important variable in the infiltration process. Higher application rates should be used to find the effect of these higher rates on soil surface breakdown.

Depth of water penetration into the soil at time-to-puddle could be measured by a neutron scattering instrument. Depth of water penetration may be some function of total water applied plus initial moisture content. It should be investigated to find if at time-to-puddle the wetting front has always penetrated to the same depth regardless of application rate.

By using the neutron scattering instrument one may be able to find at what rate the wetting front advances when water is applied at varying application rates. By varying application rates one could tell the rate at which water movement first occurs. The rate at which water movement first occurs should be the optimum rate.

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APPENDIX

Table 4

Test of Cans of Different Diameters

Group	Can Diameter inches	Water depth, inches		
		Test no. 1	Test no. 2	Test no. 3
1	2 (no. 2)	0.826	0.995	1.111
	2 (no. 3)*	0.832	0.954	1.065
	4	0.776	0.900	0.994
	6	0.800	0.952	1.045
2	2 (no. 4)	1.095	1.082	1.283
	2 (no. 5)*	1.131	1.081	1.265
	4	1.115	1.117	1.304
	6	1.145	1.129	1.318
3	2 (no. 6)	0.799	1.000	0.932
	2 (no. 7)*	0.791	0.974	0.881
	4	0.807	0.994	0.908
	6	0.798	0.974	0.900
4	2 (no. 1)	0.768	0.873	0.887
	2 (no. 8)*	--	0.862	0.874
	4	0.715	0.808	0.843
	6	0.752	0.856	0.874
	plastic rain gage	0.750	0.850	0.878

* Cans no. 3, no. 5, no. 7, and no. 8 were filled about half full of diesel oil during each test.

Note: An analysis-of-variance test showed that the size of the cans does not make any difference in the amount of water per area caught in cans.

Table 5

Collecting Cans

No.	Area, $in.^2$	No.	Area, $in.^2$
1	2.795	36	2.810
2	2.888	37	2.807
3	2.804	38	2.822
4	2.822	39	2.834
5	2.804	40	2.825
6	2.819	41	2.804
7	2.795	42	2.807
8	2.804	43	2.810
9	2.804	44	2.819
10	2.816	45	2.822
11	2.813	46	2.807
12	2.924	47	2.816
13	2.813	48	2.810
14	2.804	49	2.819
15	2.819	50	2.816
16	2.804	51	2.819
17	2.834	52	2.810
18	2.816	53	2.828
19	2.801	54	2.831
20	2.828	55	2.819
21	2.825	56	2.933
22	2.813	57	2.831
23	2.819	58	2.828
24	2.813	59	2.828
25	2.810	60	2.819
26	2.819	61	2.970
27	2.807	62	2.867
28	2.795	63	2.855
29	2.810	64	2.840
30	2.927	65	2.810
31	2.828	66	2.810
32	2.807	67	2.810
33	2.807	68	2.807
34	2.822	69	2.849
35	2.825	70	2.873
		71	2.810

Table 6

Variation in Soil Moisture Determination

	Moisture, percent					
Depth	3	9	15	21	27	33
Hole						
1	19.21	22.96	25.55	25.62	26.25	31.58
2	20.59	21.34	24.58	25.33	25.75	27.70
3	19.28	22.26	24.29	25.09	26.97	26.56
4	21.52	23.27	24.60	25.25	26.70	29.25
5	21.38	24.60	25.43	25.81	27.79	31.38
6	21.81	23.48	25.56	25.14	26.08	30.36
7	20.86	24.09	24.70	23.90	27.04	28.16
8	30.60	24.06	23.84	25.45	24.82	24.71
9	17.16	23.61	23.42	24.90	25.61	26.76
LSD*	±2.9633	±.7911	±.5946	±.4328	±.7043	±1.8428

* Least Significant Difference

Table 7

Bulk Densities

Depth	Plot no. 1	Plot no. 4	Prepared Plot no. 5	Plot no. 7
3 in.	1.305	1.236	1.336	1.158
9 in.	1.341	1.368	1.385	1.317
15 in.	1.435	1.433	1.447	1.373
21 in.	1.416	1.431	1.484	1.483
27 in.	1.300	1.405	1.479	1.506
33 in.	1.273	1.390	1.504	1.548
39 in.				1.570

Field no. 5

Depth	Selected Plot no. 1	Selected Plot no. 2	Selected Plot no. 3	Selected Plot no. 4
3 in.	1.280	1.290	1.250	1.260
9 in.	1.290	1.350	1.320	1.280
15 in.	1.320	1.430	1.440	1.400
21 in.		1.360	1.410	1.460
27 in.	1.370	1.380	1.410	1.530
33 in.	1.360	1.350	1.390	1.540

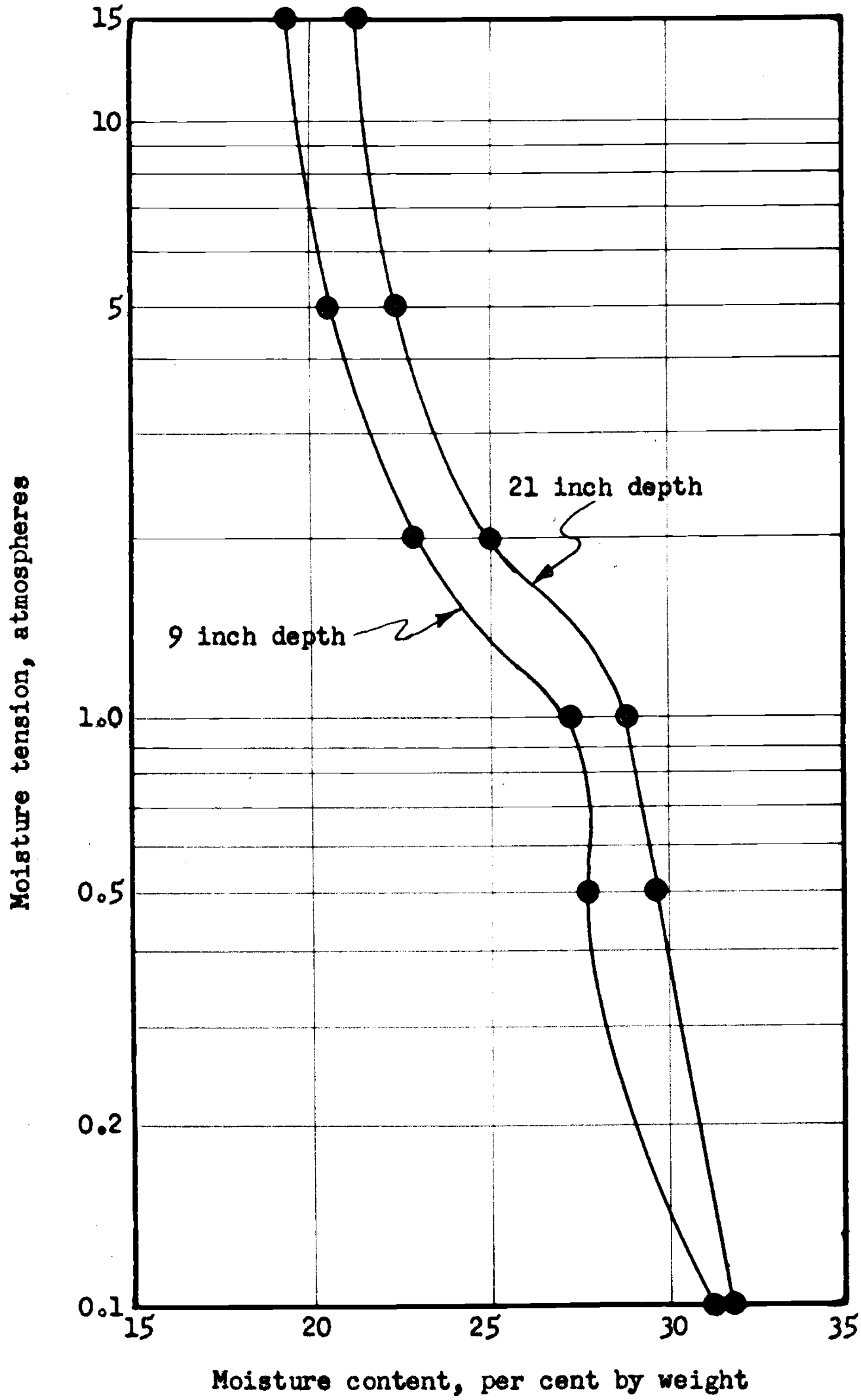

Figure 24. Moisture tension curves for soils in Dairy no. 5

Table 8

Grid Points At Which Puddling Occurred

Field Test no.	Grid no.	Time to Puddle, hours	Corrected Time to Puddle, hours	Application Rate, inches per hour	Caught in Cans, inches	Soil Moisture Increase -Water Caught in Cans, inches	Soil Moisture Increase, inches	Total Water in Soil Until Time To Puddle, inches
6	17	35	110.03	0.163	7.832	-3.088	4.744	17.935
6	20	31	118.18	0.140	6.717	-2.137	4.580	16.540
7	31	7	22.80	0.602	7.368	3.229	10.597	13.724
7	32	12.25	42.12	0.320	3.953	2.821	6.774	13.480
7	33	12.25	56.28	0.270	3.317	1.510	4.827	15.198
7	34	12.25	39.36	0.367	4.493	6.716	11.209	14.45
7	35	12.25	38.21	0.387	4.740	1.512	6.252	14.79
	Blocks							
8	14, 15 18, 19	21.25	78.63	0.214	5.78	-1.278	4.502	16.82
8	15, 16 17, 18	22.5	57.11	0.342	9.22	-3.727	5.593	19.71
8	17, 18 23, 24	22.5	55.23	0.365	9.84	-3.517	6.323	20.16
8	26, 27 21, 22	27	92.44	0.202	5.46	1.766	3.694	18.67

Table 8

Grid Points At Which Puddling Occurred

Field Test no.	Grid no.	Time to Puddle, hours	Corrected Time to Puddle, hours	Application Rate, inches per hour	Caught in Cans, inches	Soil Moisture Increase -Water Caught in Cans, inches	Soil Soil Moisture Increase, inches	Total Water in Soil Until Time To Puddle, inches
9	21	4.5	79.18	0.258	3.085	2.426	5.434	20.43
9	22	4.5	89.90	0.259	3.103	0.526	3.667	23.29
9	23	4.5	75.47	0.252	3.020	-0.939	2.081	20.78
9	24	4.5	46.41	0.459	3.121	-2.881	0.240	21.31
9	25	4.5	56.93	0.283	3.400	2.186	5.586	16.11
9	26	3.5	34.69	0.493	5.922	-1.074	4.848	17.11
9	27	3.5	43.69	0.501	6.012	1.007	7.019	21.89
9	28	3.5	38.04	0.493	5.903	2.245	8.148	18.76
9	29	3.5	39.99	0.476	5.711	-0.313	5.398	19.04
9	30	3.5	43.79	0.446	5.352	-1.889	3.463	19.53
9	31	3.5	41.47	0.446	5.036	-1.338	2.698	18.47
9	32	3.5	34.75	0.525	6.294	-0.346	5.948	18.25
9	33	3.5	30.22	0.620	7.439	-2.616	4.823	18.74
9	34	3.5	31.63	0.575	7.900	0.258	7.158	18.19
9	35	3.5	43.42	0.424	5.070	-0.892	4.178	18.41
9	36	4.5	49.41	0.340	4.087	0.041	4.128	16.80
9	37	4.5	35.44	0.510	5.118	2.479	7.597	18.08
9	38	4.5	30.40	0.564	5.762	0.991	7.753	17.17
9	39	4.5	49.76	0.414	4.965	-0.775	4.190	20.60
9	40	4.5	51.78	0.298	3.572	3.383	6.955	15.43
11	31	8.75	28.33	0.58	6.088	-0.517	5.518	16.44
11	35	8.75	33.17	0.450	6.950	-1.624	5.326	14.93

Table 8

Grid Points At Which Puddling Occurred

Field Test no.	Grid no.	Time to Puddle, hours	Corrected Time to Puddle, hours	Application Rate, inches per hour	Caught in Cans, inches	Soil Moisture Increase -Water Caught in Cans, inches	Soil Soil Moisture Increase, inches	Total Water in Soil Until Time To Puddle, inches
11	36	9.25	38.33	0.414	4.957	-1.521	3.436	15.87
11	37	10.25	37.88	0.435	5.221	-0.502	4.719	16.46
11	38	10.25	46.15	0.386	4.622	-1.543	3.079	17.82
11	40	8.75	32.65	0.507	5.400	-0.393	5.007	16.56
12	27	11.75	49.64	0.328	3.939	-0.330	3.609	16.28
12	31	2	24.63	0.576	6.931	-4.160	2.771	14.19
12	32	11.75	57.94	0.268	3.219	0.669	3.888	15.53
12	34	11.75	49.87	0.314	3.774	0.312	4.086	15.66
12	35	11.75	31.75	0.616	7.379	-3.861	3.518	19.55
12	36	11.75	51.68	0.307	3.686	0.098	3.784	15.87
12	37	11.75	52.67	0.302	3.625	-0.676	2.949	15.91
12	40	9.35	44.02	0.366	3.194	-0.105	3.089	16.11
12	41	11.75	64.32	0.241	2.898	-0.396	3.294	15.50
12	44	11.75	53.69	0.245	2.938	-0.132	2.806	14.92

Table 9

Non-Puddling Points

1 Field Test	2 Grid no.	3 Water Caught in Cans	4 Application Rate, inches per hour	5 Soil Moisture Increase	6 3 - 5
6	5	4.442	0.0925	4.349	-0.093
	9	4.171	0.0871	5.290	1.119
	14	4.324	0.0904	4.364	0.040
7	22	2.335	0.190	4.541	2.206
	26	5.037	0.411	3.965	-1.072
	29	4.200	0.343	10.738	6.538
	37	4.299	0.350	4.850	0.551
	41	3.988	0.326	6.112	2.124
8	8	0.282	0.0108	0.645	0.363
	10	2.072	0.0797	0.570	-1.502
	13	5.330	0.205	5.342	0.012
	30	0.794	0.0303	3.440	2.646
9	16	1.934	0.161	2.515	0.581
	18	1.741	0.145	5.890	4.149
	46	3.303	0.275	6.646	3.343
	49	3.595	0.299	7.440	3.845
	51	2.319	0.193	7.860	5.541
11	14	0.231	0.019	-0.062	-0.293
	18	1.009	0.0845	0.833	-0.176
	22	3.059	0.255	3.522	0.469
	27	4.368	0.364	5.888	1.520
	43	4.116	0.342	4.734	0.618
	48	1.356	0.112	2.976	1.620
	51	0.282	0.023	1.182	0.900
12	14	0.550	0.0456	0.730	0.180
	17	1.570	0.131	2.109	0.539
	21	2.872	0.239	3.105	0.233
	26	3.859	0.321	4.009	0.150
	40	3.194	0.266	3.089	-0.105
	44	2.938	0.245	2.806	-0.132
	49	2.188	0.187	2.502	0.314

Table 10

Data From Summer 1959

Field Test no.	Length of set, hours	Pressure, psi	Wind, mph	Temp., °F	Humidity, per cent	Size of Nozzle, inches	Type of Set	Spacing, feet	C.U.	Application Rate, inches per hour
1	13.3	37.5	4.87	61.9	70.5	3/16 x 3/32	one lateral	40 x 50	74.9	0.281
2	14	45	--	--	--	3/16 x 3/32	one lateral	40 x 50	75.8	0.309
3	7.5	45	--	--	--	3/16 x 3/32	one lateral	40 x 50	76.1	0.301

Note: All data obtained from prepared plot no. 5.

Table 11

Data From Summer 1960

Field Test	Length of Set, Hours	Plot	Measured Evap., %	Evap. Frost's Nomo., %	Pressure, psi	Wind, mph	Temp., °F
1	48	Selected No. 1	12.9	12.5	54	3.7	71.0
2	46.5	Selected No. 2	10.0	11.2	56	3.69	63.9
3	23.3	Selected No. 3	11.67	12.4	56	4.10	64.7
4	48	Selected No. 4	12.8	14.3	54	4.93	68.2
5	48	Selected No. 1	24.2	14.1	52	2.95	79.8
6	48	Selected No. 2	11.4	12.0	51	4.22	71.0
7	12.25	Prepared No. 5	12.4	7.0	40	5.98	81.4
8	26	Selected No. 3	22.1	8.6	55	5.91	69.0
9	12	No. 4	13.5	9.5	55	5.82	79.4
10	12	No. 1	--	3.25	48	1.81	59.3
11	12	Prepared No. 5	2.79	4.2	50	3.23	68.9
12	12	No. 7	20.85	3.98	41	2.25	74.9

Table 11 (continued)

Field Test	Humidity, %	Size of Nozzle, Inches	Type of Set	Spacing, Feet	C. U.	Application Rate, inches per hour
1	59.6	5/64	solid	30 x 40	95.3	0.086
2	62.9	5/64	solid	30 x 40	91.6	0.093
3	59.9	5/64	solid	30 x 40	80.9	0.087
4	54.9	5/64	solid	30 x 40	92.5	0.086
5	56.0	5/64	solid	30 x 40	82.6	0.074
6	59.6	5/64	solid	30 x 40	94.0	0.088
7	42.3	3/16 x 3/32	one lateral	40 x 50	82.6	0.365
8	65.5	1/8	one lateral	30 x 40	93.8	0.231
9	54.6	3/16 x 3/32	one lateral	40 x 50	78.9	0.391
10	68.8	3/16 x 3/32	one lateral	40 x 50	90.96	0.432
11	62.4	3/16 x 3/32	one lateral	40 x 50	90.96	0.422
12	47.8	1/16 x 3/32	one lateral	40 x 60	85.70	0.32