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Effect of Wind Variation on Water Distribution from Rotating Sprinklers

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Introduction

Numerous experiments have been conducted to determine the uniformity of water distribution from slowly revolving sprinklers. 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.

Rather limited data are available on the effect of wind on water distribution from the use of sprinklers under conditions of comparatively high wind velocities. Sprinkler installations in the past have been developed in areas of relatively low wind velocities. In the Missouri River Basin area, where the average wind velocities exceed 10 m.p.h., sprinkler designs must be modified to meet this condition if satisfactory irrigation efficiencies are to be obtained.

To compare sprinkler patterns and to determine how various factors affect the distribution of water, the numerical expression as developed by Christiansen[2] was used. The uniformity coefficient (K) expressed as a percentage is defined by the equation:

$$K=100\left(1-\frac{\Sigma X}{m\,n}\right)$$

where X is the deviation of an individual observation from the mean value m, and n is the number of observations. An absolute uniform application would be expressed by the number 100 and a less uniform application by a correspondingly lower number.

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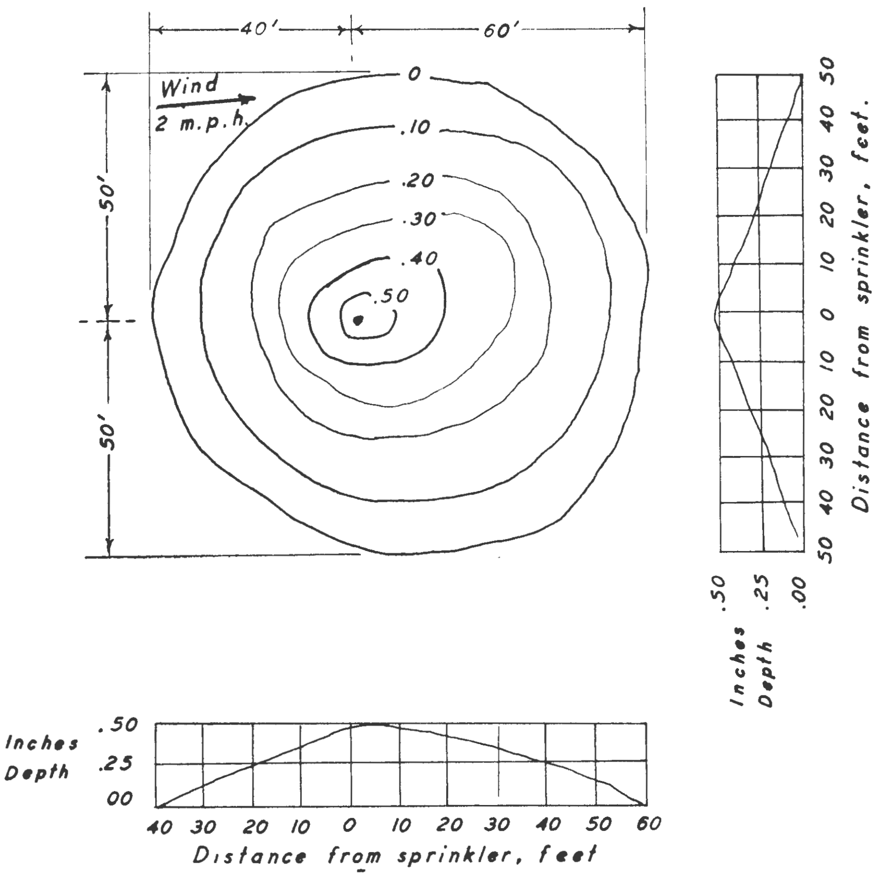
[2]Christiansen, J. E., *Irrigation by Sprinkling*, Calif. Agr. Expt. Sta. Bull. 670, 1942.

Before an analysis of actual field sprinkler patterns is discussed an analysis of a typical geometric pattern will indicate desirable field patterns and also help clarify field results. Figure 1 represents a typical distribution pattern under favorable conditions. The pattern from one sprinkler head is triangular and with the overlays from adjacent heads a nearly uniform application would result.

In the presence of a 14.3 m.p.h. wind a pattern such as in figure 2 might result. The same general pattern exists as in figure 1 except that the triangle is considerably larger on one side of the sprinkler head than on the other. A tendency for a heavy concentration of water near the sprinkler head can be noted. The uniformity coefficients for these two patterns are shown in table 1.

The overlapping uniformity coefficients for the slightly distorted pattern typified by the single sprin-

Figure 1. Typical pattern under favorable conditions.



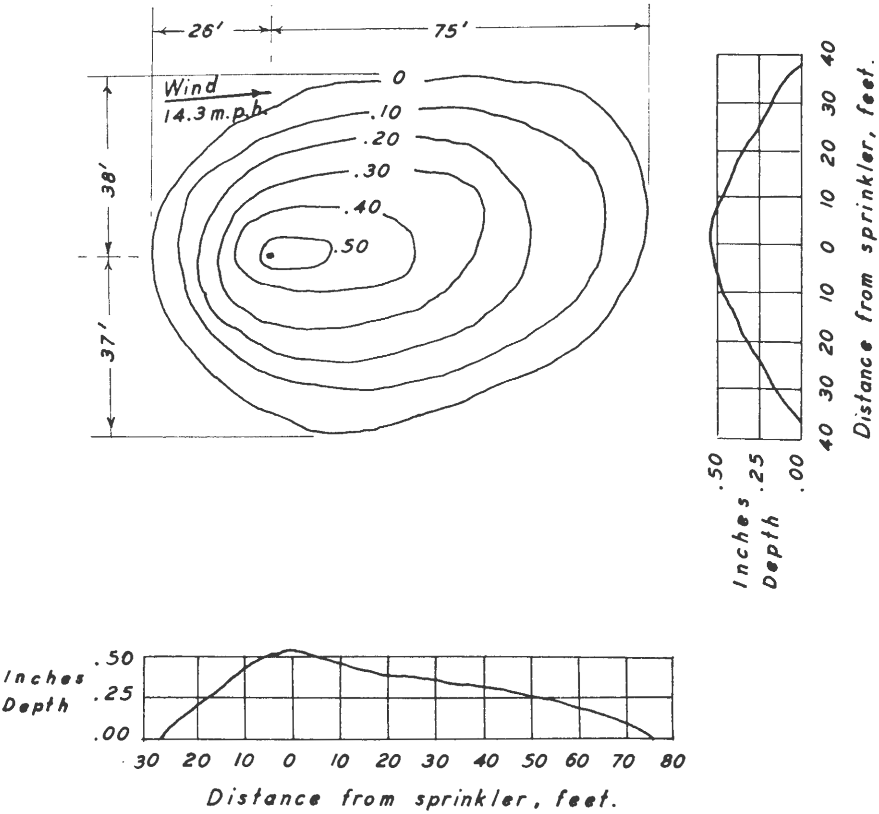


Figure 2. Typical pattern under windy conditions.

kler in figure 1 are higher and considerably less variable than those for the overlapping pattern typified by the single sprinkler in figure 2. Where there is a 14.3 m.p.h. wind, a sharp break in coefficient values is suggested between the 50 feet and 60 feet spacing between lines. The sharp break is present at wider spacing between sprinkler lines in the lower wind velocity pattern.

To overcome the poor water distribution and to locate the point of sharp break in uniformity, a field study was undertaken with the fol-

Table 1. Overlapping Pattern Coefficients for Various Spacing of Heads Within Lines and Spacings Between Lines

Spacing of Heads Within Lines	Spacings Between Lines in Feet 30	40	50	60	70
		(Wind 2 m.p.h.)			
10	97	96	95	91	88
20	95	95	90	89	85
30	94	94	90	87	82
40	94	92	89	86	79
50	92	90	88	84	73
		(Wind 14.3 m.p.h.)			
10	90	90	83	64	57
20	89	89	82	64	53
30	88	87	81	63	50
40	82	80	76	60	43
50	80	76	72	57	37

lowing variables: (1) wind velocity, (2) height of riser, (3) angle of wind with respect to lateral line, (4) water pressure at riser, (5) riser spacing within and between laterals, (6) quantity of water per sprinkler head, and (7) type of sprinkler head.

The angle of wind to lateral line was classified into one of three categories as shown in figure 3. Wind velocities and wind angles were taken at random as they occurred. Wind movement greater than 20 m.p.h. was considered unsuitable. The lowest wind velocity encountered was 4.8 m.p.h.

All sprinkler heads used in this study were made by one manufacturer. A medium weight head with ¾-inch riser outlet was the standard or check head. A heavier head with a 1-inch riser outlet was used, having a longer nozzle but not necessarily a larger size opening. A medium weight head with low angle (under tree) nozzles was also used. A "wind head"[3] was also used, this having a range nozzle only.

Deliverages of different water quantities were made from three sets of nozzle combinations on the standard ¾-inch outlet sprinkler head—5/32 x 3/32 inches, 13/64 x 5/32 inches, and 9/32 x 7/32 inches. The "wind head" used only a 9/32-inch nozzle. The head with a 1-inch riser outlet opening had a 7/32- x 3/16-inch nozzle, and the low angle head had a 3/16- x 3/16-inch nozzle.

Four riser heights were used—6-, 12-, 24-, and 48-inch. The 24-inch riser was most often used. Only medium weight heads with 13/64- x

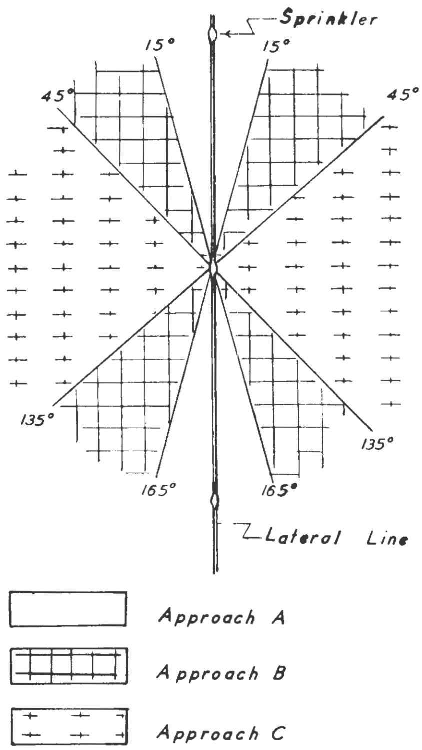


Figure 3. Division of wind approach.

5/32-inch nozzle combinations are used on the 6-, 12-, and 48-inch risers.

Water pressures from 25 to 70 pounds per square inch gauge were used in these tests. The major portion of the tests were conducted at pressures between 30 and 50 pounds. In previous experiments pressures below 30 pounds gave poor distribution patterns even with all other factors favorable. Be-

[3]The term "wind head" is slang terminology for a sprinkler head which has only a range nozzle. It would refer to a head which was designed for a single nozzle or a head on which the spreader nozzle has been replaced by a plug or another range nozzle.

cause of cost, a riser pressure of more than 60 pounds per square inch gauge is seldom used.

A maximum number of combinations of riser spacings within lines and of spacings between lines were used. The riser spacings within lines varied from 10 to 40 feet and between the lateral lines from 30 to 60 feet, all in 10 feet increments. A total of 16 different combinations was used.

Arrangement used to determine the effect of wind on water distribution.

Procedure

The first series of tests were run on a standard sprinkler system with risers spaced 40 feet apart on the lateral line. Sixteen-ounce soil cans were placed 5 feet apart on a grid system between the risers as far as the water was sprinkled to either side of the lateral. The second series of tests were run with three risers spaced a sufficient distance apart to prevent overlap of sprinkled area between heads. One-quart oil cans were spaced on a 5-foot grid around each riser. By placing a different type head on each riser or by combining different nozzle sizes on each head, a comparison was possible between sprinklers or nozzles under identical conditions.

A 3-cup totalizing type anemometer with dial for registering wind movement was mounted 4 feet above the ground during all tests. A pressure gauge was mounted on each riser.

Duration of the first series of tests was 1 hour and the second series 2 hours. Uniformity of sprinkler head rotation was checked repeatedly during each test, and when rotation was not uniform, the tests were discarded. The speed of sprinkler rotation for all tests was between one and three revolutions a minute.

Water deposited in the cans was measured to the nearest 1 cc. in the 16-ounce cans and to the nearest 5 cc. in the 1-quart cans.

To obtain patterns for specific spacings, the patterns were overlapped and the resulting depth of application was calculated for points spaced 5 feet apart both ways. The application from all sprinklers affecting the net area was included.

Except for "t" tests of paired comparisons the data were analyzed by computing the linear regression of uniformity coefficients on wind velocity, using like conditions with different wind velocities. The equation $K=a+bX$, where K = uniformity coefficient; X = wind velocity; a is equal to K when X is equal to zero; and b = slope of the line. The following formulas were used to compute a and b;

$$a=\frac{(\Sigma X^2)(\Sigma K)-(\Sigma XK)(\Sigma X)}{N\Sigma X^2-(\Sigma X)^2}$$

$$b=\frac{(\Sigma XK)-(\Sigma X)(\Sigma K)}{N\Sigma X^2-(\Sigma X)^2}$$

where N is the number of tests.

Correlation coefficients r, were also computed for each set of data using the equation:

$$r=\frac{Sxk}{(Sx^2)(Sk^2)}$$

Results

Comparison of Riser Heights

Riser height has little or no effect on distribution pattern for wind velocities of less than 4 m.p.h. For the present comparisons wind velocities of 4.8 m.p.h. or greater were selected. Riser heights were 6, 24, and 48 inches. Sprinkler heads discharging 12 gallons per minute (g.p.m.) at 40 pounds per square inch (p.s.i.), were spaced 40 feet apart on the lateral lines and the lateral moves of 40, 50, and 60 feet apart were used.

As may be seen from the analysis shown in table 2 there was a highly significant difference between the 6- and 24-inch riser heights, a lower significant difference between the 24- and the 48-inch riser heights and a still lower significant difference between the 12- and 24-inch riser heights. However, there was a 12-inch difference in riser heights in the last comparison while the difference was greater in the other two comparisons.

In all subsequent tests a riser height of 24 inches was used.

Under actual irrigation practice the type of crop grown will influence the minimum height of riser that can be used. The sprinkler head must be above the vegetative growth of the crop irrigated. Corn requires the tallest riser of the common crops grown in this area. The limitations of the maximum height riser will be influenced by the ease of handling the lateral line when moved from one position to another, the tall risers being more difficult to handle. On specialized equipment such as the wheel move laterals, there are also limitations on length of risers that can be used.

It is recommended that sprinkler installations be equipped with the tallest riser that can be easily handled by the operator.

Angle of Wind with Respect to Lateral Line

Distribution coefficients affected by wind angles are compared in table 3.

The comparisons were confined to sprinkler heads discharging 11 to 13 g.p.m. at pressures of 40 to 58 p.s.i. Sprinkler heads were spaced 40 feet on the lateral line, with lateral moves 50 to 60 feet apart.

In no case was the pattern coef-

Table 2. Summary of Comparison of Different Riser Heights

	Comparing 6″ with 24″		Comparing 12″ with 24″		Comparing 24″ with 48″	
Difference of K	10.9		4.9		3.7	
Mean wind velocity	13.4 m.p.h.		9.6 m.p.h.		8.2 m.p.h.	
Range in wind velocity	1.5 –14.7		4.8 –12.3		6.4 –10.1	
Number of tests	12		24		24	
S_x	3.65		3.13		1.78	
t	2.99		1.46		2.08	
P	less than 2%		greater than 16%		less than 5%	
	6″	24″	12″	24″	24″	48″
Mean value of K	64.0	74.9	73.9	78.5	79.2	82.9

ficient signficantly different when the angle of wind was different. However, a better pattern seemed to be obtained when the wind angle was 15 to 45 degrees with the lateral than when the angle was higher or lower. In the remaining analysis the wind approach was disregarded except when it was parallel to the lateral line.

Manufacturers recommend that in design, lateral lines should run perpendicular to the direction of the prevailing wind. Except in certain localized areas, direction of prevailing winds is a meaningless term during the irrigation season. The actual percent of time winds are in the prevailing direction is small. It is of greater importance to the irrigator to make allowances for changes in wind direction from day to day. This will be discussed under the section on riser spacing and lateral move.

Pressure

The calculated linear regressions of pattern coefficients on wind velocity and their correlation coefficient at water pressures of 30, 40, 48, and 56 p.s.i. are shown in figures 4 and 5. In these tests, a medium weight sprinkler head was used with ¾-inch riser outlet on a 24-inch riser, and 13\64- x 5\32-inch nozzles.

Little or no difference of pattern coefficients was obtained between 56 and 48 p.s.i. while a slight difference was obtained between 30 and 40 p.s.i. However, the higher pressures are superior, and the slope of the line is less, indicating that as wind velocities increase the effect of pressure is more pronounced. There are indications that pressures greater than 56 p.s.i. would be of little value in obtaining better patterns.

When a sprinkler head is operating within the manufacturers recommended range of pressures the increase in uniformity by increasing pressure is not significant enough to verify the increase of pumping costs to obtain this added pressure.

Riser Spacing and Lateral Move

This analysis was confined to the medium weight sprinkler head on a 24-inch riser with 13/64- x 5/32-inch nozzles operating at a pressure of 40 p.s.i.

As may be seen from the calculated regression lines in figure 6, the

Table 3. Summary of Comparison of Angle of Wind With Respect to Lateral Line

	Comparing Group A & B		Comparing Group A & C		Comparing Group B & C	
Difference of K	1.7		0.5		1.8	
Mean wind velocity	9.5 m.p.h.		9.2 m.p.h.		8.8 m.p.h.	
Range of wind velocity	7.1 –12.6		7.3 –12.6		6.4 –12.0	
Number of tests	20		10		20	
S_x	3.11		3.70		2.8	
t	0.55		0.14		0.64	
P	greater than 50%		greater than 50%		greater than 50%	
	A	B	A	C	B	C
Mean value of K	71.6	73.3	76.1	75.6	74.8	76.6

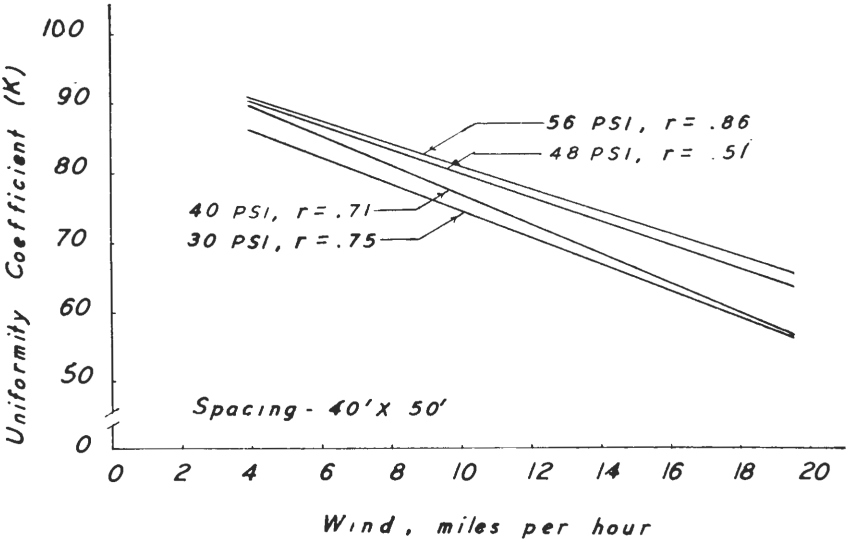
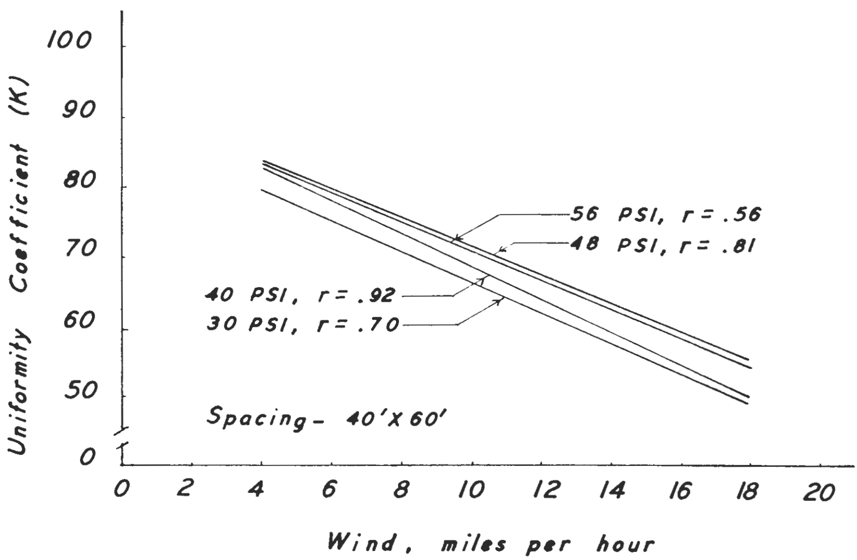


Figure 4. Comparison of uniformity for various pressures—40 by 50 foot spacing.
r=Correlation Coefficient

Figure 5. Comparison of uniformity for various pressures—40 by 60 foot spacing.
r=Correlation Coefficient



lines are grouped closer by lateral move than by riser spacing. The grouping is significant, as many irrigators are attempting to improve patterns by decreasing riser spacing rather than lateral move. This is natural because the labor involved in moving pipe is greater.

In calculating the distance a lateral is to be moved, not only wind velocity but wind direction with respect to previous setting must be taken into account. It is 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.

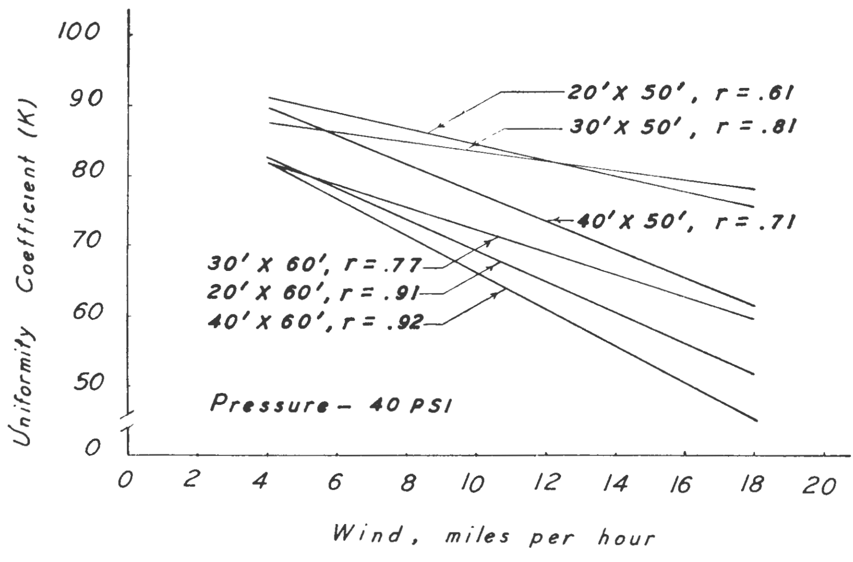
Refer to figure 2 for an explanation of this recommendation and assume the lateral to be in a north-south direction. The wind could change direction between lateral moves. It may be in a westerly direction as indicated for one setting, and if the next setting were the next day it could be in an easterly direction.

Applying the recommendation to a lateral move in which the wind did not change in velocity or direction, the wetted diameter would be 101 feet (26 + 75 feet). Therefore the lateral would be moved 50 feet (50 percent of 101 feet).

If the wind changed from west to east, and the pipe line was being moved to the right, the wetted diameter would be 150 feet (75+75 feet). The pipe should be moved not more than 75 feet.

If conditions were as above but the pipe was being moved to the

Figure 6. Comparison of uniformity for various spacings. r=Correlation Coefficient



left, the wetted diameter would be 52 feet (26 + 26 feet). The maximum distance of the move would be 26 feet (50 percent of 52 feet). The actual recommended move would be 20 feet due to standard pipe lengths.

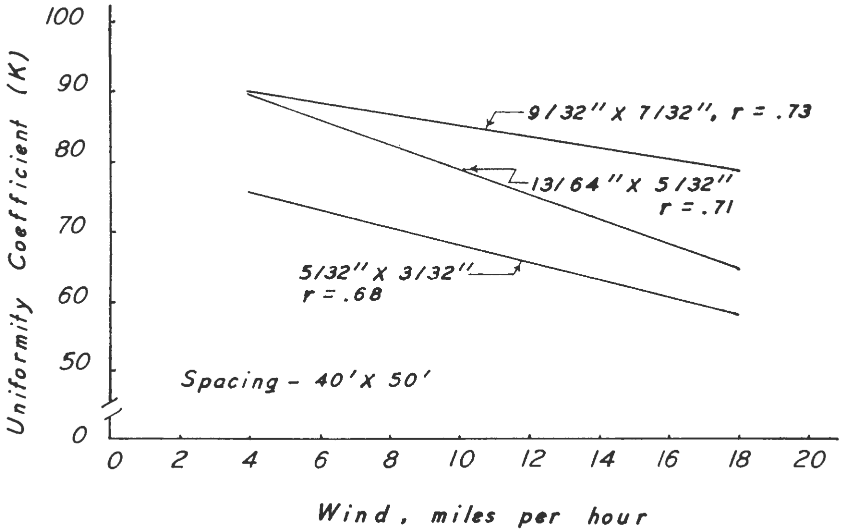
Quantity of Water

The quantity of water delivered from a given type head may be changed by altering the size of the nozzle. In this study, 5/32 x 3/32 inch, 13/64 x 5/32 inch, and 9/32 x 7/32 inch nozzle combinations were used within the medium weight sprinkler head on a 24-inch riser. The operating pressure was 40 p.s.i.

The calculated regression lines for distribution coefficient on wind velocity are shown in figures 7 and 8. Nearly the same coefficients were obtained from the medium as from the large nozzle at low wind velocities, but at higher wind velocities the larger nozzle was superior to the medium nozzle. The small nozzle cannot compete with the larger nozzles under any wind condition. At higher wind velocities, its efficiency approaches that of the medium nozzle.

For a given sprinkler spacing, the rate of water discharge per sprinkler head has a direct relationship to the precipitation rate. In certain instances an irrigator may have a choice of the precipitation rate for which the system will be designed. The water intake rate of the soil, quantity of water available, the labor schedule, and the farm layout

Figure 7. Comparison of uniformity for different size nozzles—40 by 50 foot spacing. r=Correlation Coefficient



will influence the most desirable precipitation rate to use.

It is recommended that to gain uniformity of water distribution, the greatest possible discharge per sprinkler be used within recommended lateral line and sprinkler spacing.

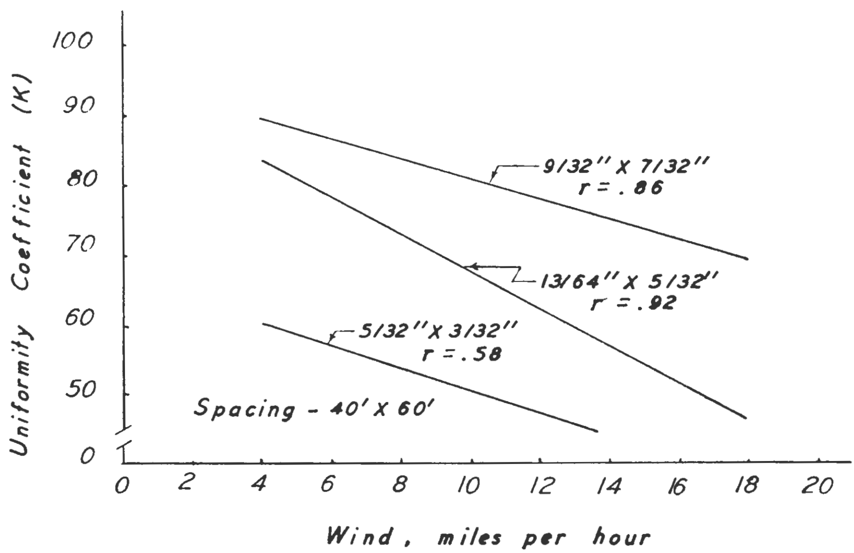
Type of Sprinkler Head

Four types of sprinkler heads mounted on 24-inch risers were tested: standard medium weight head with a ¾-inch riser outlet, as used in other tests; a heavier 1-inch riser outlet head with longer nozzle inlets, on which 7/32- x 3/16-inch nozzles were used; a low angle (under tree) head, with 3/16- x 3/16-inch nozzles; and a head provided with a single 9/32-inch range nozzle ("wind head"). All tests were conducted at a pressue of 40 p.s.i.

Figures 9 and 10 provide a comparison of the calculated linear regression of uniformity coefficients on wind velocities for various heads and nozzle sizes at 40 x 50 feet and 40 x 60 feet spacing. At both spacings the uniformity coefficients were affected more by the quantity of water discharged from the range nozzle than by the type head used. However, the low angle head was decidedly inferior to other types. The "wind head" appeared superior for lower precipitation rates during excessive wind.

The calculated linear regression of the distribution pattern coefficients on wind and velocity produced by different nozzle sizes and

Figure 8. Comparison of uniformity for different size nozzles—40 by 60 foot spacing. r=Correlation Coefficient



types, and spaced to precipitate 0.9-inch water per hour, are shown in figure 11.

The low angle head, the head with 13/64- x 5/32-inch nozzles, and the "wind head," all were spaced 20 feet on the lateral line and 50 feet on the lateral move. The larger head with 9/32- x 7/32-inch nozzles was spaced 40 feet on the line and a lateral move of 50 feet was made. The arrangement is such that the

Figure 9. Comparison of uniformity for various heads and nozzles—40 by 50 foot spacing.

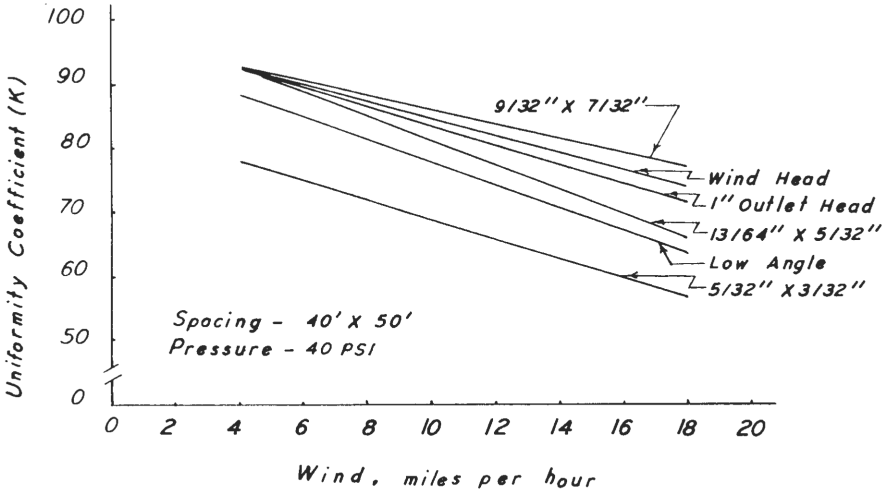
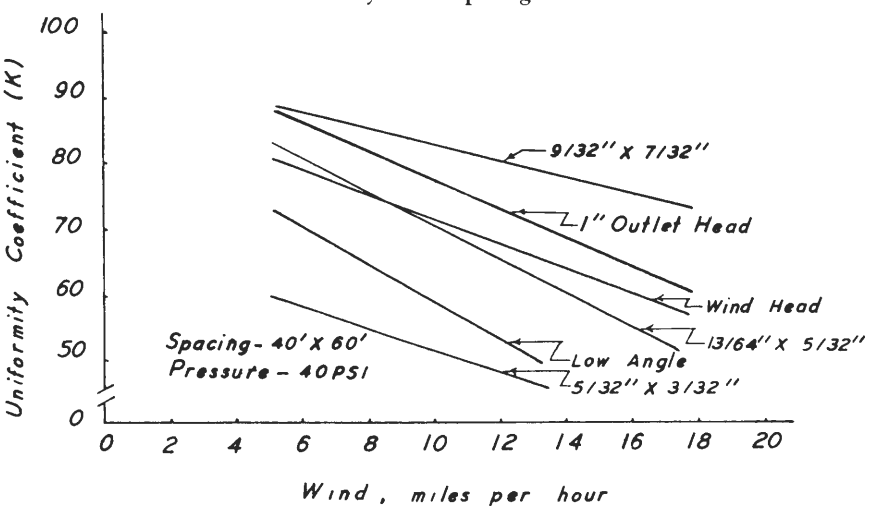


Figure 10. Comparison of uniformity for various heads and nozzles—40 by 60 foot spacing.



same amount of labor would be required to move the pipe under actual irrigation conditions.

The difference was in the spacing of the heads on the line. At low wind velocities of 4 m.p.h. or less, there was little difference in the pattern produced by any nozzle. With wind velocities of 8 m.p.h., or greater, the "wind head" with a spacing of 20 x 50 feet was superior to any other nozzle combination. The low angle nozzle line was the least efficient, especially as the wind velocity increased.

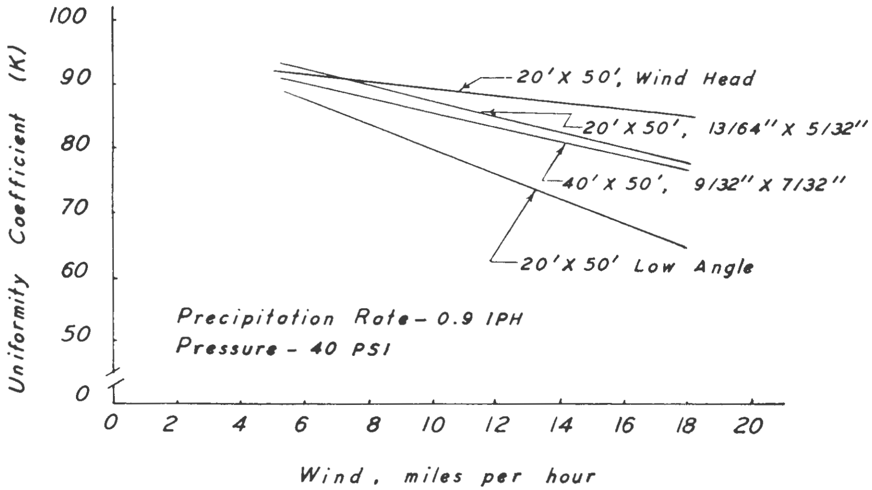
The efficiency of the larger nozzle with a 40-foot spacing on the line and of a medium size nozzle with a 20-foot spacing in the line were very nearly the same. By spacing these nozzles 20 feet in the line, twice as many heads per lateral line would be required than at the 40-foot spacing. The installation cost of a sprinkler system would be increased with no resulting benefits. However, if a "wind head" were spaced 20 feet on the line a much better pattern would be obtained in the higher wind velocities. At wind velocities of less than 4 m.p.h., the "wind heads" would not distribute the water as evenly as other types.

In a further comparison of efficiencies of nozzle sizes and spacings shown in figure 12, in which the precipitation rate was 0.6 inch per hour, nearly the same conclusions may be drawn as from figure 11. There would be less labor with 30 x 60 feet spacings but it is inferior to other types of heads at higher wind velocities. For wind velocities of 7 m.p.h. or greater, the wind type or single nozzle sprinkler is superior to other heads.

Miscellaneous Results and Observations

Two other types of sprinklers, the perforated pipe and the hydraulic

Figure 11. Comparison of uniformity for equal precipitation rate—0.9 IPH.



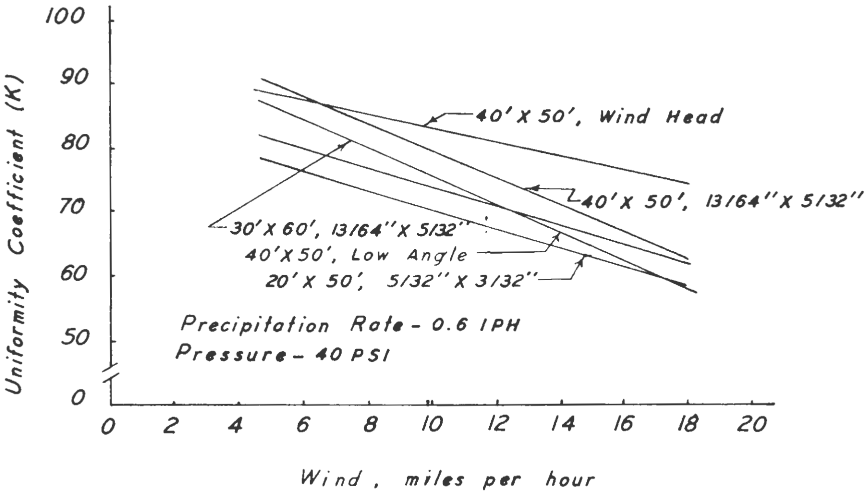
sprinklers, are becoming more popular. The operating characteristics differ from the sprinklers tested in the previous discussion.

The perforated pipe, which operates at a low pressure, is gaining in popularity due to savings in power costs. Increased labor is needed to move the pipe the short distances that are applicable. A number of tests were completed to determine the effect of wind on the distribution pattern. It was concluded that wind had less influence on the perforated pipe pattern than on conventional sprinklers. However, extreme caution must be exercised in determining the distance the lateral can be moved. It should be carefully calculated as explained in the section on sprinkler spacing and lateral move.

The large hydraulic type sprinkler heads, which operate at pressures ranging from 70 to 120 p.s.i. and discharge from 100 to 600 gallons of water a minute offer a savings in labor when conditions are such that they can be used. A limited number of tests were completed to test uniformity of distribution. Until more work is completed they are not recommended unless operation is confined to times when wind velocities are less than 4 m.p.h.

Work has been completed to determine the effect of uniformity of water distribution when the riser pipe on which the sprinkler head was installed is not vertical. It shows a significantly better pattern is obtained from vertical risers than from those having an angle as small as 5 degrees from the vertical. Angles greater than this result in even poorer patterns. It is recommended that the system be designed so a minimum amount of caution need be exercised by the operator to have

Figure 12. Comparison of uniformity for equal precipitation rate—0.6 IPH.



risers vertical after laterals are moved.

Crop responses indicate uniformity of application can be improved by offsetting the lateral one-half of the normal move every other irrigation. Several patterns were analyzed to evaluate this possibility.. It is recommended that if a standard move is adapted by an operator instead of using a calculated move as explained in the section on lateral moves, that laterals be offset every other irrigation one-half of the distance of the standard move.

Summary

Sprinkler systems have been designed in the past on the basis of a maximum wind velocity of 4 m.p.h. or less. In South Dakota an average wind velocity in excess of 10 m.p.h. is often experienced during the irrigation season. Unless original designs are modified poor irrigation efficiency is obtained.

A number of tests were made from which uniformity coefficients were calculated. From an analysis of these data the following conclusions were reached:

(1) Tall risers are superior to short risers.

(2) Angle of wind with respect to lateral line has little or no effect on the distribution pattern.

(3) A definite breaking point occurs between a 50-foot move between lines and a 60-foot move between lines.

(4) High pressures are superior to low pressures.

(5) Large quantities of water per nozzle result in better patterns than small quantities of water.

(6) In winds of 8 m.p.h. or greater, a head with only the range nozzle is more efficient than a head with both a range nozzle and a spreader nozzle.

(7) A sprinkler head with a large water capacity spaced 40 feet on the line is as good as heads with water capacity spaced 40 feet on one-half of the water capacity spaced 20 feet on the line.

In this study, the distribution coefficient was the only criterion considered. The conclusions may have to be modified when soil crusting, evaporation losses, labor schedules, rates of soil infiltration, size of water supply, type of equipment available, and the types of crops grown are considered in assessing the efficiency of sprinkler systems.