AN ABSTRACT OF THE THESIS OF

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Date thesis is presented May 13, 1965

Title Relationships Between Degree of Ponding and Uniformity of Soil Moisture Distribution Under Irrigation Sprinklers

Redacted for Privacy

Abstract approved (Major professor)

Often low intake rate soils need special consideration when applying water during an irrigation. Surface flooding for extended periods may cause adverse crop growth conditions. Properly designed sprinkler systems often eliminate irrigation problems, because the application rate and quantity of water applied can be readily controlled.

Research workers who have studied sprinkler irrigation disagree on many things. Differences are found in the literature concerning the procedures used to determine sprinkler distribution uniformity and the optimum rate of application of water to the soil. Several authors suggest that moisture movement within the soil occurs after an irrigation. If translocation of moisture occurs, it may be possible to use sprinkler system design specifications that are less critical than those now in use.

In order to determine the effect of sprinkler application rate on the resulting soil moisture distribution it is necessary to have criteria relating degree of ponding, crop cover, and slope of the land to the uniformity of soil moisture. Experimental plots were designed and prepared to study and relate these factors to each other. Sprinkler distribution measurements were made to be used in computing sprinkler uniformity. Using neutron equipment, soil moisture determinations were made before the irrigation, one day after irrigation, and three days after irrigation to determine the effect of the irrigation.

Final analysis of the data from the experiment indicated that there was not an optimum degree of ponding. In fact, ponding, application rate, grade of plots, and crop cover did not appear to appreciably affect the distribution of soil moisture after an irrigation.

RELATIONSHIPS BETWEEN DEGREE OF PONDING AND UNIFORMITY OF SOIL MOISTURE DISTRIBUTION UNDER IRRIGATION SPRINKLERS

by

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A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1965

APPROVED:

Redacted for Privacy

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Date thesis is presented May 13, 1965

Type by Luanne Bayless

ACKNOWLEDGEMENT

Sincere appreciation goes to the Agricultural Engineering Department for the Research Assistantship that made this study possible, to Dr. J. W. Wolfe under whose guidance and direction the experiment developed, and to D. G. Watts who took over while Dr. Wolfe was studying in the Netherlands. Many thanks to Douglas Bennett and Rick Campbell whose long hours in the field helped obtain the necessary data. Appreciation also goes to Dr. Donald Guthrie and Dr. Donald Jensen who helped in the statistical analysis and interpretation of the data. Much gratitude goes to my wife, Barbara, whose patience and understanding helped to make this thesis possible.

I wish to dedicate this thesis to my parents Robert and Stella Dehlinger whose faith, assistance and insistance kept me in school during the early months of my college career.

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INTRODUCTION

In many areas irrigated soils having a low water intake rate present special problems. Using surface irrigation, water must stand on the soil for hours and in some cases days before the soil moisture can be raised to field capacity. Ponding for extended pe-iods often causes adverse crop growth conditions.

Sprinklers are sometimes utilized where surface irrigation is impractical, because the application rate and quantity of water applied can usually be more easily controlled. An application rate that is greater than the intake rate will cause ponding, runoff, and on sloping lands, erosion. The application rate should be high enough to allow completion of the irrigation in a reasonable length of time, yet it must be low enough so that appreciable runoff does not occur. A slower rate of applying water to the soil may keep runoff from being excessive. A low application rate may even eliminate runoff.

Research workers who have studied sprinkler irrigation disagree on the application rate to use. Many feel that water should be left standing on the soil surface at the end of an irrigation. Others suggest that application rates well below the intake rate of the soil are better.

For many crops soil moisture uniformity should be kept high. With a uniform soil moisture distribution there is a greater probability that all the plants will develop uniformly, resulting in a higher quality, more marketable product. It has been suggested that sprinkler distribution uniformity is a measure of the uniformity of soil moisture distribution. If translocation of moisture occurs after an irrigation, a sprinkler distribution uniformity below specifications now used might give an acceptable soil moisture distribution uniformity. If this is true, the uniformity factor in the design of sprinkler systems may not be as critical as is now supposed. In many areas a lower allowable sprinkler distribution uniformity would mean less expense in purchasing and operating a sprinkler system.

Additional criteria relating soil moisture and application rate are needed. The objectives of this thesis are:

1. Determine the optimum degree of ponding.
2. Determine the effect of degree of ponding on the resulting soil moisture distribution.
3. Relate degree of ponding, initial moisture content, degree of crop cover, and slope of ground to the final distribution of soil moisture.

LITERATURE REVIEW

Many authors have given consideration to sprinkler irrigation system design. One of the factors which has received careful study is application rate and its effect on soil moisture uniformity. Stippler feels that important factors in determining proper application rates are soil slope and ground cover (17, p. 22).

Several methods of measuring soil intake rate have been suggested for determining safe sprinkler application rates. For this project, Tovey's method was deemed most adaptable (19, p. 109). He has designed a portable single sprinkler that applies water to a strip of soil through a wide range of application rates. The soil is first brought to field capacity with a soaker hose. Then catch cans are set out on a pre-determined grid where the sprinkler is to be operated. The maximum recommended application rate occurs when the water applied to the area just disappears before the sprinkler completes a revolution. Most authors feel that a properly designed sprinkler system should not cause water to stand on the surface of the soil.

Schwalen and Frost feel that the maximum rate at which water should be applied to a soil is dependant upon and should not exceed the infiltration rate of the soil (16, p. 16). According to Langa and Davis, the primary function of sprinklers in an irrigation system is to distribute water uniformly over the design area at a rate equal to or less than the intake rate of the soil (12, p. 497). Water should not be standing on the surface of the soil after the sprinklers have been shut off, nor should runoff occur during the normal operation period, according to Quackenbush (15, p. 272).

Other authors feel that application rates well below the intake rate of the soil are better. According to Gray, application rates as low as .04 inch per hour on soils have actually improved the soil structure. He attributes the soil structure improvements to less soil disturbance and soil pore clogging from fast water entry and a better air-water ratio (7, p. 1). In some cases Gray feels soil compaction due to irrigation has been eliminated (6, p. 20). Keller has shown that there is a critical application rate above which soils start to compact. These rates appear to be below 0.2 inches per hour for some soils (11, p. 18).

Pair feels that it is possible to allow five to ten percent of the area irrigated to be ponded by the end of an irrigation. He suggests that ponding occurs when the application rate of the water exceeds the intake rate of the soil (14, p. 119). The length of time for ponding to first appear is dependent on sprinkler application rates and initial soil moisture content according to Vongsuri (22, p. 33).

Veihmeyer suggests that after an irrigation, water moves downward and sideways for a period of two to three days (21, p. 4). Lateral translocation of soil moisture continues after irrigation ceases, according to Vongsuri. The lateral translocation becomes negligible by the third day after an irrigation, because the soil moisture approaches an equilibrium (22, p. 44). Berney found that water moved from points of high application rates to points of lower application rates (2, p. 56).

In limited testing Vongsuri found the uniformity of total moisture in the profile lower one day after an irrigation than before the irrigation (22, p. 47). However, by the third day the uniformity of the moisture in the profile was higher than before the irrigation (22, p. 43). He found the uniformity of water application was usually higher than the uniformity of soil moisture increase (22, p. 47). He also feels that water can be applied at a relatively low uniformity because moisture movement in the soil increases the final uniformity of distribution (22, p. 46).

Several methods have been developed to give a measure of the uniformity of application from sprinklers. Christiansen uses the coefficient of uniformity to determine an index of the uniformity obtained. The coefficient is expressed as a percentage and the equation takes the form:

$$C_u = 100 \left(1.0 - \frac{x}{mn}\right).$$

Where

x is the absolute deviation of individual observations from the mean,

m is the mean,

n is the number of observations (4, p. 94).

Another method suggested by Wilcox and Swailes has been used to measure the uniformity of sprinkler distribution. Their uniformity coefficient U is defined by the equation:

$$U = 100\ (1. - \frac{s}{x}).$$

Where,

s is the standard deviation, and

x is the general mean of the readings (23, p. 570).

A different coefficient has been devised by Benami and Hore. The equation of this coefficient is,

$$A = C_1/C_2.$$

Expanding the coefficient they give,

$$C_1 = M_b - \frac{X_b}{N_b}$$

and

$$C_2 = M_a + \frac{X_a}{N_a}.$$

Where,

M_a is the mean of the group of the readings above the general mean,

M_b is the mean of the group of the readings below the general mean,

N_a is the number of readings above the general mean,

N_b is the number of readings below the general mean,

X_a is the absolute deviation from M_a of the individual readings,

X_b is the absolute deviation from M_b of the individual readings (1, p. 157).

These coefficients have been developed to be used in conjunction with catch can measurements.

Pair suggests a measure of the distribution uniformity of a sprinkler system is the slope of the line of depth of application versus percent of area covered, where a uniform distribution between lateral sets would give a horizontal line (14, p. 123). It seems that he is suggesting that water accumulation pattern data be used to give a measure of the uniformity of soil moisture.

If one were to use sprinkler application uniformity to represent the uniformity of soil moisture distribution it would be necessary to assume that all moisture is absorbed where it falls, that no lateral translocation occurs and that soil moisture was uniform before the irrigation. These assumptions are not realistic if translocation of moisture occurs after an irrigation as suggested by Veihmeyer (21. p. 4) and Vongsuri (22, p. 46). Another consideration is the probability that not all moisture will be absorbed where it falls, because runoff will occur. There is no guarantee that the moisture remaining in the soil before the irrigation will be uniform.

The problem then becomes what is the relationship between the moisture caught in the soil and catch in can with respect to degree of ponding and time, when the soil slope and ground cover are considered. It is necessary to find what degree of ponding, if any, will give maximum uniformity of soil moisture distribution, on the third day after an irrigation. By relating catch in can data and degree of ponding to uniformity of soil moisture distribution, a desired uniformity could be selected to determine the degree of ponding to allow and the depth of water to apply during an irrigation.

A direct measurement of moisture distribution in the soil would require numerous samples. Neutron meters have been used successfully for repeated measurements of this type (8, p. 100).

EQUIPMENT AND PROCEDURE

On a Woodburn soil at the Hyslop Agronomy Farm near Corvallis a site was chosen that would accommodate four plots. The bulk densities of the soil were obtained at six inch increments to a depth of 42 inches. The bulk density by depth (shown in Table 1) increases from the soil surface to a depth of 24 inches and decreases below that point. This is characteristic of a typical Woodburn soil.

The plots were first grouped in pairs of one level plot and one graded plot. The positions within the group were then picked randomly. The general layout and dimensions of the experiment are shown in Figure 1.

The sloping plot was prepared using a bulldozer to do the rough work and a tractor-mounted land level to do the finish work. It was prepared so that both a ridge and a swale would be present (Figure 3). The slope had an eight inch drop in twenty feet. The plots were left level in the north-south direction.

All plots were then disked in preparation for seeding. A 15-7 John Deere drill was used to sow the seed. The east pair of plots were densely seeded while the west pair were seeded to simulate a row crop (Figure 1). For the row seeding the grain drill was prepared such that the grass was sown in strips 14 inches wide with a 24 inch bare space between strips (Figure 5). Sudan grass seed was banded with ammonium nitrate fertilizer at the time of seeding. Two hundred pounds of fertilizer per acre were used. The ammonium nitrate contained thirty percent nitrogen. After seeding a one man, gas powered, auger (Figure 4) was used to drill the holes for the placement of aluminum access tubes for the neutron moisture probe.

On the first irrigation, Rainbird 30 sprinklers with a 11/64 inch range nozzle and a 5/32 inch spreader nozzle were used. At the start of the second irrigation ponding was noticed almost immediately with the same sprinklers. The number 30 sprinklers were replaced with number 20's because of the decreased intake rate of the soil. The decreased intake rate was probably a result of surface compaction caused by excessive traffic. Crusting of the soil surface and a slight compaction due to the irrigation was also noticed. Another factor causing a decreased intake rate was that the soil had more moisture in it at the start of the second irrigation.

During each experimental irrigation two sprinklers were placed on each plot as shown in Figures 2 and 3. A typical scene during an irrigation can be seen in the picture, Figure 5. The application rate of water to the soil decreased as the distance from the sprinklers increased. The application rate varied in the north-south direction only.

Catch in can measurements were made by placing catch cans on top of the access tubes using a metal sleeve (Figure 6). Catch in can is the amount of water that would have fallen on the area of soil covered by the can. The information is used to compute sprinkler distribution uniformity. The cans were made from two inch O. D. aluminum pipe, cut to 12 inch lengths, and sealed at the bottom with a welded aluminum plug. The rim was sharpened in accordance with United States Weather Bureau Standards to record only the amount of water falling through the opening (10, p. 2). They were polished on the outside and filled one-third full of diesel oil to prevent evaporation (5, p. 527).

Just prior to the start of the irrigation, the catch cans plus oil were weighed and placed in position. At the end of the irrigation the cans were reweighed. The depth of water in inches was computed, using the catch can areas listed in Berney's thesis (2, p. 65). Catch in can was adjusted for height of placement using data from the Wyoming Agricultural Experiment Station progress report (3, p. 6).

A two and one half inch Badger water meter was used to determine the amount of water applied during the irrigation. In the original design of the experiment only 50 percent of the water passing through the meter was to be applied to the plot. The sprinkler system was designed so that each sprinkler applied water to the plot during one half of each revolution. Due to the spacing of the sprinklers and high pressure, overlap was greater than 40 feet. This indicates that slightly less than 50 percent of the water passing through the meter was actually applied to the plot. The water meter readings were converted from gallons applied and adjusted to consider only water applied directly to the plot.

Degree of ponding, or the percentage of the area having free water standing on the surface of the soil around a tube at the end of an irrigation, was estimated using a ten foot by ten foot frame divided with string into one foot by one foot squares. The area ponded in each square foot was added to obtain the total ponded area in a ten foot by ten foot area around the tube.

Two Troxler model 104 probes were used interchangeably in combination with a Nuclear-Chicago scaler to measure total soil moisture. A Troxler S-4 shield was used as a standard. Seven readings were taken at six inch increments down the access tubes to get soil moisture content per six inch depth. Readings were made one day before, one day after, and three days after an irrigation. Figure 7 shows typical soil moisture readings in progress.

The neutron equipment was field calibrated using volumetric soil samples. The samples were taken with a core sampler, weighed, dried and reweighed. Two sets of core samples were used to determine bulk density and moisture tension curves (Table 1).

Neutron readings were taken at two inch increments in a completely saturated soil. They were converted to percent standard count and plotted on rectangular coordinate paper. From six to 12 inches, percent standard count varied directly with depth in the soil profile (Figure 8). This indicates the necessity of having three separate curves for converting percent standard count to soil moisture content.

Calibration of the neutron equipment consisted of preparing one curve for each probe for the six inch, the 12 inch and the 18 to 42 inch depths. A standard statistical procedure, an F test was used to determine whether or not the curves for the two probes could be put together. A significant difference between curves at a given depth was not found. This allowed one calibration curve to be used at each depth. A linear regression of percent moisture by volume versus percent standard count was used to fit the curves (Figure 9). The regression equations from the calibration curves were used to convert field readings from percent standard count to inches of moisture. The conversions were made on an IBM 1620 computer. A trial case was computed by hand to make sure the computer program was working properly. The data from the third and fourth plots on both replications were corrected for the rainfall which fell during the period in which the readings were being taken.

RESULTS AND DISCUSSION

The data obtained from the water meter readings, the catch in can, the neutron readings for before irrigation, first day after irrigation, and third day after irrigation show inconsistancies when compared with catch in soil. This comparison is shown in Table 2. An example is plot one, trial one, where average catch in can is 1.140 inches, the meter reading is 1.340 inches, but average catch in soil is 2.455 inches. Catch in soil is the total moisture in the soil first day after irrigation minus total moisture in the soil before irrigation. This is almost an inch difference. Another example is plot one trial two where the average total moisture in the soil before the irrigation is greater than the average total moisture the third day after the irrigation. These comparisons indicate that some of the measurements may have been in error and that the conclusions should be regarded with the inconsistancies in mind.

Problems were encountered in trying to keep the access tubes dry. They were opened, aired out and dried prior to the moisture measurement. One neutron probe used in the experiment was later found to be sensitive to temperature changes. The neutron count varied with respect to the temperature differences between the air above the ground and the air in the access tubes.

The neutron scaler had two separate circuits that could be used interchangeably. One circuit operated on direct current from a battery contained within the scaler. The other circuit operated on alternating current and needed an external power source. During the last part of the experiment the direct current side of the scaler failed to operate. A portable alternator was then used to provide alternating current for operation of the neutron equipment.

Further consideration needs to be given to the design of the experiment and analysis of the data obtained. The experiment was designed to determine the effect degree of ponding had on soil moisture uniformity, and if there was an optimum degree of ponding that would give maximum soil moisture uniformity. The experiment was also designed to determine the effect crop cover and slope of the plots would have on the resulting soil moisture uniformity. Another factor considered was whether irrigation caused a difference in the uniformity of soil moisture. Sprinklers were placed on the east-west centerline of the plots as shown in Figures 2 and 3. This gave a decreased application rate as distance from the sprinklers increased. For effective analysis of the data it was necessary to divide each plot into a north and south section with respect to the east-west centerline of the plot.

It was assumed that following an irrigation on a sloping plot the soil moisture in the ridge would be less than the soil moisture in the swale. Curves in Figure 10 characterize the effect of application rate by column for plot one, trial one, north. The curves show that as the degree of ponding increases, differences in soil moisture between the ridge and swale increase. However, the curves were not significantly different statistically.

Uniformity of sprinkler distribution, uniformity of catch in soil, uniformity of total soil moisture, and uniformity of catch in can were calculated using the methods suggested by Christiansen (4, p. 94), Wilcox and Swailes (23, p. 570), and Benami and Hore (1, p. 157). The calculations for plot one, trial one, north are shown in Table 3. Calculations for uniformity of total soil moisture were made for before, first day after, and third day after irrigation. Catch in soil moisture uniformities were made for first day after and third day after irrigation. Catch in soil first day after is the total soil moisture first day after minus the total soil moisture before irrigation. Catch in soil third day after is the total soil moisture third day after minus total soil moisture before irrigation. As can be seen in Table 3 the calculated values of uniformity of catch in soil do not necessarily agree with the uniformity of distribution of the sprinklers.

The uniformities do not agree with each other, because some consumptive use, evaporation, and water movement within the soil have occurred. Negative values are noticed for catch in soil especially on rows receiving low application rates. Uniformities as calculated by the three equations presented are dependent upon and influenced by deviations from the mean and the size of the mean. A large deviation greater than one and a small positive mean less than one may give uniformities that are relatively high but do not reflect the true uniformities. These conditions may even give a negative value if the deviation is greater than one and the mean is exceedingly small.

In cases where application rates are low and consumptive use occurs the computed value of the uniformity of catch in soil may become positive even though there was no appreciable increase in soil moisture. This happens when the mean is a negative value and the deviation is greater than one. As can be seen by this breakdown several different conditions will give the same results. These results are more critical when the mean is small and the variation of each reading is large. This discussion indicates that different magnitudes of the mean and variations from the mean may give the same results. Exceedingly large and small uniformities may also be obtained. The difficulty encountered is how to determine what uniformities represent the true picture.

This line of reasoning suggests that using the uniformity of sprinkler distribution is not necessarily a good measure of the uniformity of soil moisture distribution. This is true especially when using low application rates.

Final analysis was done using the uniformity of soil moisture values computed from the formula of Benami and Hore (1, p. 57). Since this procedure uses two means, the resulting uniformities are not as greatly affected by the magnitude of any single mean. In computing the various uniformities there were large differences in the magnitude of the values used. For each section and trial the Benami and Hore coefficients of uniformity were grouped according to time taken and plotted on rectangular coordinate paper against average degree of ponding as shown in Figure 11. This gave three groups of points for each section and trial. There were two sections, two irrigations, and three readings on each of the four plots which gives a total of 48 groups of five points each. A linear regression was run on each grouping of points (13, p. 244). This gave 48 regression equations that needed to be tested among themselves for significant statistical differences. Figure 11 shows the method of plotting and the regression equations obtained for the three sets of readings for plot one, trial one, north.

Standard statistical analysis was used to determine whether the regression coefficients were significantly different from zero (13, p. 263). It was found that the regression coefficients of each of the 48 regression equations were not different from zero. All zero coefficients would mean that the degree of ponding had no effect on soil moisture uniformity, and hence there was no optimum degree of ponding to give maximum soil moisture uniformity.

An application rate greater than the intake rate causes ponding and possibly runoff. Degree of ponding can be defined as:

$$\text{Degree of ponding} = \frac{\text{Area ponded}}{\text{Total area considered}}$$

The area ponded is the area in which the application rate of water exceeds the intake rate of the soil by a visible amount. From this definition it can be seen that ponding is a function of the application rate. Therefore, the varied application rate did not affect soil moisture uniformity.

An analysis of variance for a factorial experiment was used to determine whether there were apparent differences among the constants of the 48 regression equations (13, p. 163). Differences in the constants would suggest that the experimental factors trial, reading, plot and direction might affect the overall uniformity of soil moisture distribution. The results of the analysis are shown in Table 4. Plot characteristics caused a significant difference in the magnitude of the constants value. There was also a slight plot by direction interaction.

The plot factor was divided into single degrees of freedom to compare the dense versus row seeding on the flat plots, the dense versus row seeding on the graded plots, and the flat versus the graded plots. Only two of the single degrees of freedom showed a significant effect. The varying of the density of crop cover affected the magnitude of the constants of the two flat plots. The grade of the plots caused a significant difference in the magnitude of the constants.

The constants were significantly higher on the flat plots than on the sloping plots. The constants were higher on the densely seeded flat plot than they were on the row seeded flat plot. The plot by direction interaction indicates the wind may have caused a slight difference in soil moisture uniformity on the north and south side of the sloping plots.

The plot differences did not seem to be caused by the irrigations. The readings did not show differences among themselves. This suggests the differences were due to a factor or factors not considered in the experiment. A possibility is that the differences were caused by soil disturbance in shaping the graded plots. Creating the ridge and swale on the graded plots may have changed the soil moisture retention properties of the plots making the retention properties different from those of the flat plots. Slight differences in slope and y-intercept could be seen in plotting the regression equations even though the differences were not statistically significant. Perhaps a larger sample size would show the differences to be statistically significant. Figure 11 shows the differences in the regression equations for plot one, trial one, north. The differences were inconsistent when grouped according to plot and trial and compared according to the reading.

SUMMARY AND CONCLUSION

Sprinkler tests were run to determine an optimum degree of ponding, the effect of degree of ponding and to relate degree of ponding, initial moisture content, degree of crop cover, and slope of the ground to the final distribution of moisture in the soil. Analysis of variance and linear regression were among the standard statistical procedures used in analysis of the data. Linear regressions were computed on the data relating uniformity coefficients of sprinkler distribution, total soil moisture, and catch in soil to degree of ponding. The analysis of variance was used to determine if differences existed in the constants of the regression equations.

The analysis indicated that there was not an optimum degree of ponding. In fact, ponding, grade of plot, and crop cover did not appear to appreciably affect the distribution of soil moisture after an irrigation. It is possible that a larger sample size for computing the uniformity of soil moisture distribution would have given different results.

In plotting the regression equations, differences were not consistent. The inconsistencies were probably due to difficulties encountered in operating the neutron scattering equipment for measuring soil moisture. The major factor influencing the uniformity of soil moisture distribution among the plots was the grade of the plots. The sloping plots had a lower uniformity of soil moisture distribution than did the flat plots. The soil moisture retention properties of the graded plots were possibly changed in shaping the plots. The crop cover on the flat plots had a slight effect on the uniformity of soil moisture distribution.

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APPENDIX

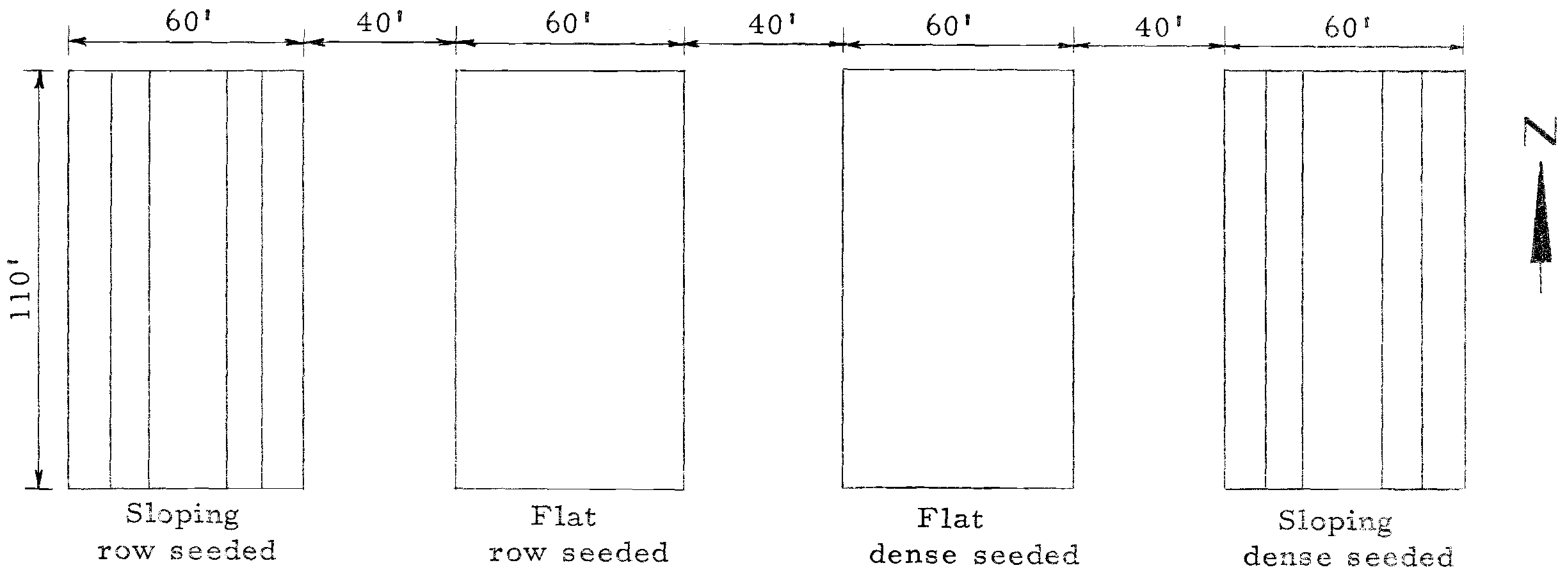


Figure 1. General layout and dimensions of the plots.

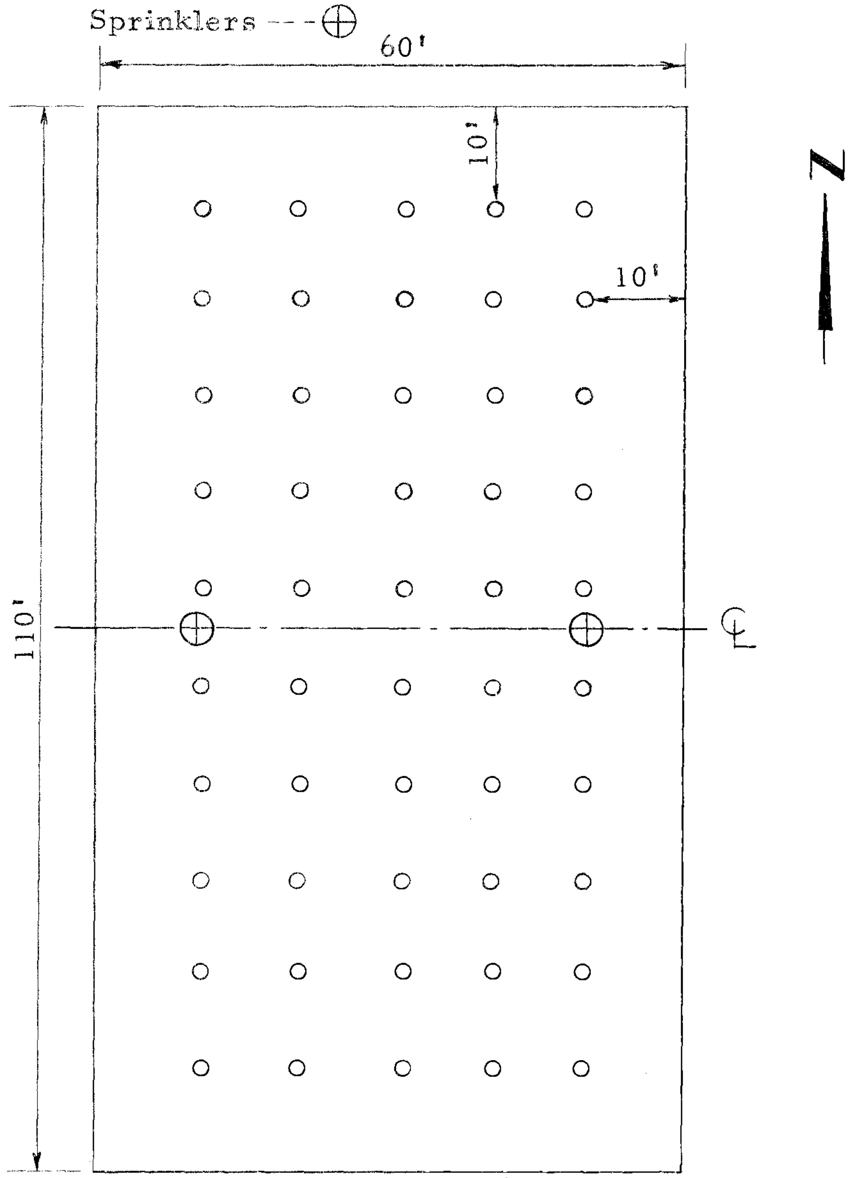


Figure 2. Tube layout and demension of the flat plots.

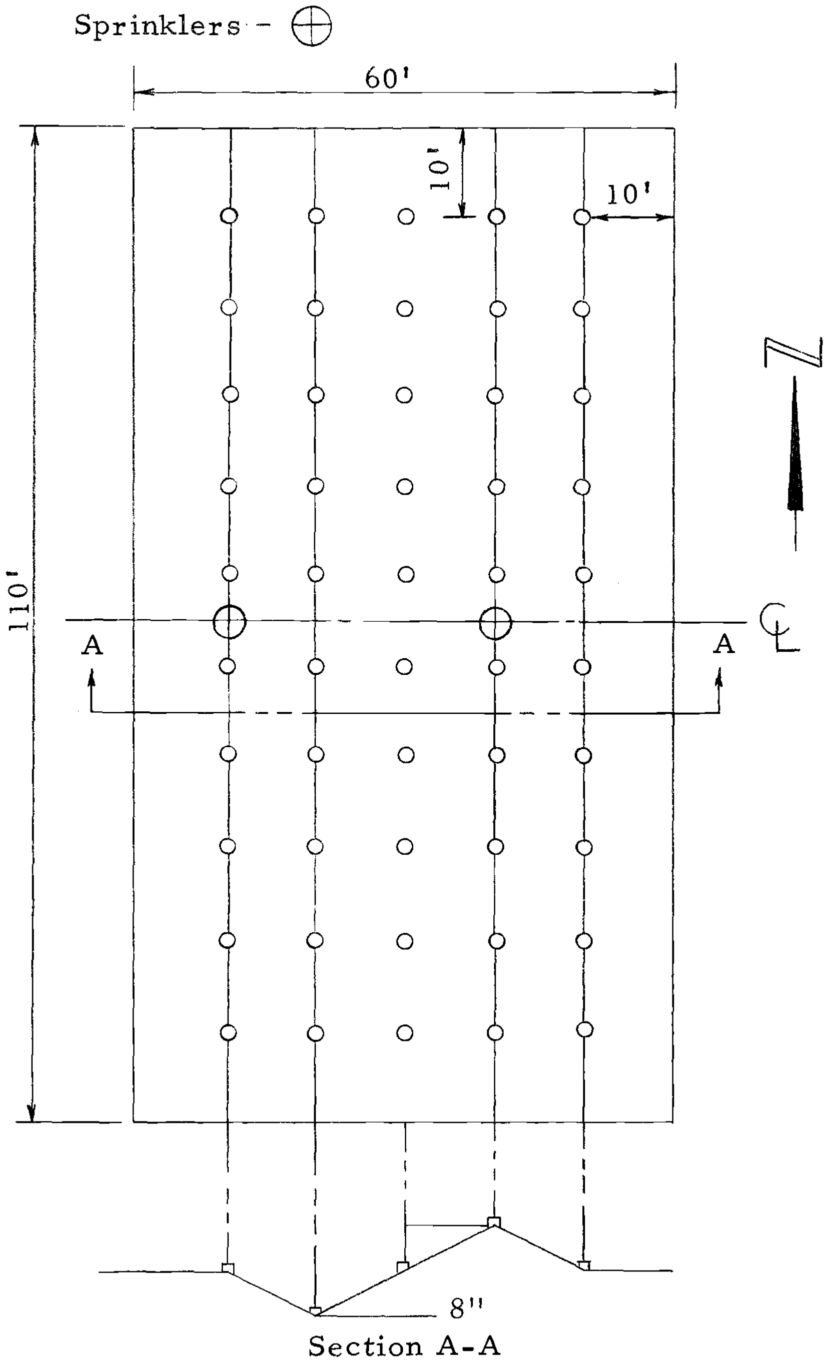


Figure 3. Tube layout and dimension of the graded plots.

FIGURE 4 Gas-powered auger used in preparing holes for the access tubes.

FIGURE 5 Typical scene during an irrigation

FIGURE 6 Method used to hold catch cans.

FIGURE 7 A soil moisture reading in progress using neutron scattering equipment.

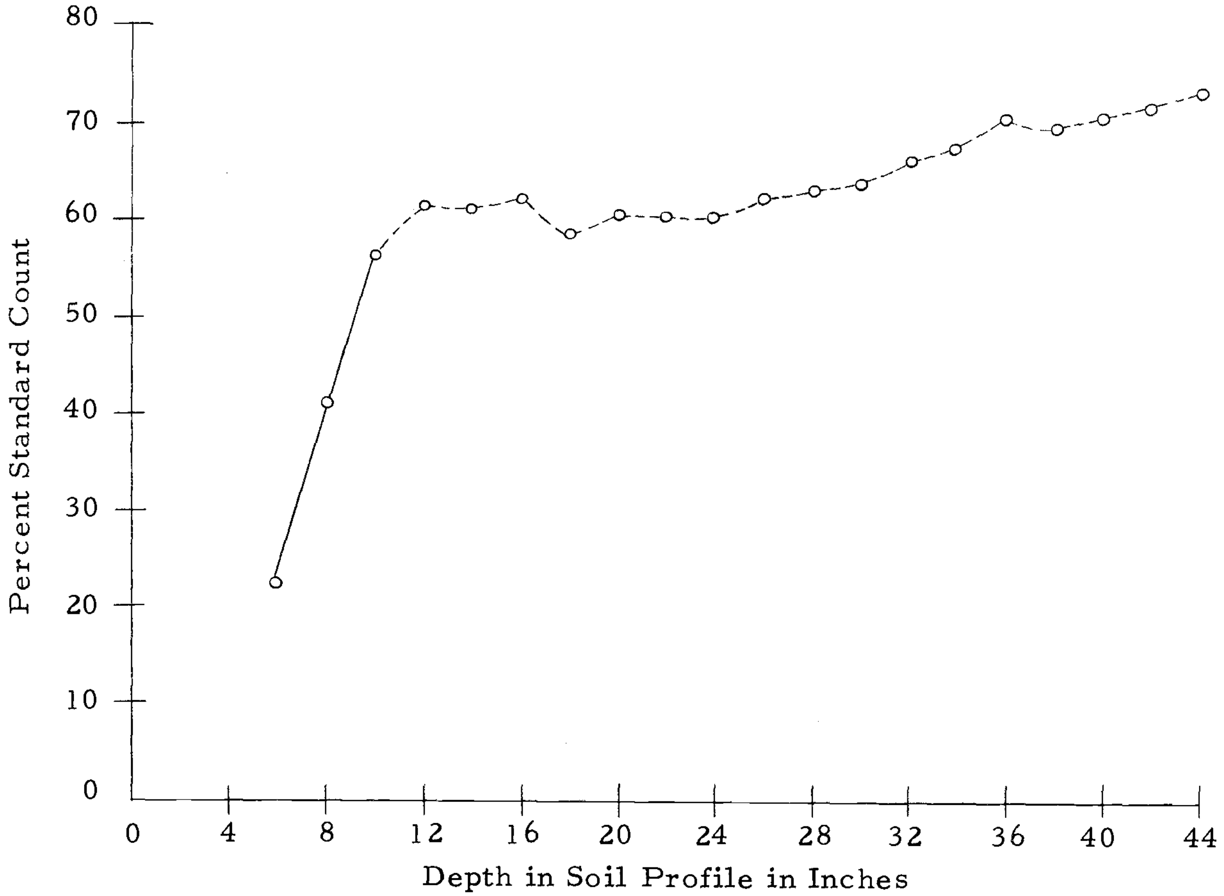


Figure 8. Response of neutron probe to depth in soil profile.

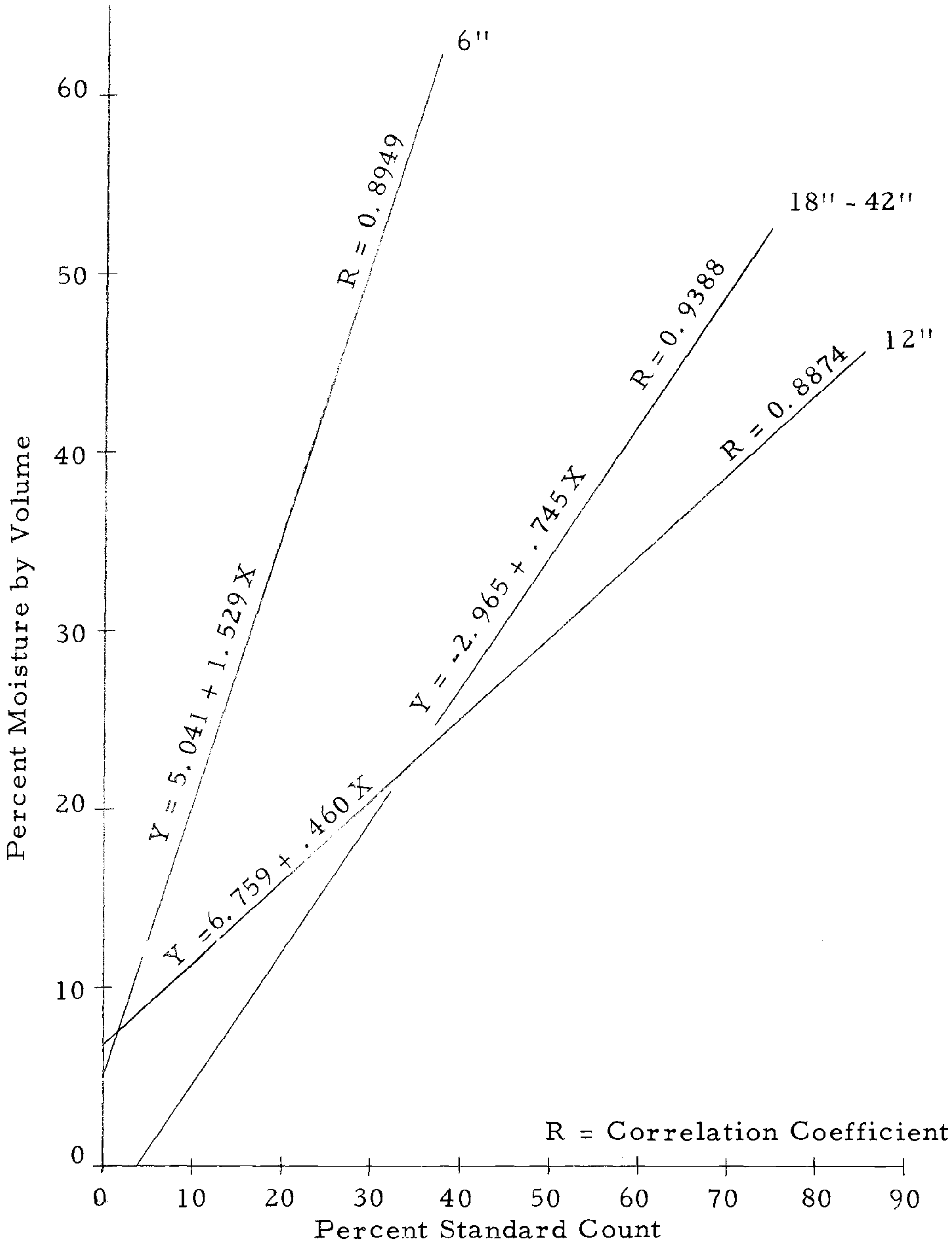


Figure 9. Calibration curves used in converting neutron readings to equivalent soil moisture.

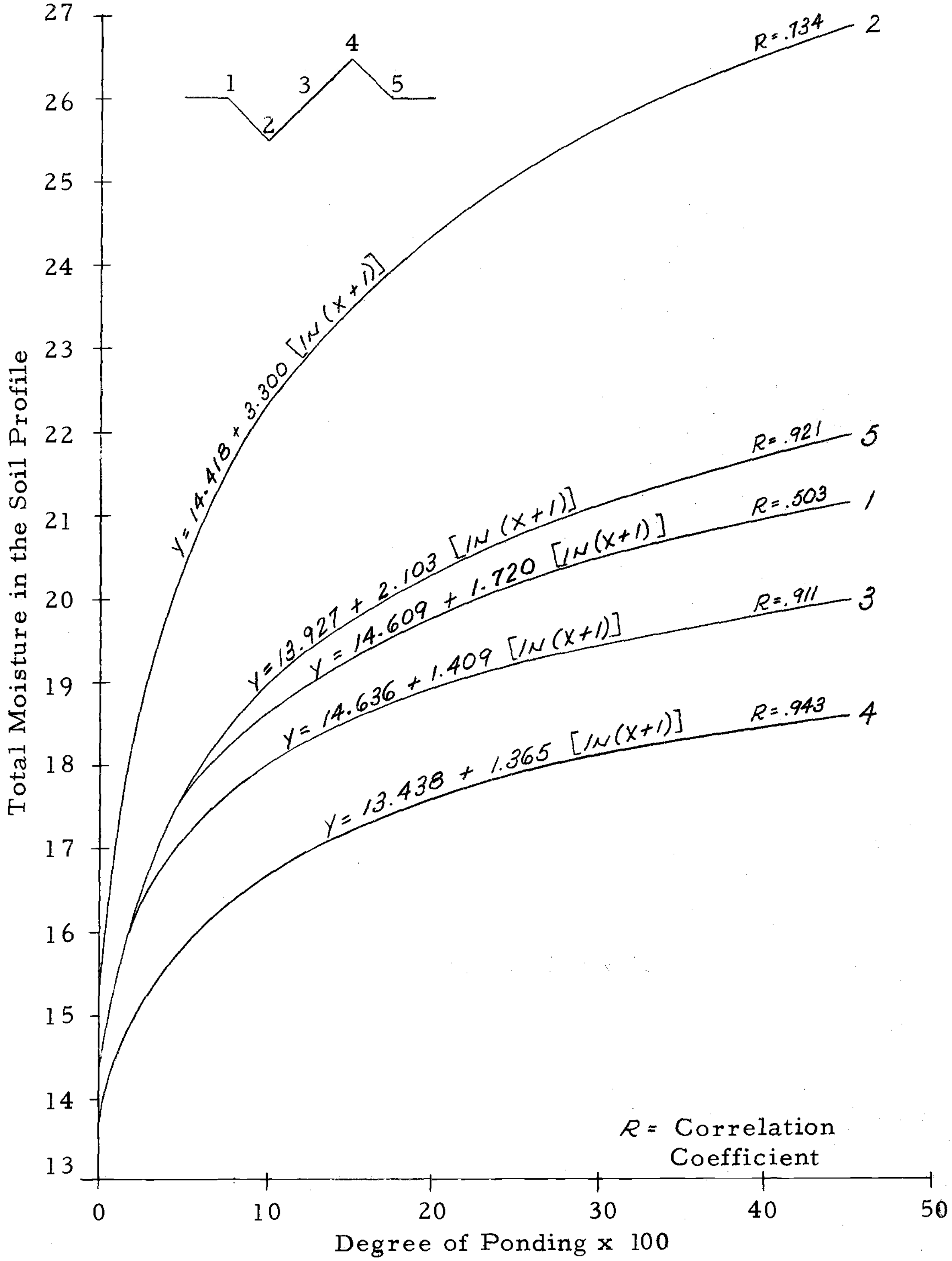
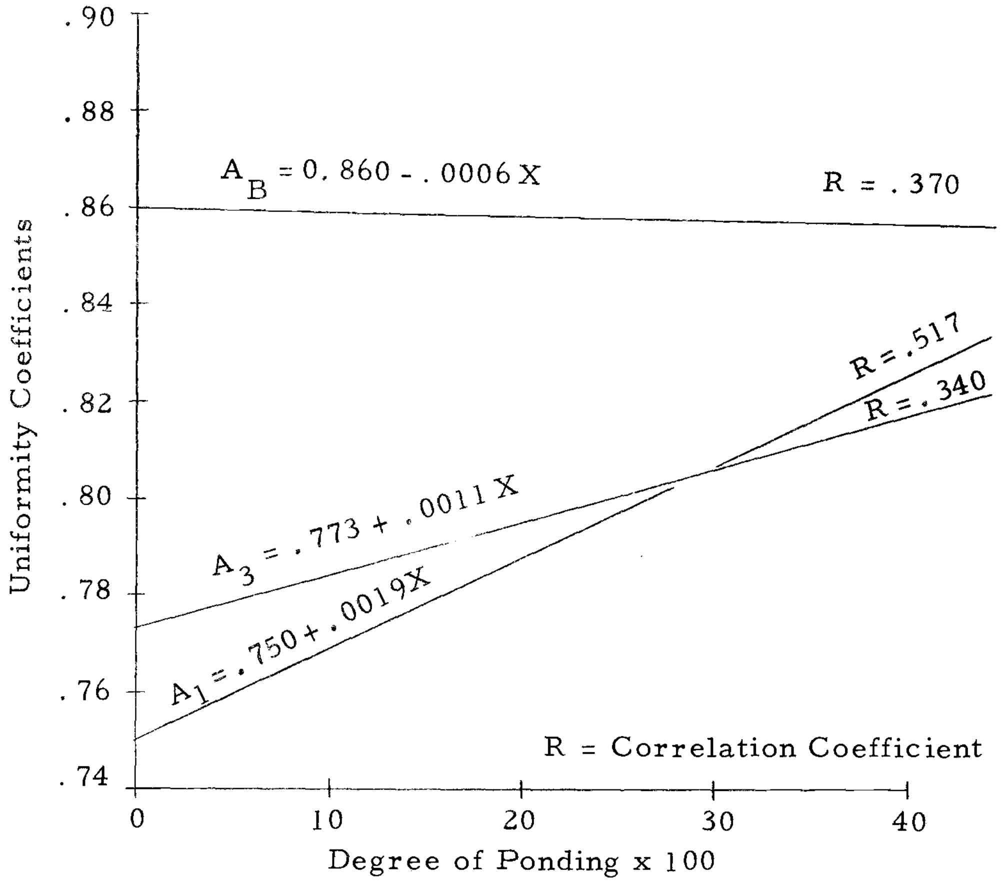


Figure 10. Soil moisture distribution in graded plots characterized by column example for Plot 4, Trial 1, North, for first day after irrigation.



A_B = Uniformity of total soil moisture before irrigation.

A_1 = Uniformity of total soil moisture one day after irrigation.

A_3 = Uniformity of total soil moisture three days after irrigation.

Figure 11. Uniformity coefficients versus percent ponding by reading for plot one, trial one, north.

Table 1. Moisture determinations and bulk densities for six inch intervals in the soil profile

Sample		Percent moisture at				
Core	Depth	.1 ATM	.3 ATM	.5 ATM	1.0 ATM	Bulk density
16	6	30.16	27.59	26.61	25.22	1.32
28	12	28.98	26.64	25.87	25.05	1.45
105	18	28.24	25.58	25.04	24.40	1.47
91	24	28.70	27.01	26.67	26.42	1.53
203	30	35.07	33.67	33.16	32.60	1.40
206	36	36.93	35.49	34.79	33.77	1.32
14	42	37.62	36.39	35.76	35.00	1.37
187	6	29.99	27.27	26.22	24.93	1.30
183	12	27.91	25.20	24.43	23.48	1.40
193	18	26.38	24.08	23.50	22.87	1.48
185	24	29.17	27.15	26.66	26.11	1.53
98	30	35.59	33.89	33.80	32.68	1.43
235	36	36.19	35.31	41.18	34.16	1.37
211	42	35.72	34.72	34.19	33.42	1.36

	Percent Moisture at		
	2.0 ATM	5.0 ATM	15.0 ATM
6	20.36	16.40	10.59
12	20.91	16.51	10.99
18	21.67	17.82	12.17
24	21.62	18.56	12.48
30	24.51	20.94	14.17
36	28.02	24.65	17.14
42	28.37	25.28	16.96

Table 2 Comparison of data obtained during the experiment.

Plot	Trial	Total rainfall	*Meter reading	Catch in can	Moisture in soil profile before irrigation	Moisture in soil profile 1 day after irrigation	Moisture in soil profile 3 days after irrigation	Catch in can
1	1	0.0	1.340	1.140	15.943	18.389	16.367	2.455
1	2	0.0	0.940	1.006	16.182	17.085	15.820	0.903
2	1	0.0	1.591	1.559	15.844	16.207	16.607	0.353
2	2	0.0	0.239	0.462	16.281	16.806	16.618	0.525
3	1	0.6	1.820	1.854	14.245	16.764	15.353	2.519
3	2	0.1	0.931	0.734	15.622	15.999	16.108	0.377
4	1	0.6	1.375	2.030	13.145	15.925	15.704	2.780
4	2	0.3	1.187	0.865	14.804	15.603	15.628	0.799

* Includes rainfall

Table 3 Uniformities, Average ponding in percent and average catch in can by row for plot one, trial 1, north.

Row	Average ponding in percent	Average catch in can	Before irrigation	1st day after irrigation	3rd day after irrigation	Catch in soil 1st day after irrigation	Catch in soil 3rd day after irrigation	Catch in can
			Uniformity by Benami and Hore method					
1	0.0	0.146	0.863	0.699	0.730	0.098	-0.269	0.653
2	0.4	0.556	0.862	0.775	0.820	0.350	-0.125	0.712
3	0.5	1.223	0.834	0.736	0.731	0.405	0.110	0.720
4	29.0	2.163	0.897	0.912	0.906	0.786	0.570	0.775
5	46.0	2.608	0.794	0.773	0.765	0.677	0.365	0.735
			Uniformity by Christiansen method					
1	0.0	0.146	94.392	89.809	90.185	16.653	-348.934	87.629
2	0.4	0.556	95.987	91.700	93.650	59.196	0.233	89.996
3	0.5	1.223	93.354	90.425	90.196	68.414	18.741	89.141
4	29.0	2.163	96.754	97.357	97.138	93.006	86.167	88.571
5	46.0	2.608	93.730	93.579	92.274	85.368	65.057	88.128
			Uniformity by Wilcox and Swailes method					
1	0.0	0.146	93.947	86.726	87.357	-6.048	-482.015	84.285
2	0.4	0.556	94.634	90.328	92.069	56.052	- 12.900	88.239
3	0.5	1.223	92.788	88.575	88.262	59.635	- 3.350	83.439
4	29.0	2.163	95.988	96.526	96.280	91.661	81.850	88.285
5	46.0	2.608	91.814	91.179	89.708	83.870	61.644	87.244

Table 4 Analysis of Variance used in examining constants of the linear regressions.

Source of Variation	Sum of Squares	Degrees of freedom	Mean Square	F
		Analysis of Variance		
Trial	0.00128	1	0.00128	2.625
Reading	0.00215	2	0.00107	2.208
Plot	0.13813	3	0.04604	94.284
Row flat vs. Dense flat	0.00470	1	0.00470	9.633
Row slope vs. Dense slope	0.00011	1	0.00011	0.239
Graded vs. flat	0.13331	1	0.13331	272.981
Section	0.00111	1	0.00111	2.275
Reading by Plot	0.00481	6	0.00080	1.641
Read. by Section	0.00116	2	0.00058	1.887
Plot by Section	0.01082	3	0.00360	7.388
Plot by Section vs. Crop Flat	0.00078	1	0.00078	1.599
Plot by Section vs. Crop graded	0.00911	1	0.00911	18.663
Plot by Section vs. Slope of Plot	0.00092	1	0.00092	1.907
Read. by Row by Sec.	.00206	6	0.00034	0.703
Error	0.01123	23	0.00048	
Total	0.17277	47		