A New Way to Characterize Landscape Sprinklers Performance

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Over the years, there has been various ways used to characterize how landscape sprinklers perform and various ways to measure performance in the field. These methods have been adapted from agricultural irrigation to describe system performance. There have also been computerized programs that allows a designer to consider spacing and sprinkler configuration to determine the optimal spacing for best performance.

Christiansen (1942) developed a numerical index representing the system uniformity of overlapping sprinklers. This coefficient of uniformity (CU) is a percentage on a scale of 0 to 100 (absolute uniformity). It considers the average deviation and treats dry areas and wet areas equally.

$$CU = 100\left(1 - \frac{\sum x}{n \times m}\right)$$

CU = Equal distribution coefficient developed by Christiansen (%)
x = The total absolute value of deviations from average volume of water caught
m = Average amount of water (mm, mL)
n = The number of water accumulation containers

Distribution Uniformity lower quarter has been the metric most commonly used to measure sprinkler performance in landscape applications. It is focused on the areas receiving the least amount of water and compares the lowest 25 percent of catchments to the average of all of the catchments.

$$DU_{lq} = \frac{V_{lq}}{V_{avg}}$$

DU_{lq} = Distribution Uniformity lowest quarter expressed as a decimal fraction
V_{lq} = average volume of water of lowest 25% of catchments
V_{avg} = average volume of all catchments

In recent years there has been discussion that for landscape irrigation, using distribution uniformity lower half would be a better metric and especially when considering additional run time for irrigation stations. DU_{lh} provides a metric that is very similar to CU, especially in well-designed irrigation systems. The Irrigation Association introduced the concept of Scheduling

Multiplier first in the Golf Irrigation Auditor book and later in the in the Landscape Irrigation Auditor book to provide guidance on the amount of extra water or additional run time to compensate for the non-uniformity of water application and how it manifests itself in the appearance of the turfgrass. The SM is based on DU_{lq} and a simplified equation that would make it nearly equal to DU_{lh}, especially on good performing systems, while on poor performing systems the SM would reduce the extra amount of water or run time than just using DU_{lh}. The SM essentially made a "cap" on how much extra water or run time is added to the calculated depth of water or run time assuming nearly perfect conditions.

Scheduling coefficient is another metric that has been used to evaluate the effectiveness of a particular layout of sprinklers considering sprinkler spacing and sprinkler configuration such as square, rectangular or triangular. SC is calculated for landscape irrigation as the driest contiguous five percent of the area compared to the overall area. The ideal SC = 1.0. This particular metric is not measured in the field, but rather is a determined from computer programs that can use a sprinkler profile as shown in Figure 1 to create densograms as shown in Figures 2 and 3. The densograms provide a picture of the distribution of water with wet areas indicated by the darker shading and the drier areas indicated by lighter shading. Figures 1 and 2 show the same sprinkler but in different spacing configuration with the metrics of DU_{lq} and SC calculated.

Figure 1. Sprinkler profile

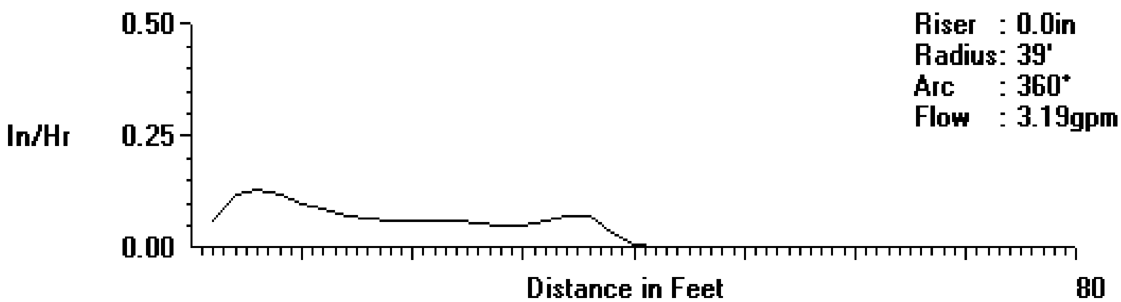
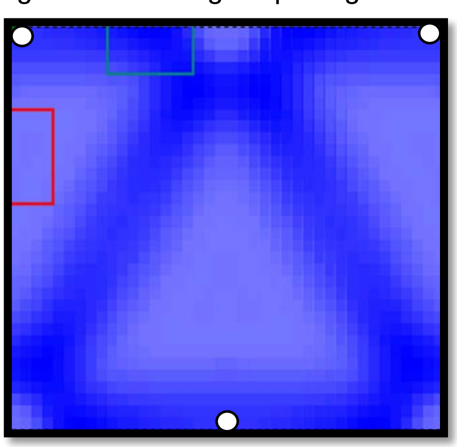
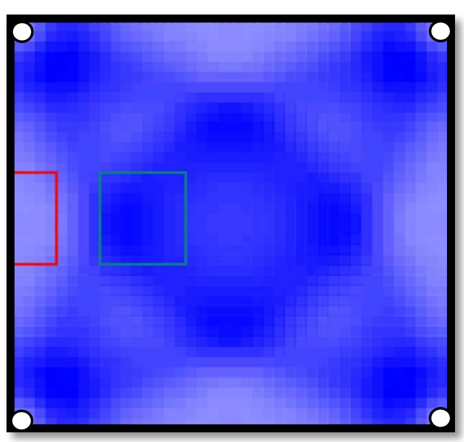


Figure 2. Triangle Spacing



39' x 34' SC = 1.3 DU_{lq} = .82

Figure 3. Square Spacing



39' x 39' SC = 1.6 DU_{lq} = .73

The densograms show the distribution of water for the sprinkler indicated in the sprinkler profile with a maximum radius of throw of 39 feet. In this particular instance, equilateral triangular spacing provides a better distribution of water to the area rather than square spacing. This tool helps designers determine the optimal sprinkler spacing and configuration for each type of sprinkler and nozzle being considered for use in the field. This can change with each sprinkler and operating pressure, so it is difficult to provide a rule of thumb. A common design practice is to reduce sprinkler spacing by 10 percent to improve performance. However, the densograms don't show what happens to the water that is thrown off target and the computer program doesn't allow you to reduce the radius of throw as would be done in the field, so the results are often different than the design.

So while the various metrics for evaluating sprinkler performance have been used they have focused on the dry areas of coverage and then irrigation scheduling has been modified, usually with additional run times for the stations covering the area to reduce or eliminate any stressed areas for the best possible appearance. What is not measured is the amount of water that has been applied beyond the target area such as overspray or the amount of water that has percolated below the root zone. While overspray is visible, characterizing or accounting for deep percolation has not been evaluated in landscape irrigation.

A New Testing Methodology

Beginning in 2012, Smart Water Application Technologies began to develop a testing protocol for sprinkler nozzles. Originally, the intent was to test nozzles that were advertised or sold as being more efficient. A final testing protocol was published in April 2015. A few unique concepts with this testing protocol was to test sprinklers more as they are used in the field. Two defined areas based on the radius of throw of the sprinkler is a square that is twice the diameter of throw in dimensions and allows for four quarter-circle nozzles, four half-circle nozzles and one full- circle nozzle to create the test area, therefore a 15-foot radius nozzle would have a 30-foot by 30-foot square. The other shape is a circle, the diameter of the circle being twice the radius of throw and includes one full-circle nozzle and six part-circle nozzles with arcs adjusted to minimize overspray. The square shape being the one that should be optimal and the circle representing amoeba-shaped turf areas where keeping all of the water on target is a challenge.

The sprinkler nozzles would be evaluated for distribution uniformity and also sprinkler operational efficiency trying to characterize where all of the water is going.

In 2014, the Center for Irrigation Technology (CIT) was asked to develop a protocol that would be useful in administering sprinkler rebate programs. The objective of the program was to encourage the development of more efficient turf irrigation sprinklers. If successful in developing the test protocol, it could be administered by third-party testing agencies to pre-quality turf sprinklers for rebate programs. Threshold performance standards would be prepared by extensive testing of currently available sprinklers. This testing would establish the current state of the commercial art. Threshold performance values thus set should result in rebates being offered to encourage improved irrigation sprinkler operating efficiencies.

The challenge was no test protocol existed that provided a calculation of the sprinkler operating efficiency. Further, the current commonly used test protocol is scientifically suspect. This current protocol involves using a wetted radius lab study with computerized overlap simulations as a basis for system performance metric calculations. The protocol makes no allowance for jet mechanical interference and its effect on uniformity of application and other mechanics. This new protocol then uses a full grid testing layout with sprinklers located to duplicate actual field installations. Currently, used performance metrics such as distribution uniformity (DU) and coefficient uniformity (CU) were abandoned in this effort except for historic reference.

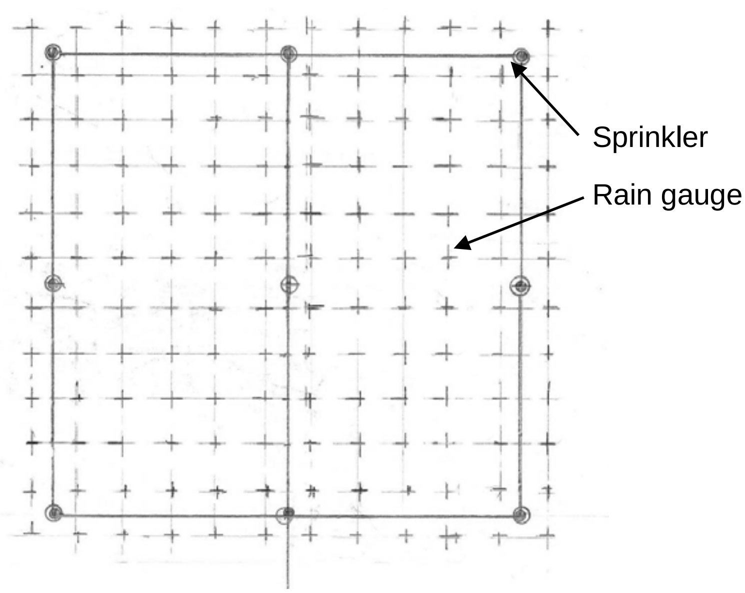
LABORATORY LAYOUT AND INSTRUMENTATION

Whenever feasible, products should be tested in a manner that duplicates their actual field use as closely as possible. The sprinklers in this study were all tested in a full-scale layout on the smooth concrete floor of the CIT sprinkler test building.

The sprinkler spacing was a square grid with a distance of 15 ft between sprinklers. The PVC piping network was sized to keep velocities below 3.0 fps. Test pressures were as registered to an accuracy of 0.5 percent in the plumbing network into which the sprinklers were attached. Rain gauges had a 4-in. diameter and recorded applications to the nearest 0.01 in. Flow measurement accuracy was to 1.0 percent. The building environment represents a zero wind environment. Sprinkler run times were set to provide an average catchment of 0.50 to 0.75 inches. Environmental measurements included temperature, humidity, and barometric pressure.

Grid rain gauge spacing was 3.0 ft by 3.0 ft. The target area was 30 ft by 30 ft representing a model yard and contained 100 evenly-spaced rain gauges (see Figure 1). The target area was surrounded by a single row of rain gauges. The gauges were spaced to represent the catchment within three feet of the target boundary. Virtually no water droplets were detected beyond the rain gauge grid geometry. A special valving arrangement allowed for nearly instantaneous system start up and shut down.

Figure 1. Sprinkler layout and catch device placement



EVOLUTION OF PERFORMANCE PARAMETERS

Inefficiencies in turf sprinkler performance result from: losses to deep seepage caused by pattern non uniformities; losses due to over spraying of the target area; and losses to atmospheric evaporation. With the water distribution measured at the grass canopy, surface evaporation of drops that never reach the grass canopy is automatically accounted for. Strictly speaking, this evaporation loss should be accounted for because it could be caused by a variable in sprinkler design. Instrumentation to account for evaporation losses is prohibitively expensive.

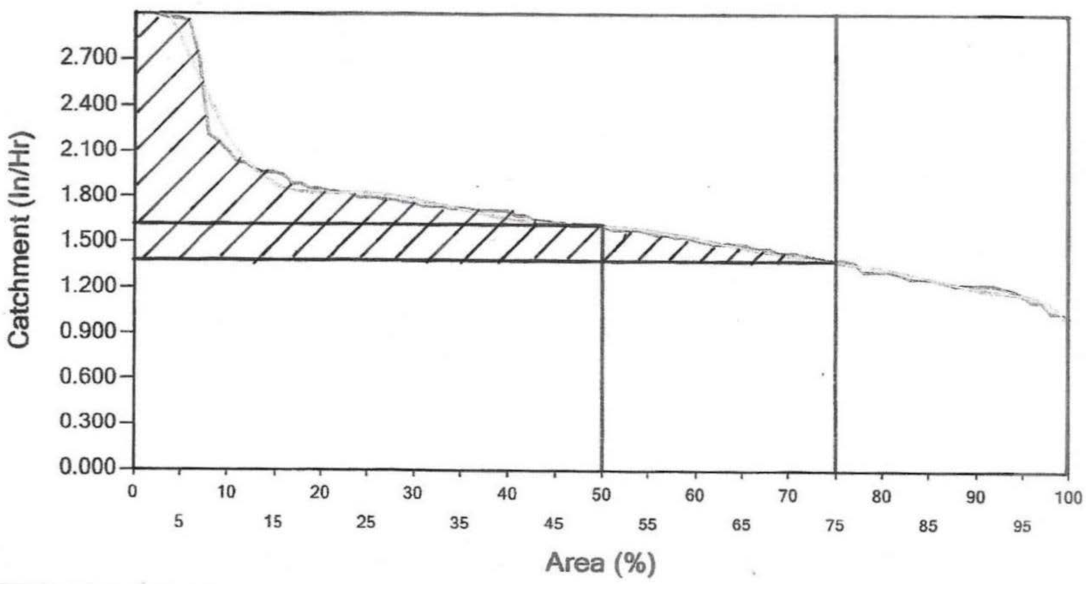
Losses to deep seepage result from the repeated use of non-uniform patterns. Repeated use results in a tendency to index wet-on-wet and dry-on-dry spots between irrigation rounds. In practice, this is compensated for by over-irrigating the dry spot to maintain adequate dry spot quality. As a result of this over-irrigation, the wet spot will drive the surplus water through the wet spot into the subsoil. The formula for calculating this percolation loss (PL) is as follows:

$$PL = \frac{\sum_{1}^{75}(x......x_i)}{n(\bar{X})}$$

PL = Percolation losses
x = application rate of each individual catchment
x_i = application rate at 75% of area
n = number of catchments
$\bar{X}$ = average application rate

The calculation is shown graphically in Figure 2.

Figure 2 Graphic representation of percolation loss



The 100 catchments are arrayed from wet (left side) to dry (right side). The percolation loss is represented by the shaded area in Figure 2. The concept makes the assumption that the commercial grass quality is adequate as long as 75 percent of the target area receives the scheduled amount of irrigation.

Overspray (OS) is directly related to the water caught in the rain gauges outside of the target area. The formula for the overspray losses is as follows:

$$OS = \frac{\sum os}{n(\bar{X}) + \sum os}$$

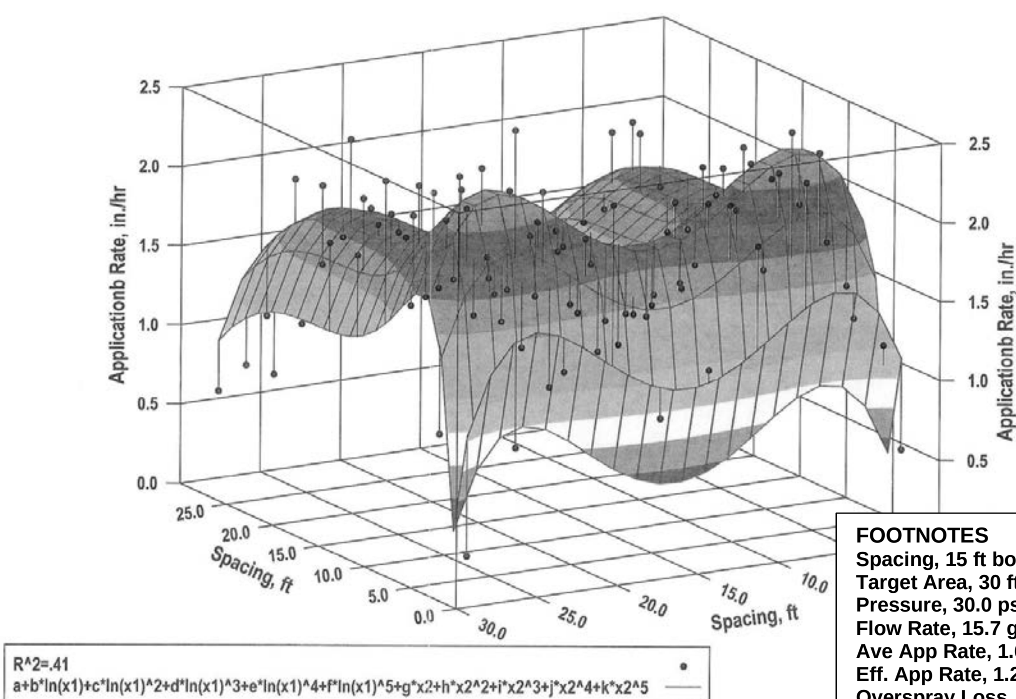
The sprinkler operating efficiency (S_{OE}) combines the percolation and overspray losses in the following formula:

$$S_{OE} = (1.0 - PL)(1.0 - OS)100$$

The sprinkler operating efficiency metric has physical significance and is useful in studies requiring a scientific characterization of the irrigation system water use efficiency.

GRAPHICAL CHARACTERIZATION OF SPRINKLER OPERATING EFFICIENCY

Figure 3 provides a graphical representation of the results suitable for determining the system required design parameters. Shown in Figure 3 is a 3D plot of a representative sprinkler pattern test.



FOOTNOTES
Spacing, 15 ft both ways
Target Area, 30 ft by 30 ft square
Pressure, 30.0 psi
Flow Rate, 15.7 gpm
Ave App Rate, 1.63 in./hr
Eff. App Rate, 1.26 in./hr (75%)
Overspray Loss, 1.9%
Percolation Loss, 26.3%
Sprinkler Operating Efficiency, 72.3%

Figure 3. 3D plot of a representative nine sprinkler overlapped pattern

The sprinkler operating efficiency is 72.3 percent reflecting a percolation loss of 26.3 percent and an overspray loss of 1.9 percent. The plot is useful in experimenting with the overlapping of patterns to achieve better uniformity. This leads also to the best relationship between the flow rates of full and part circle sprinklers. It also graphically shows the jet interference phenomenon and the chronic problem of achieving satisfactory coverage next to the sprinklers. It may be possible to partially correct for this by a two-set system providing for different run times of full circle sprinklers complemented by a longer run time for the part circle boundary sprinklers.

REPRESENTATIVE METRICS

Table 1 shows the results of testing sprinklers in the manner proposed. The square target area is as shown in Figure 1. The round target area is as proposed in the SWAT testing protocol. The importance of combining the percolation loss and the overspray loss can be seen by comparing the results from square Test #2 with #3. Both tests have sprinkler operating efficiencies over 80 percent. In Test #2, the overspray loss was negligible at 0.1 percent. With Test #3 however, the overspray loss was 6.2 percent. This degree of overspray is apparently required to develop the designed-in uniformity of the target area. The difficulty of designing for coverage on the round area is shown with a relatively low overall average sprinkler operating efficiency of 68.4 percent (vs 78.6 percent for the square pattern).

Table 1. Selected Summary of Distribution Patterns – January 8, 2015

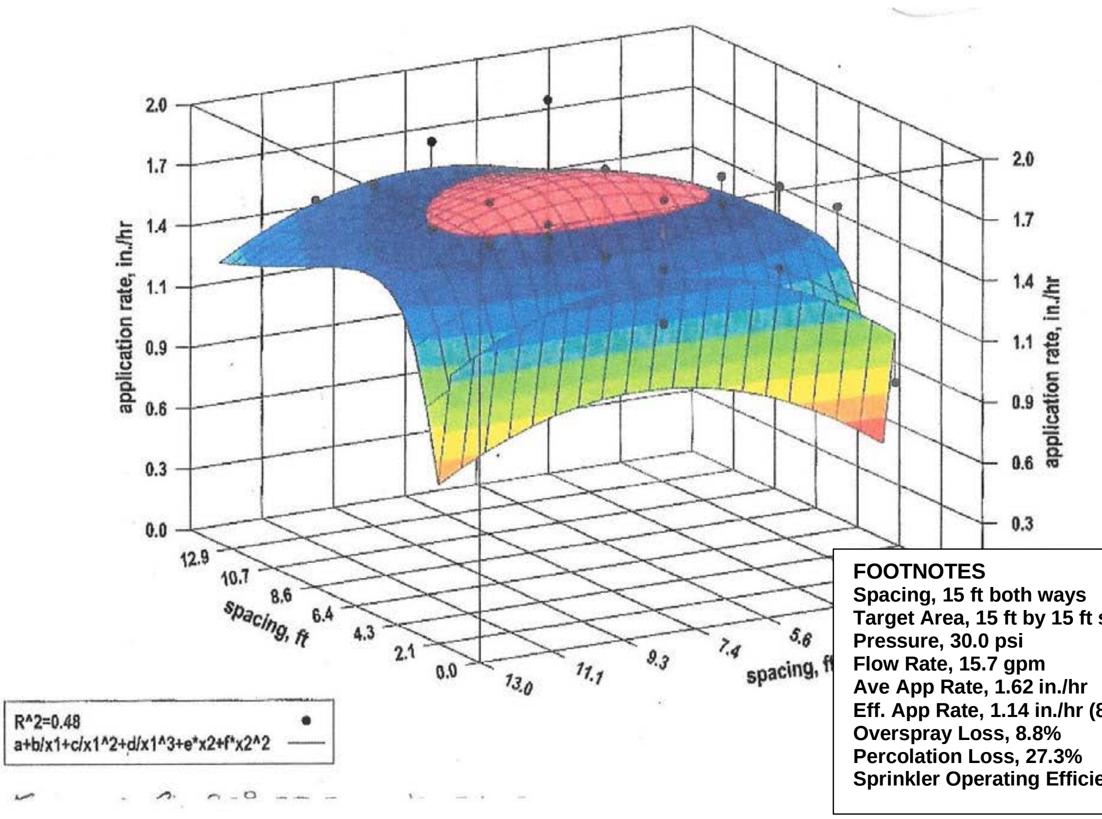
TEST #	SPRINKLER ID	TARGET SHAPE[1]	PRESSURE *psi*	FLOW RATE *gpm*	AVERAGE APPLICATION RATE[2] *in/hr*	EFFECTIVE APPLICATION RATE[3] *in/hr*	PERCOLATION LOSS[4] %	OVERSPRAY LOSS[5] %	SPRINKLER OPERATING EFFICIENCY[6] %	DU
1	Test #1SHV	□	30	15.50	1.616	1.384	20.1	1.0	79.1	74.0
2	Test #1SU	□	30	15.38	1.606	1.400	19.3	0.1	80.6	74.3
3	Test #3IR	□	40	6.20	0.611	0.556	12.7	6.2	81.9	78.7
4	Test #5 IPF	□	30	15.80	1.627	1.279	25.4	2.0	73.1	62.5
5	Test #4 USN	□	30	12.60	1.253	1.085	21.2	0.9	78.1	65.1
						AVERAGE	**19.7**	**2.04**	**78.6**	**70.9**
1	Test #1SHV (7)	O	30	14.50	1.749	1.468	24.2	7.0	70.5	63.0
2	Test #1SHV (8)	O	30	13.53	1.862	1.399	33.6	0.2	66.3	28.9
3	Test #5 IR	O	40	4.59	0.641	0.490	27.6	6.0	67.9	40.5
4	Test #1 UPS	O	30	7.00	0.902	0.732	30.8	1.1	68.4	54.7
5	Test #4 IPA	O	30	15.06	1.823	1.449	23.6	10.0	68.7	63.6
						AVERAGE	**28.0**	**4.9**	**68.4**	**50.2**

1 See SWAT protocol 2 Average application rate 3 Effective application rate (75%) 4 Percolation loss 5 Overspray loss 6 Sprinkler operating efficiency

The difficulty of indexing the jets to a round boundary is seen by the average overspray loss of 4.9 percent with the round area vs 2.0 percent with the square area.

JET INTERFERENCE PHENOMENA

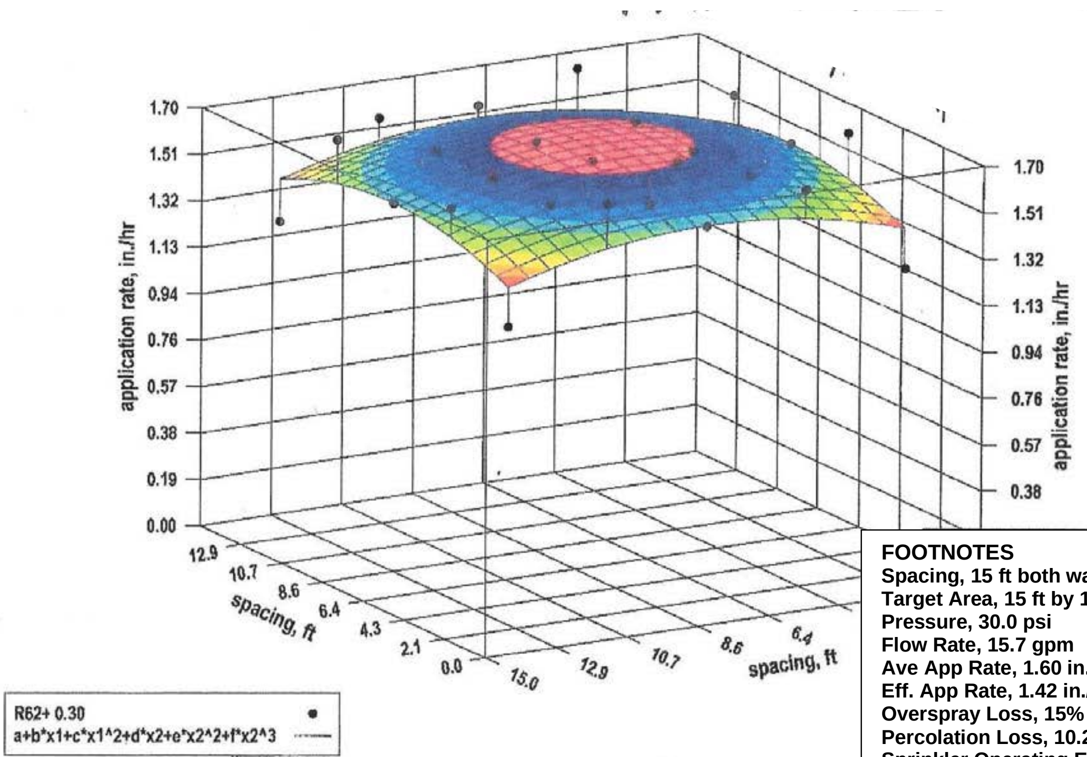
The phenomenon of jet interference can be observed in Figure 4.



FOOTNOTES
Spacing, 15 ft both ways
Target Area, 15 ft by 15 ft square
Pressure, 30.0 psi
Flow Rate, 15.7 gpm
Ave App Rate, 1.62 in./hr
Eff. App Rate, 1.14 in./hr (85%)
Overspray Loss, 8.8%
Percolation Loss, 27.3%
Sprinkler Operating Efficiency, 59.8%

The 3D plot shows an accumulation of water deposited in a haystack fashion in the center of the pattern. This seems to be caused by the four opposing jets mechanically impacting each other. The haystacking effect is further demonstrated in Figure 5.

In the case shown in Figure 5, the overlapped pattern was developed by running catchment tests on the corners individually and overlapping them by hand. A sense of the improvement can be gotten by comparing the sprinkler operating efficiency of 59.8 percent to 76.3 percent that was achieved when the jet interference is avoided.



FOOTNOTES
Spacing, 15 ft both ways
Target Area, 15 ft by 15 ft square
Pressure, 30.0 psi
Flow Rate, 15.7 gpm
Ave App Rate, 1.60 in./hr
Eff. App Rate, 1.42 in./hr (85%)
Overspray Loss, 15%
Percolation Loss, 10.2%
Sprinkler Operating Efficiency, 76.3%

Figure 5. Overlapped pattern from Figure 4 developed by hand overlapping single catchment pattern

ENGINEERING IMPROVEMENTS

Figure 6 shows a 3D printout of a representative overlapped pattern. It provides a measurement of actual value in scheduling irrigations and characterizing the system's water application efficiency.

The actual value of sprinkler or programming changes can be quantified as relates to water management objectives. This evaluation concept provides a procedure for characterizing how efficiently sprinkler systems are applying water. This protocol, together with studies to determine the current state of the commercial art, will provide incentives for manufacturers to improve the efficiency of their products.

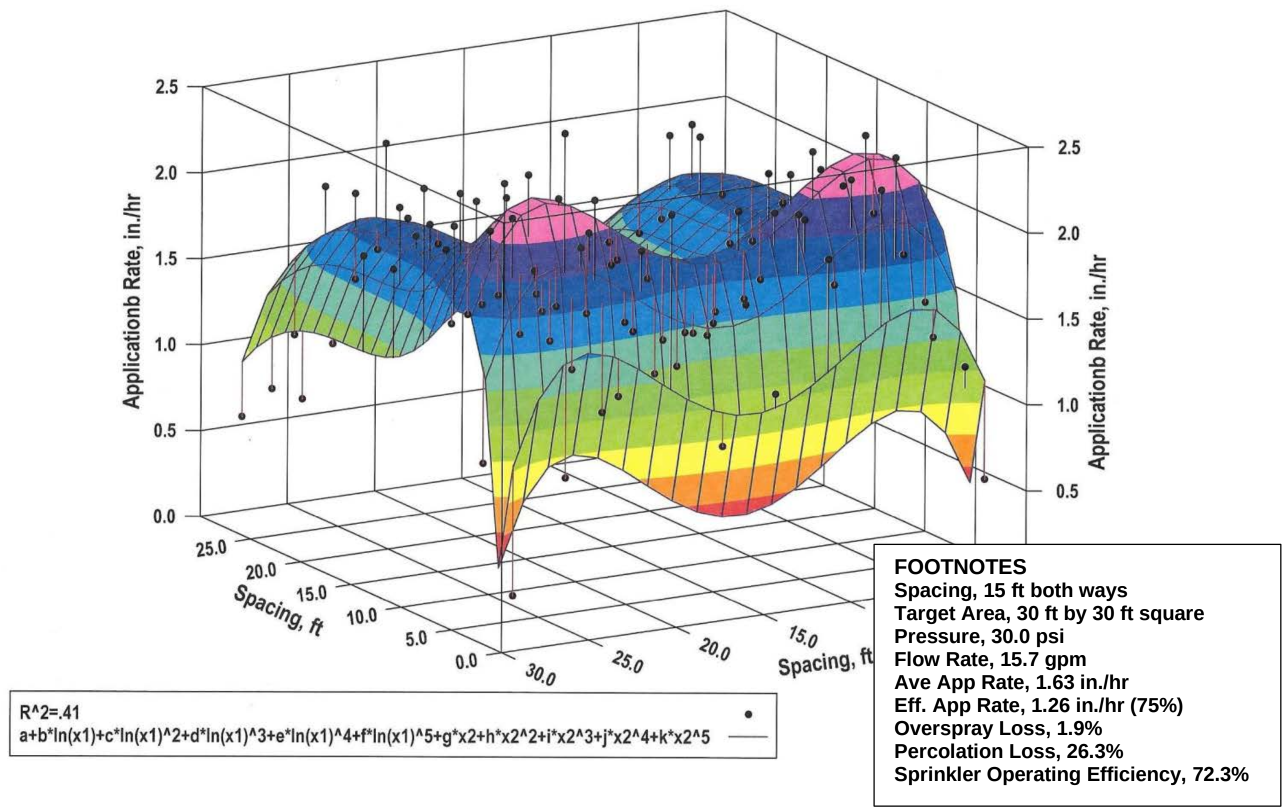


Figure 6. Representative nine-sprinkler square pattern performance

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