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Title: The Uniformity Coefficient a Function of Sprinkler Types, Pressure Spacings and Wind Conditions

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John W. Wolfe

It has been established in the literature that pressure, nozzle size, spacing and wind conditions are among the most important factors that affect uniformity of water distribution in a sprinkler irrigation system. Investigation, analysis and evaluation of existing sprinkler systems revealed the necessity for a better understanding of how these factors affect uniformity of water distribution in order that improvements may be made in future system designs.

To study how these factors affect the uniformity coefficient (an index of water distribution) data obtained from Hawaiian Sugar Planters' Association Experiment Station were used for multiple regression analysis. The data were arbitrarily arranged in five dominant wind groups and each group was arranged in two orientations.

Using a regression model that considers the following factors: nozzle size, pressure, wind velocity, spacing on the mainline and

spacing on the lateral, 20 independent variables comprising these factors and their combinations were used to estimate the Uniformity Coefficient.

After the regression analyses were made, the following conclusions were reached:

(a) that the Uniformity Coefficient is determined not only by such factors like pressure, nozzle size, wind velocity etc., but also by how these factors are related to each other.

(b) that orientation of sprinkler system with respect to wind direction appears to affect the Uniformity Coefficient.

If the regression analysis were repeated on a larger number of sprinkler tests, it is likely that the results could be presented in a graphical form that could be easily used by designers of sprinkler systems.

The Uniformity Coefficient
a Function of Sprinkler Types, Pressures, Spacings, and Wind Conditions

by

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INTRODUCTION

Sprinkler irrigation is a versatile means of applying water to the surface of any crop or soil. A sprinkler system can apply water to soils at rates equal to, greater than, or less than the infiltration rate; it can be completely automatic or can be manually operated.

Numerous experiments have been conducted to determine the uniformity of water distribution from slowly revolving sprinklers. Since uniform water distribution is necessary to maximize crop yield and quality, even distribution of water over a field by sprinkler irrigation is acknowledged by most to be an important aspect of system design.

It is generally recognized by irrigation engineers that the important factors in obtaining uniform water distribution include wind, operating pressure, spacing of sprinklers, uniformity of sprinkler rotation, and ratio of size of range nozzle to spreader nozzle. Generally, manufacturers of this type of equipment have facilities to test their sprinklers and to make necessary adjustments. But it is accepted that prediction of the distribution must be based on performance of the sprinklers operating under the conditions expected to exist in the field at the time of irrigation. Branscheid and Hart have designated these expected conditions as "system conditions" (3, p. 801) and have divided the system conditions into four general categories: Climatic, equipment, operating, and aerodynamic. All the environmental factors which may affect the distribution of water from the sprinklers are included in the climatic conditions. Of these, the most important are wind speed and wind direction. Equipment conditions consist of those factors which are essentially constant in the design, the most important being sprinkler make and model, riser height, nozzle sizes and configurations, and approach conditions to the sprinkler. Operating conditions are those that are conveniently at the control of the irrigator; they include and are restricted to nozzle pressure and sprinkler spacing. The interaction of water droplets from adjacent sprinklers or of the masses of air set in motion by the sprinkler jets has been classified under aerodynamic conditions. Although these effects have not yet been measured as indicated by Branscheid and Hart, qualitative observations indicate that they do exist.

Since uniform water distribution by a sprinkler irrigation system is necessary not only for maximization of crop yield and quality but also for more efficient use of the available irrigation water supplies, the objective of this thesis therefore is:

> to find the manner in which the uniformity of distribution is dependent upon sprinkler nozzle size, pressure, spacing on the mainline, spacing on the lateral, wind velocity, and wind direction.

LITERATURE REVIEW

Sprinkler recommendations are usually made on the basis of the uniformity of distribution within an overlapped sprinkler pattern. To compare sprinkler patterns and to determine how various spacings affect the resulting distribution of water, one needs a numerical expression to serve as an index of the uniformity obtained. For this purpose Christiansen (4, p. 1) adopted an expression he called the Uniformity Coefficient, UC, which is calculated by the equation $UC = 100\,(1.0 - \frac{\Sigma|X|}{mn})$ where $\Sigma|X|$ is the sum of the absolute deviation of individual readings from the mean value m, and n is the number of readings. Wilcox and Swailes (30, p. 565) developed another Uniformity Coefficient, U, defined by the equation $U = 100\,(1 - \frac{s}{x})$ where s is the standard deviation of the readings and x is the mean of the readings. This coefficient depends upon the standard deviation as a measure of dispersion which involves the square of all the deviations of the readings from the mean. Benami and Hore introduced a new coefficient with a distinguishing title "A". This coefficient is defined by the equation $A = C_1/C_2$ where $C_1 = M_b - \frac{\Sigma|X|_b}{N_b}$ and $C_2 = M_a + \frac{\Sigma|X|_a}{N_a}$. M_a is the mean of the group of readings above the general mean; M_b is the mean of the group of readings below the general mean; N_a and N_b are the number of readings above and below the general mean respectively; $|X|_a$ is the absolute deviation from M_a of the group of individual readings above the general mean, and $|X|_b$ is the absolute deviation from M_b of the group of readings below the general mean. The U. S. Soil Conservation Service (Criddle et al, 1956) proposed the concept of pattern efficiency, PE, which can be expressed by the equation PE = 100 (a/m) where a is the average depth for the 25 percent of the observation having the least water depth and m is the mean depth. After studying a large number of actual sprinkler patterns and comparing the various indices, Dabbous concluded that the general relationship between these various coefficients could be expressed approximately by the relation:

$$U = 1.25UC - 0.25$$

$$PE = 1.45UC - 0.45$$

Branscheid and Hart used yet another uniformity coefficient referred to as UCH and defined as follows:

$$UCH = 1 - \sqrt{\frac{2}{\pi}\,\frac{S}{\bar{x}}} \qquad \text{where} \qquad S = \frac{\sqrt{\sum_{i=1}^{n} (X_i - \bar{x})^2}}{n-1}$$

In the above equation X_i is any observation in the overlapped pattern $\bar{x}$ is the mean of these observations, and n is the number of observations. According to Branscheid and Hart (4, p. 157) the UCH is identical to Christiansen's index.

Coefficients of uniformity and pattern efficiency are single-valued indices of water distribution. However, they do not fully describe the entire distribution pattern nor are they accurate indications of crop yields. Since even distribution of water over a field by sprinkler irrigation is acknowledged by most to be an important aspect of system design, it is generally accepted that prediction of the distribution must be based on performance of the sprinklers operating under the conditions expected to exist in the field at the time of irrigation.

This is what prompted Brancheid and Hart to classify "System Conditions" into four general categories, climatic, equipment, operating and aerodynamic (4, p. 157). These categories were further broken down to include all environmental factors like wind speed and wind direction, equipment factors like sprinkler make and model, nozzle sizes and configurations, riser height, nozzle pressure and sprinkler spacing.

Schwab, Frevert, Edminster and Barnes suggested in their text (25, p. 23) that factors which influence the distribution pattern of sprinklers are the nozzle pressure, wind velocity and the speed of rotation. Too low a pressure will result in a "ring shaped" distribution and a reduction in the area covered, while high pressure produces smaller drops with high application rates near the sprinkler. Schwab and his co-authors indicated that a variable diameter of coverage is caused by wind. A high speed of rotation of the sprinkler, they say, greatly reduces the area covered and causes excessive wear of the sprinkler. The variation in speed of rotation is not due to the wind, but to changes in frictional resistance attributed to lack of precision in manufacture.

Hart, after making a distribution test study on small sprinklers, concluded that no variation in uniformity coefficient could be attributed to sprinkler make and model; and that uniformity coefficient increased with sprinkler height and nozzle pressure but is only slightly affected by nozzle size. He pointed out that generally the uniformity coefficient increases as the area covered by a single sprinkler decreases, and he also pointed out that shape of the area is a factor too. While the uniformity coefficient decreases with wind speed, he observed that generally when winds are perpendicular to the long dimension of a pattern a smaller uniformity results than when they are parallel to the long dimension. This observation he stressed was especially true at high wind speeds (11, p. 4).

It was indicated in a U.S. Soil Conservation Service publication (28, p. 11-18) that the degree of uniformity obtainable depends primarily on the moisture distribution pattern of the sprinkler and on the spacing of the sprinklers. When the sprinklers are properly spaced, the pattern of depth of application from an individual sprinkler that results in the most nearly uniform overlapped coverage has a cross section approaching a triangle in shape.

Wiersma, referring to the tests he made, drew the following conclusions about sprinkler irrigation uniformity coefficients: Tall risers are superior to short risers. Angles of wind with respect to lateral line has little or no effect on the distribution pattern. A definite breaking point occurs between a 50 foot move between lines and a 60 foot move between lines. High pressures are superior to low pressures; large quantities of water per nozzle result in better patterns than small quantities of water in winds of eight m. p. h. or greater; a sprinkler head with only the range nozzle is more efficient than a head with both a range nozzle and a spreader nozzle. A sprinkler head with a large water capacity spaced 40 feet on the line is as good as heads with one-half of the water capacity spaced 20 feet on the line (29, p. 16).

For very small sprinklers commonly used for solid sets in Oregon, Wolfe found that pressure in the range from 40 to 60 psi did not cause any measurable difference in uniformity coefficients (31, p. 2).

Redditt found that test results for a typical windy condition show that uniformity is more dependent on diameter of coverage than upon the distribution of water within the circle (18, p. 16). This perhaps supports Wolfe's findings of relatively insignificant influence of pressure on uniformity, because in the range of pressures he tested, the diameter did not increase much with increased pressure.

Redditt believes that wind is among the most important factors affecting the uniformity, especially at ordinary and stretched spacings. Wolfe's results from small sprinklers support this conclusion.

The direction of the wind with respect to the orientation of a rectangular pattern can be very important. Hawaiian Sugar Planters' Association found that a wind which changes direction is much better than one which consistently blows from one direction.

Redditt concluded that uniformity can generally be improved by lower wind speeds, more gustiness, more variations in wind direction, having the long side of rectangular spacings parallel to the wind direction, less spray loss, closer spacing, higher riser nozzle angles about 20°, large nozzles, smooth, straight long barrels, flow straightening vanes, fewer interruptions to the jet, alternating rotation, down-wind rotation speed matched to wind speed, acceleration of up-wind rotation, rotation axis tilted slightly up-wind, high pressure (up to a point), quick starting and stopping, and careful programing of sprinkler operating periods (13, p. 18).

Some recommendations have been made by manufacturers of sprinkler irrigation equipment on what spacing to adopt in order to achieve maximum uniformity of distribution of water. Shearer and his co-authors (25, p. 2) recommended that spacing between sprinklers on a lateral should not exceed 50 percent of the diameter of the sprinkler pattern. For medium sized sprinklers, spacing between lateral settings should not exceed 65 percent of the diameter of the pattern under no-wind conditions. Under wind conditions, they made the following recommendations:

0 to 5 mph --------------60 percent of the diameter.
5 to 10 mph -------------50 percent of the diameter.
10 mph plus -------------30 percent of the diameter.

Wiersma recognized that in calculating the distance a lateral is to be moved that not only wind velocity but wind direction with respect to previous setting must be taken into account. He recommended that the distance of the lateral move be not greater than 50 percent of the wetted diameter in the direction of the lateral move.

Considering the merits of UC as the criterion for design purposes, Amnon Benami, believes that for optimum design the actual water distribution in the field for various sprinklers and different operating conditions should be employed. Such information when assembled in catalogs can be more efficiently used than the more technical data that manufacturers include in their present catalogs (2, p. 152).

McCavitt agrees with Benami that for design purposes it should be remembered that the system must be tailored to fit the given soil conditions as well as the water requirements of the crop to be irrigated (18, p. 5).

PROCEDURE

Uniformity tests were run at the Maui test site in Hawaii with a single sprinkler at a time. Plastic funnels which serve as catch cans were spaced ten feet apart and the single nozzle sprinkler to be tested was located in the center of the testing area. The sprinkler nozzle height for Buckner sprinklers was set at eight and seven tenths feet and for Rain Bird sprinklers at nine feet. The gauge height for all the tests was three feet. All tests were one hour long. During the tests, the pressure was frequently checked and adjusted if necessary. Wind speed and direction were measured continuously during the tests. Total wind movement values were recorded and the author assumes that the wind direction reported for each test was the mean for that period. From one test with a single sprinkler, different distribution patterns utilizing several different combinations of spacings on the main line and spacings on the lateral were created by the overlapping procedure described by Christiansen (4, p. 77) to give equivalent rectangular sprinkler patterns shown in Table 1.

TABLE I. Rectangular sprinkler spacing patterns.

	Orientation "a"	
20 x 20	30 x 40	40 x 70
20 x 30	30 x 50	50 x 50
20 x 40	30 x 60	50 x 60
20 x 50	30 x 70	50 x 70
20 x 60	40 x 40	60 x 60
20 x 70	40 x 50	60 x 70
30 x 30	40 x 60	70 x 70
	Orientation "b"	
30 x 20	40 x 30	60 x 40
40 x 20	50 x 30	70 x 40
50 x 20	60 x 30	60 x 50
60 x 20	70 x 30	70 x 50
70 x 20	50 x 40	70 x 60

For regression analysis, the author arbitrarily arranged these overlaps in five different dominant wind direction groups. These groups were then arranged in two orientations--"a" and "b" (see Appendix pp. 36-43)

For orientation "a", there were the following groups:

Group 1. North, South. (wind perpendicular to mainline)
Group 2. East, West . (wind parallel to mainline)
Group 3. Northeast, Southeast, Southwest and Northwest.
Group 4. North northeast, North northwest, South southeast and South southwest. (wind nearly perpendicular to mainline)
Group 5. East northeast, East south east, West southwest and West northwest. (wind nearly parallel to mainline)

As illustrated in Appendix page 46, the groups in orientation "b" were exactly the same as for orientation "a" with respect to the wind being parallel to or perpendicular to the mainline, that is parallel to or perpendicular to the long axis of the rectangular space between adjacent sprinklers. The only difference is that in orientation "a", the main line extends in an east-west direction whereas, in orientation "b" it is north-south. Because the topography near the test site is not the same in all directions, it is possible that the results for orientations "a" and "b" will be slightly different.

The overlapping resulted in a total number of observations (measurements of depth of water caught) for each rectuangular pattern equal to the length times width divided by 100. Appendix page 47 contains a sample sheet of overlapped patterns.

Uniformity Coefficients were computed from the overlapped patterns. Other values (high value, low value, range, mean, standard deviation, skewness and kurtosis) were also computed but they were not considered in this report.

Linear regression equations were developed for the listed sprinkler patterns with the UC as the dependent variable and one or more of the following as independent variables: sprinkler nozzle size, pressure, spacing on the mainline, spacing on the lateral, wind speed, and wind direction. The calculations were performed by the computer.

The following regression equation was used for each of the wind groups.

$$UC = \beta_0 + \beta_1(S) + \beta_2(P) + \beta_3(W) + \beta_4(N) + \beta_5(M) + \beta_6(S)^2 +$$
$$\beta_7(P)^2 + \beta_8(W)^2 + \beta_9(N)^2 + \beta_{10}(M)^2 + \beta_{11}(S)(P) +$$
$$\beta_{12}(S)(W) + \beta_{13}(S)(N) + \beta_{14}(S)(M) + \beta_{15}(P)(W) +$$
$$\beta_{16}(P)(N) + \beta_{17}(P)(M) + \beta_{18}(W)(N) + \beta_{19}(W)(M) +$$
$$\beta_{20}(M)(N) + \epsilon$$

Where UC = Uniformity Coefficient, [dimensionless]

β_j = Parameters to be estimated [dimension determined by independent variable]

S = Nozzle size (diameter), [inches]

P = Nozzle pressure, [pounds per square inch]

W = Wind velocity [miles per hour]

N and M = Main and lateral spacings respectively, [feet]

ϵ = Error term

EQUIPMENT

Since the sprinkler tests for this thesis were conducted by the Hawaiian Sugar Planters' Association at their experiment station in Hawaii, the writer gives only a brief description of the equipment used and a simplified structural layout of this equipment.

Specially designed plastic funnels fastened to metal rods to hold them in place were used instead of the commonly used catch cans. These plastic funnels were connected to uniform-diameter plastic tubes that run to the central recording station where the water distribution measurements were made (Figure 1). At the end of each test, it was very easy to see in the central reading station the profile of water distribution in each of several banks of manometer tubes (Figure 2).

A three-cup totalizing type anemometer with dial for registering wind movement was mounted four feet above the ground during all tests. Shifts in wind direction were determined by a light-weight wind vane. All the meteorological measurements were recorded on strip charts. The Rainbird 40B was used for test numbers 1532 to 3533 and Buckner 860 G was used for test numbers 3006 to 4076.

RESULTS AND DISCUSSION

Analysis of Wind Direction Groups

For group 2b, there were 518 calculated uniformity coefficients. These, together with the values for nozzle size, pressure, spacing on the main, spacing on the lateral, and wind velocity associated with each one, are referred to in the following discussion as observations. The independent variables and their combinations were programed to show cumulative effects in sequence. Comparison of these effects on the Uniformity Coefficient was made on the basis of a "t" test using five percent and one percent levels of significance. The tabulated results for group 2b are as follows:

TABLE II. Group 2 b (North, South). Number of observations 518.

1	Size	NS	11	Size x Pressure	**
2	Pressure	NS	12	Size x Velocity	**
3	Velocity	NS	13	Size x Main Spacing	NS
4	Main Spacing	NS	14	Size x Lateral Spacing	NS
5	Lateral Spacing	**	15	Pressure x Velocity	NS
6	$(\text{Size})^2$	**	16	Pressure x Main Spacing	**
7	$(\text{Pressure})^2$	NS	17	Pressure x Lateral Spacing	**
8	$(\text{Velocity})^2$	NS	18	Velocity x Main Spacing	**
9	$(\text{Main Spacing})^2$	**	19	Velocity x Lateral Spacing	**
10	$(\text{Lateral Spacing})^2$	**	20	Main Spacing x Lateral Spacing	**

NS--not significant **--highly significant

This regression equation accounts for 79.7 percent of the variations in the uniformity coefficient.

For this particular group, the nozzle size alone showed no measurable effect on the Uniformity Coefficient since the computer did not print a "t" value for nozzle size. The author observed that although all the nozzle sizes namely 3/16 inches, 5/32 inches, 7/32 inches and 3/32 inches diameter nozzles were represented in this data for this group, 7/32 inch-diameter nozzle was used 22 of 35 times the test was run and this could account for the insignificant influence sprinkler nozzle size has on the Uniformity Coefficient in this particular case. The other three sizes were used less often and as such the effect of differences in sizes on Uniformity Coefficient did not show. The discharge of an individual sprinkler nozzle can be thought of as a function of the water-application rate and the two-way spacing of the sprinklers. Since the multiple regression test for this group and other groups were programed to show the cumulative effects of the independent variables in sequence, the significance of nozzle size as a function of UC could have shown better if the cumulative effect of pressure and other combined factors were added.

The cumulative effect of size and pressure for this group has a "t" value of $1.43 < 1.96$ which means that at even 5 percent level the combination of these independent variables produced no significant effect on the Uniformity Coefficient. The author does not consider

40, 60, and 70 pounds per square inch pressures used for the tests of this group to be low pressure, but he feels that the non-significance of pressure as an added factor could be attributed to the repeated use of the 7/32 inch diameter nozzle in this group of tests. Perhaps if there had been enough range of size, wind velocity, and pressure to cause a significant difference, that would have shown in the "t" value. The author believes that each type of sprinkler has certain pattern characteristics that change as nozzle size and operating pressure change. Each sprinkler has an optimum range of operating pressures for each nozzle size. Only two types of sprinklers--namely Rain Bird and Buckner--were tested. For this group, Rain Bird model 40B was used 86 percent of the time the tests were run, and Buckner only 14 percent. This could have made some difference in whatever effects the combined independent variables might have had on the Uniformity Coefficient.

As one goes through the 20 independent variables which include combined factors, one notices that the following independent variables were highly significant: lateral spacing, $(\text{nozzle size})^2$, $(\text{main spacing})^2$, $(\text{lateral spacing})^2$, and the products of size and pressure, velocity and size, pressure and main spacing, pressure and lateral spacing, velocity and main spacing, velocity and lateral spacing, and main spacing and lateral spacing. The following independent variables showed no significant effect on the Uniformity Coefficient, namely nozzle size, pressure, wind velocity, main spacing, $(\text{pressure})^2$, $(\text{wind velocity})^2$ and the products of nozzle size and wind velocity, nozzle size and main spacing, and nozzle size and lateral spacing.

From the computer printout arrangement, the results showed that the cumulative effect of factors one through four (see Appendix p. 37) produced no measurable effects on the Uniformity Coefficient for this group. It is a proven fact that wind velocity is one of the primary factors that affect even distribution of water in a sprinkler system. Wind distorts the application pattern and the higher the wind velocity, the greater the distortion. Since wind velocity is one of the independent variables treated in the first four combination of factors the author feels that the range of wind velocities measured was not large enought to cause a significant difference. Fourteen to 16 miles per hour wind velocity predominated in this group. Referring to the independent variables according to their sequential order, the author observed that when factor five was added, this produced a measurable influence on the Uniformity Coefficient. This was also true when factor six was added. The addition of factor seven and eight to the group of variables showed no measurable effect on the Uniformity Coefficient, but Uniformity Coefficient was influenced again by the addition of factors nine, ten, eleven and twelve. The addition of factors 13, 14 and 15 showed no measurable influence on Uniformity Coefficient. The addition of factors 16, 17, 18, 19, and 20 each showed a highly significant effect on Uniformity Coefficient. The sequential addition of these independent variables and the resultant effects they have on the Uniformity Coefficient reveal one important fact. It does matter how and when these independent variables are considered as a function of the Uniformity Coefficient. This leads the author to believe that proper handling of these factors, namely spacing on mainline and lateral, pressure, nozzle size, and wind velocity and direction could determine what the index of distribution could be either for design purposes or in the fields. The author will like to add at this point that besides these independent variables under consideration, the designer of a sprinkler system should add in his consideration other vital conditions like type of crops to be raised, type of soil, and topography of the area to be farmed.

The coefficients of these independent variables (β_j) are constants that represent the change of the dependent variable UC which is associated with a one-unit change in the independent variables listed. This particular wind group regression equation accounts for 79.7 percent of the variation in the UC which the author considers good. The author made a study of other groups and the results are tabulated in the following tables.

TABLE III. Group 5a (ENE, ESE, WSW, WNW). Number of observations 525 with 21 tests.

1	Nozzle Size	NS	11	Nozzle Size x Pressure	**
2	Pressure	NS	12	Nozzle Size x Wind Velocity	**
3	Wind Velocity	**	13	Nozzle Size x Main Spacing	NS
4	Main Spacing	NS	14	Nozzle Size x Lateral Spacing	**
5	Lateral Spacing	**	15	Pressure x Wind Velocity	NS
6	$(\text{Nozzle Size})^2$	NS	16	Pressure x Main Spacing	**
7	$(\text{Pressure})^2$	**	17	Pressure x Lateral Spacing	*
8	$(\text{Wind Spacing})^2$	NS	18	Wind Velocity x Main Spacing	NS
9	$(\text{Main Spacing})^2$	**	19	Wind Velocity x LateralSpacing	*
10	$(\text{Lateral Spacing})^2$	NS	20	Main Spacing x Lateral Spacing	**

NS--not significant **--highly significant *--significant

This regression equation accounts for 90.8 percent of the variation in the Uniformity Coefficient.

TABLE IV. Group 5b (NNE, NNW, SSE, SSW). Number of observations 812 with 58 tests.

1	Nozzle Size	NS	11	Nozzle Size x Pressure	*
2	Pressure	**	12	Nozzle Size x Wind Velocity	NS
3	Wind Velocity	**	13	Nozzle Size x Main Spacing	**
4	Main Spacing	*	14	Nozzle Size x Lateral Spacing	NS
5	Lateral Spacing	**	15	Pressure x Wind Velocity	NS
6	$(\text{Nozzle Size})^2$	NS	16	Pressure x Main Spacing	NS
7	$(\text{Pressure})^2$	NS	17	Pressure x Lateral Spacing	NS
8	$(\text{Wind Velocity})^2$	**	18	Wind Velocity x Main Spacing	**
9	$(\text{Main Spacing})^2$	NS	19	Wind Velocity x Lateral Spacing	**
10	$(\text{Lateral Spacing})^2$	NS	20	Main Spacing x Lateral Spacing	**

NS--not significant **--highly significant *--significant

This regression equation accounts for 87 percent of the variation in the Uniformity Coefficient

TABLE V. Group 3a (NE, SE, SW, NW). Number of observations 550 with 22 tests.

1	Nozzle Size	NS	11	Nozzle Size x Pressure	*
2	Pressure	**	12	Nozzle Size x Velocity	NS
3	Wind Velocity	**	13	Nozzle Size x Main Spacing	**
4	Main Spacing	*	14	Nozzle Size x Lateral Spacing	NS
5	Lateral Spacing	**	15	Pressure x Velocity	NS
6	$(\text{Nozzle Size})^2$	NS	16	Pressure x Main Spacing	NS
7	$(\text{Pressure})^2$	**	17	Pressure x Lateral Spacing	**
8	$(\text{Wind Velocity})^2$	**	18	Wind Velocity x Main Spacing	*
9	$(\text{Main Spacing})^2$	**	19	Wind Velocity x Lateral Spacing	**
10	$(\text{Lateral Spacing})^2$	**	20	Main Spacing x Lateral Spacing	NS

NS--not significant **--highly significant *--significant

This regression equation accounts for 83 percent of the variation in the Uniformity Coefficient.

TABLE VI. Group 3b (NE, SE, SW, NW). Number of observations 308 with 22 tests.

1	Nozzle Size	NS	11	Nozzle Size x Pressue	**
2	Pressure	**	12	Nozzle Size x Velocity	**
3	Wind Velocity	**	13	Nozzle Size x Main Spacing	NS
4	Main Spacing	NS	14	Nozzle Size x Lateral Spacing	NS
5	Lateral Spacing	NS	15	Pressure x Velocity	**
6	$(\text{Nozzle Size})^2$	NS	16	Pressure x Main Spacing	**
7	$(\text{Pressure})^2$	NS	17	Pressure x Lateral Spacing	NS
8	$(\text{Wind Velocity})^2$	**	18	Wind Velocity x Main Spacing	NS
9	$(\text{Main Spacing})^2$	**	19	Wind Velocity x Lateral Spacing	**
10	$(\text{Lateral Spacing})^2$	NS	20	Main Spacing x Lateral Spacing	**

NS--not significant **--highly significant *--significant

This regression equation accounts for 82.8 percent of the variation in the Uniformity Coefficient.

TABLE VII. Group 1a (North, South). Number of observations 925 with 38 tests.

1	Nozzle Size	**	11	Nozzle Size x Pressure	NS
2	Pressure	NS	12	Nozzle Size x Wind Velocity	**
3	Wind Velocity	*	13	Nozzle Size x Main Spacing	NS
4	Main Spacing	NS	14	Nozzle Size x Lateral Spacing	NS
5	Lateral Spacing	NS	15	Pressure x Velocity	NS
6	$(\text{Nozzle Size})^2$	**	16	Pressure x Main Spacing	**
7	$(\text{Pressure})^2$	*	17	Pressure x Lateral Spacing	**
8	$(\text{Wind Velocity})^2$	NS	18	Wind Velocity x Main Spacing	**
9	$(\text{Main Spacing})^2$	**	19	Wind Velocity x Lateral Spacing	NS
10	$(\text{Lateral Spacing})^2$	NS	20	Main Spacing x Lateral Spacing	*

NS--not significant **--highly significant *--significant

This regression equation accounts for 76.3 percent of the variation in the Uniformity Coefficient.

TABLE VIII. Group 4b (ENE, ESE, WSW, WNW). Number of observations 294 with 21 tests.

1	Nozzle Size	NS	11	Nozzle Size x Pressure	**
2	Pressure	NS	12	Nozzle Size x Wind Velocity	NS
3	Wind Velocity	**	13	Nozzle Size x Main Spacing	**
4	Main Spacing	NS	14	Nozzle Size x Lateral Spacing	NS
5	Lateral Spacing	**	15	Pressure x Wind Velocity	**
6	$(\text{Nozzle Size})^2$	*	16	Pressure x Main Spacing	**
7	$(\text{Pressure})^2$	*	17	Pressure x Lateral Spacing	**
8	$(\text{Wind Velocity})^2$	**	18	Wind Velocity x Main Spacing	NS
9	$(\text{Main Spacing})^2$	NS	19	Wind Velocity x Lateral Spacing	NS
10	$(\text{Lateral Spacing})^2$	NS	20	Main Spacing x Lateral Spacing	**

NS--not significant **--highly significant *--significant

This regression equation accounts for 93 percent of the variation in the Uniformity Coefficient.

TABLE IX. Group 4a (NNE, NNW, SSE, SSW). Number of observations 1450 with 58 tests.

1	Nozzle Size	NS	11	Nozzle Size x Pressure	**
2	Pressure	NS	12	Nozzle Size x Wind Velocity	NS
3	Wind Velocity	*	13	Size x Main Spacing	**
4	Main Spacing	**	14	Size X Lateral Spacing	**
5	Lateral Spacing	**	15	Pressure x Wind Velocity	NS
6	$(\text{Nozzle Size})^2$	NS	16	Pressure x Main Spacing	**
7	$(\text{Pressure})^2$	**	17	Pressure x Lateral Spacing	NS
8	$(\text{Wind Velocity})^2$	NS	18	Wind Velocity x Main Spacing	**
9	$(\text{Main Spacing})^2$	**	19	Wind Velocity x Lateral Spacing	NS
10	$(\text{Lateral Spacing})^2$	NS	20	Main Spacing x Lateral Spacing	**

NS--not significant **--highly significant *--significant

This regression equation accounts for 85.6 percent of the variation in the Uniformity Coefficient.

Although there was no statistical comparison programed, the author made a visual comparison amongst groups and between orientations. There were similarities and dissimilarities as can be seen from Table X.

TABLE X. Comparison of orientation "a" and "b."

	Orientation "a"				Orientation "b"			
	β_1	β_3	β_4	β_5	β_2	β_3	β_4	β_5
1+	-756.68 **	NS	NS	NS	NS	NS	NS	NS
2	NS	- 5.302 **	NS	NS	NS	NS	NS	- .737 **
3	- 1.226 *	2.203 **	- .652 *	- 4.90 **	NS	3.216 **	- 8.33 **	- .996 **
4	NS	- .277 *	.46 **	NS	NS	.544 **	NS	- .395 *
5	NS	- .0038**	-366 **	- 1.13 **	- 1.18 **	NS	- 1.39 **	- .705 **
6	2295.5 **	NS	NS	- .0013**	945.0 **	NS	2252.1 *	NS
7	- .01245*	.041 **	- .015 **	NS	NS	NS	.0125*	NS
8	NS	.141 **	NS	NS	NS	.185 **	.0583**	.059 **
9	- .006 **	- .0077**	- .0075**	- .0106**	- .012 **	- .0229**	NS	NS
10	NS	- .012 **	NS	NS	.007 **	NS	NS	NS
11	NS	1.92 *	5.55 **	.022 **	- 5.874 **	12.00 **	- .1844**	3.013 *
12	5.650 **	NS	NS	27.6 **	6.349 **	- 60.55 **	NS	NS
13	NS	1.642 **	1.188 **	NS	NS	NS	7.335 **	3.442 **
14	NS	NS	2.077 **	10.43 **	NS	NS	NS	NS
15	NS	NS	NS	NS	- .005 **	.0714**	.119 **	NS
16	.0068**	NS	.0097**	.007 **	.0179**	.014 **	.0146**	NS
17	.011 **	.0145**	NS	.0038*	- .00539**	NS	.00013**	NS
18	.0085**	- .0067*	- .0123**	NS	- .033 **	NS	NS	NS
19	NS	- .0253**	NS	- .015 *	- .014 **	.0024**	NS	.0117**
20	.0015*	NS	.00279**	.0058**	.0079**	.0096**	.0124**	.0064**

+1, Nozzle Size; 2, Pressure; 3, Wind Velocity; 4, Main Spacing; 5, Lateral Spacing; 6, (Nozzle Size)^2; 7, (Pressure)^2; 8, (Wind Velocity)^2; 9, (Main Spacing)^2; 10, (Lateral Spacing)^2; 11, Size x Pressure; 12, Size x Velocity; 13, Size x Main Spacing; 14, Size x Lateral Spacing; 15, Pressure x Velocity; 16, Pressure x Main Spacing; 17, Pressure x Lateral Spacing; 18, Velocity x Main Spacing; 19, Velocity x Lateral Spacing; 20, Main x Lateral Spacing.

NS - not significant. ** - highly significant. * - significant.

Values for β_2 Orientation "a" and β_1 Orientation "b" plus the "t" value were not calculated due to insufficient number of observations and tests.

The Uniformity Coefficient in most of the groups seems to be highly influenced when nozzle size, pressure, and wind velocity were treated together; the influence was reduced by the addition of factor four (main spacing). The addition of factor five (lateral spacing) showed a significant effect on the Uniformity Coefficient. This probably suggests what effect spacing, especially on the lateral, has on the Uniformity Coefficient. Obviously, whenever the spacing of sprinklers on the lateral or the spacing of laterals along the main line is changed, the extent of overlap of the sprinklers contributing to the water falling in a given area also changes. Therefore, different spacings result in different degrees of uniformity.

The effects of the considered independent variables on the Uniformity Coefficient in the two orientations do not appear to be similar. The author feels that this could have been partially caused by the topography of the test site and the differences in wind turbulence as wind flows from the two orientations were probably not the same.

Except for the square patterns in groups 2b, the same data used for group 1a was used for 2b. The author observed that wind velocity was significant for group 1a and not significant for group 2b. Since the wind was blowing across the mainline in group 1a and across the lateral in group 2b, the result supports the observation in the literature that wind blowing across the mainline does distort water distribution pattern more than wind blowing across the lateral. A similar comparison of the effects of wind velocity between groups 4a and 5b and between 4b and 5a neither supports nor disproves this observation.

Further visual comparison of groups 1a and 2b suggests that the product of wind velocity and lateral spacing as wind blows across the mainline does not affect the uniformity of water distribution as much as it does when wind blows across the lateral. This, perhaps, should be expected because with this orientation an increase in wind velocity would help to spread the water along the lateral spacing. Similar comparison between groups 4a and 5b and between 4b and 5a, both of which used the same data but different orientations indicates that the product of wind velocity and lateral spacing has the same effect on the uniformity of water distribution as in groups 1a and 2b. This further supports the observation in the literature about the effects of wind velocity on mainline and lateral spacing.

As a practical example of the applicability of the results of this study, the following particular solution is presented.

Referring to the model equation for this regression analysis, the Uniformity Coefficient was estimated considering only the independent variables listed. To estimate the Uniformity Coefficient the following regression coefficients from the analysis of group 3b were selected.

β_0 =	207.43		
β_1 =	-247	β_{11} =	12.
β_2 =	- 4	β_{12} =	-.6
β_3 =	3	β_{13} =	1
β_4 =	.5	β_{14} =	-1
β_5 =	-.5	β_{15} =	.07
β_6 =	---	β_{16} =	.01
β_7 =	-.009	β_{17} =	-.003
β_8 =	-.1	β_{18} =	-.009
β_9 =	-.02	β_{19} =	.002
β_{10} =	.0002	β_{20} =	.009

The following independent variables were assumed:

P	=	Pressure [40 pounds per square inch]
V	=	Wind Velocity [1 mile per hour]
S	=	Nozzle Size [.15 inches]
M	=	Main Spacing [40 feet]
L	=	Lateral Spacing [50 feet]
ϵ	=	Error Term

Estimating UC, the formula becomes

$$
\begin{aligned}
UC = \; & \beta_0 + \beta_1(S) + \beta_2(P) + \beta_3(V) + \beta_4(M) + \beta_5(L) + \\
& \beta_6(S)^2 + \beta_7(P)^2 + \beta_8(V)^2 + \beta_9(M)^2 + \beta_{10}(L)^2 + \\
& \beta_{11}(S)(P) + \beta_{12}(S)(V) + \beta_{13}(S)(M) + \beta_{14}(S)(L) + \\
& \beta_{15}(S)(P) + \beta_{16}(P)(M) + \beta_{17}(P)(L) + \beta_{18}(V)(M) + \\
& \beta_{19}(V)(L) + \beta_{20}(M)(L) + \epsilon
\end{aligned}
$$

and solving for UC, the estimated uniformity will be

$$= 73\%$$

Since each of the 20 terms was significant in one or more of the wind-direction groups, the author feels that it is necessary that all the terms be included in a general equation.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Of the eight regression equations, group 4a with a total of 1450 observations and 58 tests appears to have the most validity. Besides having the highest number of tests and observations, this regression equation accounted for 85.6 percent of the variation in the Uniformity Coefficient. Non-significance of some of the terms used could be due to insufficient data in the groups. The general result of this analysis leads to the conclusion that the Uniformity Coefficient is determined not only by such factors like pressure, nozzle size, wind velocity, etc. but also by how these factors are related to each other. It appears also from the results of this analysis that orientation of sprinkler system design with respect to wind direction does affect the Uniformity Coefficient. It is necessary, therefore, in the field and for design purposes to consider what effects each of the factors that affect uniformity has on one another and how they collectively affect uniformity. Consideration of these factors and local conditions also will enable the designer of a sprinkler irrigation system to design more economically and efficiently.

Recommendation for Further Study

The author recommends the use of more data for further tests and regression analysis. It is his belief that further tests, more regression analysis with better estimates, and some analysis of variance of more independent variables may lead to a general or graphical formula that will solve for adequate spacings on the main-lines and laterals under given conditions.

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APPENDIX

Group I (N, S) Orientation "a"
N = 925

R-Square 76.3% Constant 1.4748152E 02

Variable	Coefficient	Coef T Value
x- 1***	-7.5668299E-02	-2.9205630E-00 **
x- 2	7.0237887E-01	1.8732870E-00 NS
x- 3	-1.2264312E-00	-1.9909632E-00 *
x- 4	-1.2883883E-01	-8.6311886E-01 NS
x- 5	-5.2728733E-02	3.7894548E-01 NS
x- 6	2.2955752E-03	4.8952170E-00 **
x- 7	-1.2454965E-02	-2.5155106E-00 *
x- 8	4.0129815E-03	4.2656094E-01 NS
x- 9	-6.6099108E-03	-6.1370058E-00 **
x- 10	-9.0918730E-03	-1.0274859E-01 NS
x- 11	-6.2817791E-01	-3.4823077E-01 NS
x- 12	5.6507209E-00	4.3970087E-00 **
x- 13	2.0031595E-01	6.4336484E-01 NS
x- 14	-5.6938803E-02	-1.9710539E-01 NS
x- 15	1.5358772E-02	1.7885763E-00 NS
x- 16	6.8678344E-03	4.0306471E-00 **
x- 17	1.1146393E-02	7.0507888E-00 **
x- 18	-8.5225935E-03	-3.1111665E-00 **
x- 19	-2.9605196E-02	-1.1648442E-01 NS
x- 20	1.5204392E-03	2.0096399E-00 *

NS--not significant **--highly significant *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

Group 2 (N, S) Orientation "b"
N = 518

R-Square 79.7% Constant 1.1443829E 02

Variables	Coefficient	Coef T Value
x- 1***		
x- 2	-1.5233546E-01	-4.1588362E-01 NS
x- 3	-3.5798294E-01	-6.6349059E-01 NS
x- 4	-1.7044398E-01	-7.8075288E-01 NS
x- 5	-1.1823741E-00	-4.6184687E-00 **
x- 6	9.4502066E-02	6.7846590E-00 **
x- 7	6.1543000E-03	1.6683815E-00 NS
x- 8	1.0562606E-02	1.2201039E-00 NS
x- 9	-1.2807631E-02	-7.3405054E-00 **
x- 10	7.4391314E-03	3.1076267E-00 **
x- 11	-5.8745544E-00	-8.6217690E-00 **
x- 12	6.3495740E-00	5.1973244E-00 **
x- 13	4.7164260E-01	1.1474060E-00 NS
x- 14	4.9071726E-01	1.0202920E-00 NS
x- 15	-5.5997195E-03	-7.2175062E-01 NS
x- 16	1.7928500E-02	7.9535013E-00 **
x- 17	-5.3932594E-03	-2.0486321E-00 **
x- 18	-3.3159067E-02	-9.1499099E-00 **
x- 19	1.4099872E-02	3.3313895E-00 **
x- 20	7.9546397E-03	2.7918598E-00 **

NS--not significant **--highly significant *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

Group 3 (NE, SS , SW, NW) Orientation "a"
N = 550

R-Square 82.8% Constant 2.2650545E 02

Variables	Coefficient	Coef T Value
x- 1***		
x- 2	-5.3025803E-00	-7.2568941E-00 **
x- 3	2.2036679E-00	2.4895678E-00 *
x- 4	-2.7785547E-01	-1.5396420E-00 NS
x- 5	-3.8029026E-03	-2.2581266E-02 NS
x- 6	1.4651782E-02	4.7129310E-01 **
x- 7	4.1568227E-02	5.7860962E-00 **
x- 8	1.4152906E-01	7.3268545E-00 **
x- 9	-7.7122519E-03	-5.2954031E-00 **
x- 10	-1.2983115E-02	-1.0850714E-01 **
x- 11	1.9228057E-00	8.3896959E-01 NS
x- 12	-2.6310525E-01	-3.4438065E-00 **
x- 13	1.6428025E-00	2.4920806E-00 *
x- 14	5.9301209E-02	9.6986587E-02 NS
x- 15	2.4518938E-03	1.6980647E-01 NS
x- 16	4.7958306E-03	2.7644374E-00 **
x- 17	1.4506634E-02	9.0127815E-00 **
x- 18	-6.7458050E-03	-2.1251806E-00 *
x- 19	-2.5385326E-02	-8.6200182E-00 **
x- 20	1.6495845E-03	1.6124291E-00 NS

NS--not significant **--highly significant *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

Group 3 (NE, SE, SW, NW) Orientation "b"
N = 308

R-Square 82.8%   Constant 2.0743733E 02

Variable	Coefficient	Coef T Value
x- 1***	-2.4711179E-02	-1.6854757E-00 NS
x- 2	-4.0062014E-00	-5.9828711E-00 **
x- 3	3.2164486E-00	3.1971201E-00 **
x- 4	5.4487312E-01	1.7151803E-00 NS
x- 5	-5.4548299E-01	-1.4637449E-00 NS
x- 6		
x- 7	9.4529549E-03	1.0848767E-00 NS
x- 8	1.8553555E-01	9.9737887E-00 **
x- 9	-2.2906981E-02	-8.2538862E-00 **
x- 10	2.5313450E-04	6.6480063E-02 NS
x- 11	1.2006515E-01	4.0497791E-00 **
x- 12	-6.0563952E-01	-7.1370875E-00 **
x- 13	1.4064941E-00	1.3701521E-00 NS
x- 14	-1.0106514E-00	-8.4310722E-01 NS
x- 15	7.1489008E-02	4.1109245E-00 **
x- 16	1.4030868E-02	5.1964202E-00 **
x- 17	-3.3157187E-03	-1.0515941E-00 NS
x- 18	-9.3046281E-03	-1.8832678E-00 NS
x- 19	2.4007568E-03	4.1611361E-01 NS
x- 20	9.6340938E-03	2.1257741E-00 *

NS--not significant   **--highly significant   *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

Group 4 (NNE, NNW, SSE, SSW) Orientation "a"
N = 1450

R-Square 85.6%   Constant 2.8304376 E 02

Variable	Coefficient	Coef T Value
x- 1***	-1.8700866E-03	-1.2098008E-01 NS
x- 2	-1.2279944E-01	-4.7467446E-01 NS
x- 3	-6.5201316E-01	-2.4341814E-00 *
x- 4	-4.6013484E-01	-4.6495829E-00 **
x- 5	-3.6680984E-01	-3.9677854E-00 **
x- 6	4.2081453E-03	1.4612787E-01 NS
x- 7	-1.5839955E-02	-4.2143616E-00 **
x- 8	6.0615278E-02	1.0635917E-01 NS
x- 9	-7.5182181E-03	-8.7308560E-00 **
x- 10	-1.2169613E-02	-1.7202061E-01 NS
x- 11	5.5546452E-00	4.6770453E-00 **
x- 12	2.2510464E-00	8.0851770E-01 NS
x- 13	1.1881822E-00	3.0464636E-00 **
x- 14	2.0776730E-00	5.7409028E-00 **
x- 15	-4.9002216E-03	-7.3146725E-01 NS
x- 16	9.7933655E-03	9.1980381E-00 **
x- 17	1.2627523E-02	1.2783101E-01 NS
x- 18	-1.2349472E-02	-6.4830424E-00 **
x- 19	-2.9381854E-02	-1.6611442E-01 NS
x- 20	2.7901282E-03	4.6127123E-00 **

NS--not significant   **--highly significant   *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

Group 4 (ENE, ESE, WSW, WNW) Orientation "b"
N = 294

R-Square 93.0% Constant 1.3392534E 02

Variable	Coefficient	Coef T Value
x- 1***		
x- 2		
x- 3	-8.3356086E-00	-3.3990745E-00 **
x- 4	-4.2583058E-01	-9.3576895E-01 NS
x- 5	-1.3929781E-00	-2.6178762E-00 **
x- 6	2.2521489E-03	2.2317330E-00 *
x- 7	2.1585047E-02	2.3572428E-00 *
x- 8	5.8398009E-02	2.8611859E-00 **
x- 9	-2.6647274E-02	-1.2410894E-01 NS
x- 10	8.3478503E-04	2.8338340E-01 NS
x- 11	-1.8448712E-01	-3.0803217E-00 **
x- 12		
x- 13	7.3354009E-01	-3.0803217E-00 **
x- 14	1.3563390E-00	6.4362962E-01 NS
x- 15	1.1932299E-01	3.2513496E-02 **
x- 16	1.4610582E-02	5.7875022E-00 **
x- 17	1.3638538E-04	4.6263904E-02 **
x- 18	-1.5067594E-02	-1.8022749E-00 NS
x- 19	8.7434230E-03	8.9559158E-01 NS
x- 20	1.2434200E-02	3.5463676E-00 **

NS--not significant **--highly significant *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$.
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

Group 5 (ENE, ESE, WSW, WNW) Orientation "a"
N = 525

R-Square 90.8% Constant 1.2151996E 02

Variables	Coefficient	Coef T Value
x- 1***		
x- 2		
x- 3	-4.9063175E-00	-2.3961199E-00 *
x- 4	-4.5263839E-01	-1.3462798E-00 NS
x- 5	-1.1394700E-00	-3.6494715E-00 **
x- 6	-1.3410609E-03	-4.3406480E-00 **
x- 7		
x- 8	4.5130894E-02	1.4828415E-00 NS
x- 9	-1.0694986E-02	-7.2759401E-01 NS
x- 10	-1.8036808E-02	-1.6381689E-01 NS
x- 11	2.2969818E-01	3.7638596E-01 **
x- 12	2.7637118E-01	3.2495701E-00 **
x- 13	1.5124592E-00	1.0980448E-00 NS
x- 14	1.0432271E-01	8.1688086E-00 **
x- 15		
x- 16	7.2381086E-03	3.7517218E-00 **
x- 17	3.8294322E-03	2.1393823E-00 *
x- 18	-7.4510931E-03	-1.1671527E-00 NS
x- 19	-1.5059172E-02	-2.5435966E-00 *
x- 20	5.8648235E-03	6.2298933E-00 **

NS--not significant **--highly significant *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

Group 5 (NNE, NNW, SSE, SSW) Orientation "b"
N = 812

R-Square 87.0% Constant 2.8283174E 02

Variables	Coefficient	Coef T Value
x- 1***	-1.6399013E-03	-1.0133574E-01 NS
x- 2	-7.3354133E-01	-2.6786804E-00 **
x- 3	-9.9680531E-01	-3.3974235E-00 **
x- 4	-3.9509102E-01	-2.4109809E-00 *
x- 5	-7.0562820E-01	-3.6686326E-00 **
x- 6	3.8799160E-03	1.2959986E-01 NS
x- 7	-4.6773710E-03	-1.1972231E-00 NS
x- 8	5.9061817E-02	9.9710492E-00 **
x- 9	-1.6114197E-02	-1.0621738E-01 NS
x- 10	1.8221227E-03	8.7541503E-01 **
x- 11	3.0134340E-00	2.4402843E-00 **
x- 12	4.0999206E-00	1.4169279E-00 NS
x- 13	3.4422241E-00	6.1335553E-00 **
x- 14	-4.3760086E-01	-6.6773162E-01 NS
x- 15	-1.0232320E-02	-1.4694542E-00 NS
x- 16	1.7618739E-02	1.1499648E-01 NS
x- 17	-2.1107370E-03	-1.1797616E-00 NS
x- 18	-3.2757033E-02	-1.1952427E-01 NS
x- 19	1.1776981E-02	3.6799324E-00 **
x- 20	6.4482519E-03	2.6028225E-00 **

NS--not significant **--highly significant *--significant

*** 1 Size
2 Pressure
3 Velocity
4 Main Spacing
5 Lateral Spacing
6 $(\text{Size})^2$
7 $(\text{Pressure})^2$
8 $(\text{Velocity})^2$
9 $(\text{Main Spacing})^2$
10 $(\text{Lateral Spacing})^2$
11 Size x Pressure
12 Size x Velocity
13 Size x Main Spacing
14 Size x Lateral Spacing
15 Pressure x Velocity
16 Pressure x Main Spacing
17 Pressure x Lateral Spacing
18 Velocity x Main Spacing
19 Velocity x Lateral Spacing
20 Main Spacing x Lateral Spacing

SPRINKLER DISTRIBUTION TESTS - PATTERN DATA 3006

Project 7F-4 Date 1-24-68 Test 3006

110 102 683 006	.007 .009	000	010	060	000 000 188
Test number	Control	WDir	Spc	Dur	Nozzles

040	043	388							087	030
Pre	Wsp	Waz	Crs	DB	Wb	Pdep	RH	Watt	Spr	Can

								.004	003	.060
Spray	Rot	ArcO	ArcD	Arc3	Tilt	TiltD	OriO	Spr	Loc	Time

000 601
GPM

					2	2					
				8	7	8	2				
			2	11	10	+10	14	4			
			7	13	8	12	18	14			
		1	10	16	15	18	19	14			
			11	12	16	20	25	11			
			3	6	14	25	20	4			
				4	7	19	9	1			
						1					

	Time	Meter Reading	Notes:
Stop	09.07	1228722	
Start	08.02	1228355	

Sprinkler
Testing Agency
Test Location
Gauge Space, ft x ft
Nozzles D, in
Pres at Noz, psi
Avg Wind Speed, mph
Avg Wind Az, ^{o}N

Spr Noz Hgt, ft
Gauge Hgt, ft
Set Time, min

F. E. Dept.
Exp. Sta., HSPA
Rev. Jan. 20, 1964

Location of sprinkler marked with plus (+) sign.

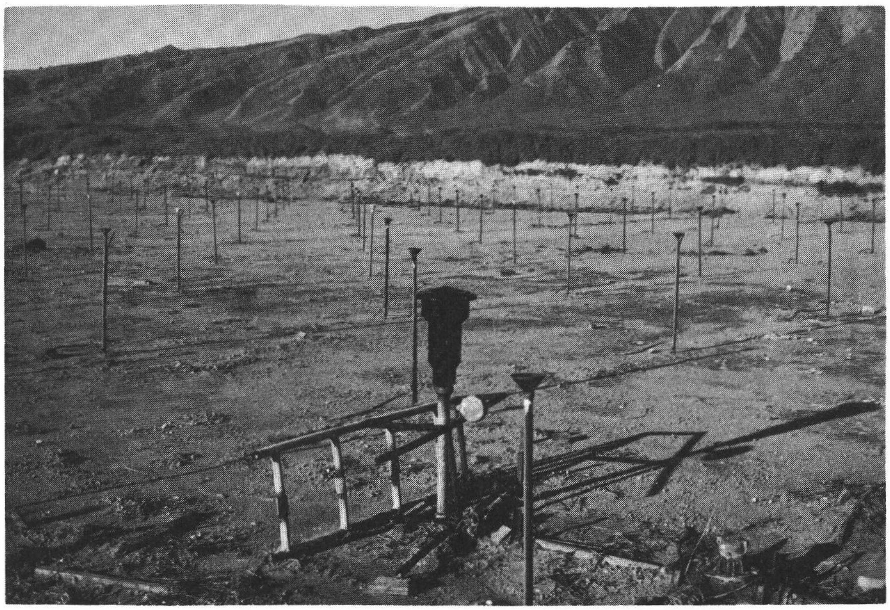


Fig. 1
Maui test site with plastic funnels for water catchment.

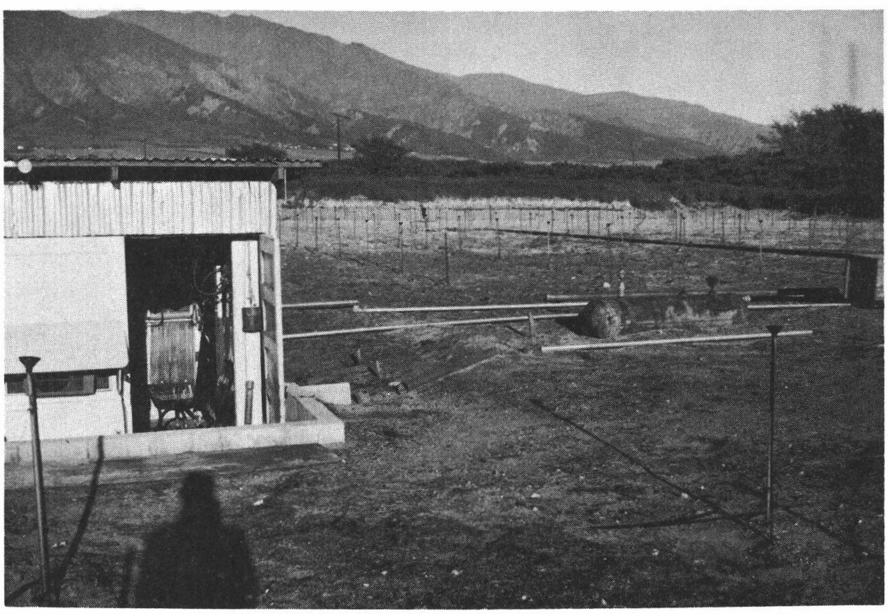
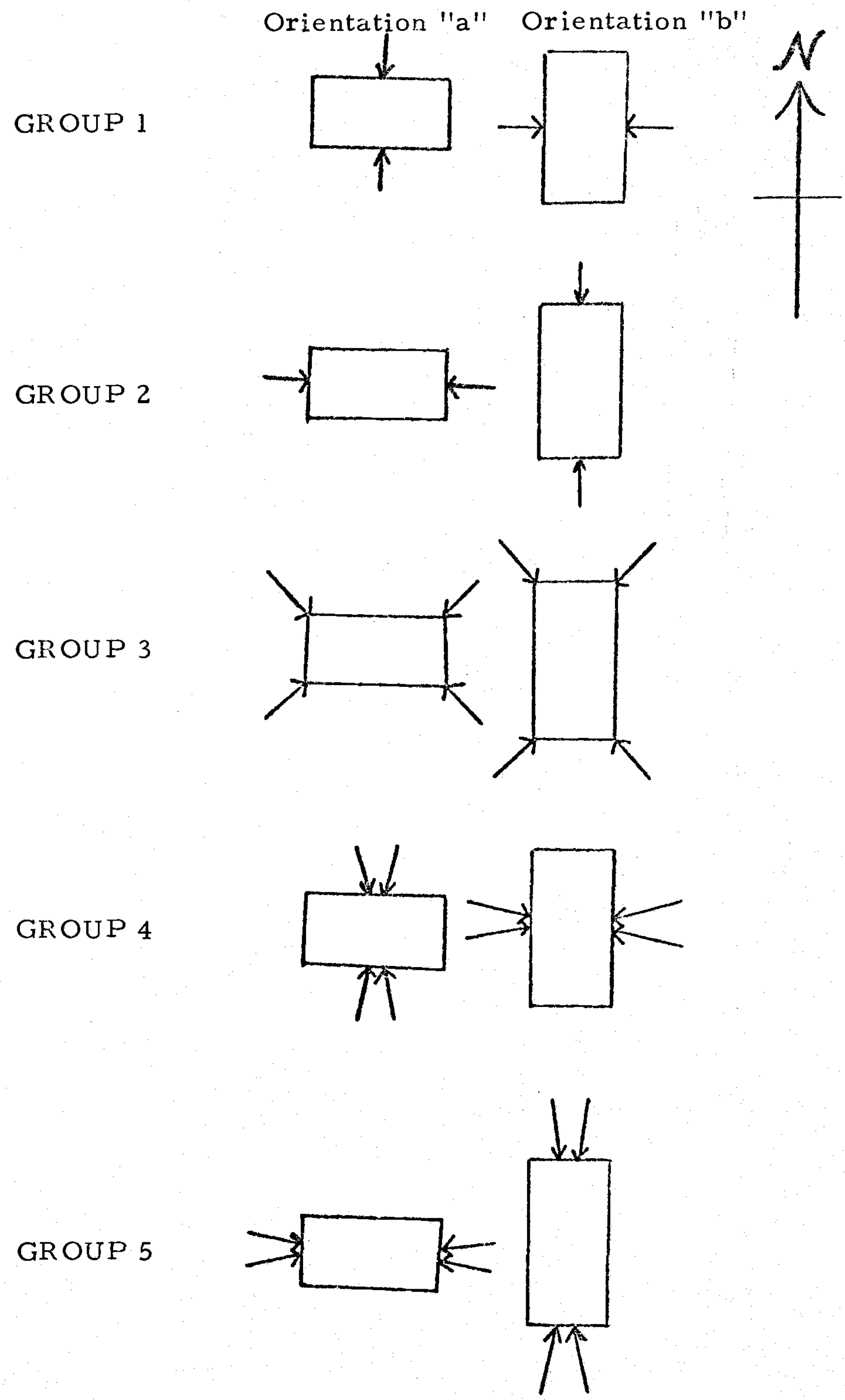


Fig. 2
One bank of manometer tubes showing depth of water caught in respective funnels.


Orientation "a"
Orientation "b"
N
GROUP 1
GROUP 2
GROUP 3
GROUP 4
GROUP 5

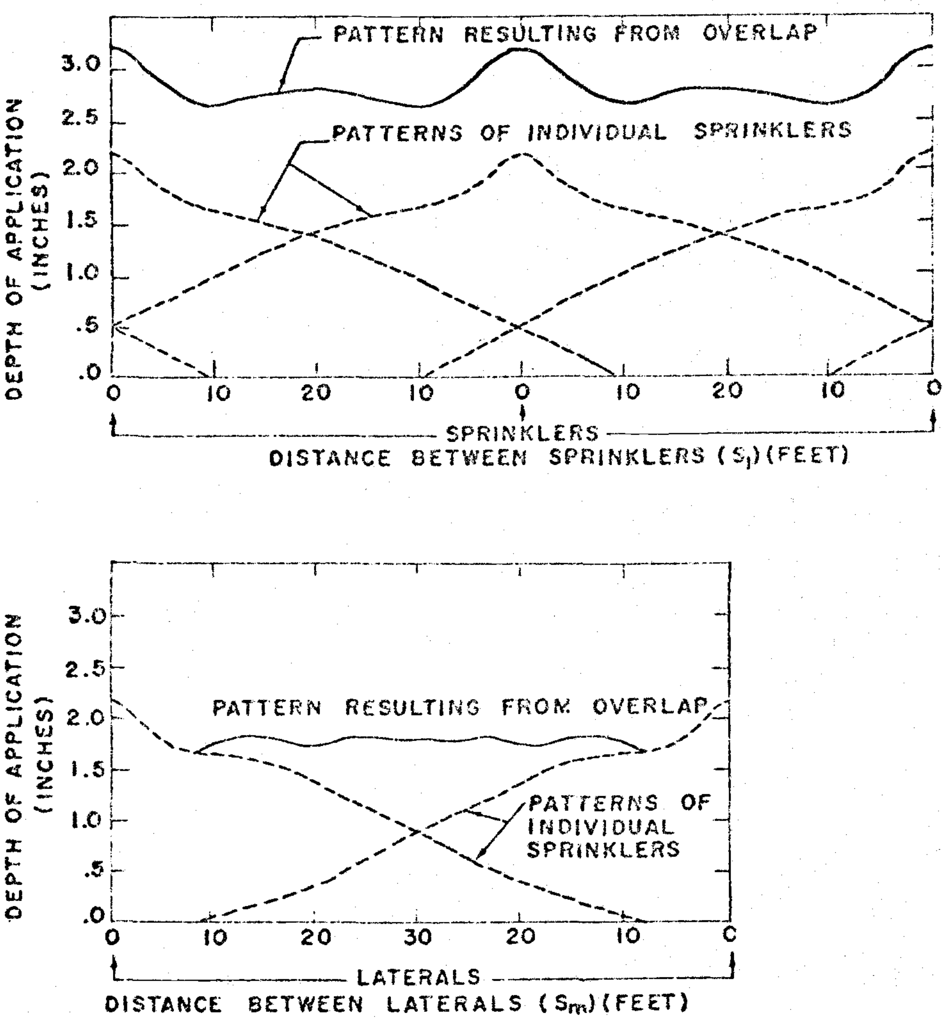


Figure 3. Distribution pattern resulting from overlapping sprinklers.