The Effect of Spray Sprinkler Spacing on Distribution Uniformity

Nina Colasurdo, CLIA

M.S. Cal Poly Pomona University, DIG Commercial Sales Representative, ctcolasurdo@csupomona.edu

Ramesh Kumar, PhD, CID, CLIA

Professor Cal Poly Pomona University, rkumar@csupomona.edu

Eudell Vis, CID, CLIA

Professor Emeritus Cal Poly Pomona University. egvis@csupomona.edu

Abstract. *A study was conducted measuring the effect on distribution uniformity (DU) when increasing or decreasing the spacing between sprinkler spray nozzles. Six nozzles were tested; three models each in the 12' and 15' series throw. Each nozzle was operated on the same irrigation system. Spacing between nozzles was increased and decreased at 10%, 20%, and 30%, intervals beyond or below recommended 50% diameter of throw. Tests were conducted outdoors on an irrigation system regulated at 30 psi, when wind conditions were below 5 mph.*

Brands A, B and C each have optimum spacing's that improved uniformity performance when compared to other spacing's. None of the nozzles had the highest DU when operated at the recommended spacing. Each nozzle has a few distances that significantly decrease their uniformity compared to other spacings.

The mean DU values for 12' nozzles were .62 and for 15' was .60.

Keywords: Spray nozzle, Sprinkler spacing, Distribution uniformity

Introduction

The irrigation spray nozzle is one of the most widely used devices to water many types of landscapes, including turf areas, shrub areas, trees, and annual flowers. Most spray nozzles sold are used in landscapes to cover distances in increments of 5', 8', 10', 12' and 15'. In addition to multiple distances, multiple arcs of 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, and 360° of a circle are available. Ideally, the nozzles radius of throw and arc and its' spacing relative to other sprinklers in the design should result in a uniform distribution of water over an area.

Water management decisions are based on irrigation systems uniformity of application to the landscape surface (Solomon 1979). The goal is to control too little or too much watering on any portion of an area as compared to the average over the entire area.

Distribution uniformity, (DU) is a measurement of uniformity calculated using a ratio (Burt et al., 1997). Ratios are calculated from field audits with catch cans.

Distribution Uniformity is calculated with the following equation (Merriam and Keller, 1978):

$$\boldsymbol{DU_{lq}} = \frac{\boldsymbol{V_{lq}}}{\boldsymbol{V_{ave}}}$$

where: $V_{lq} =$ The lowest quarter average of the volume of water collected

V_{avg} = the total average volume of water collected

DU_{lq} is represented as a ratio and not a percent (Burt et al 1979). The DU_{lq} value can be used to determine if an irrigation system is operating above or below a standard. A system with a .50 uniformity ratio uses twice the water than a system with a DU of 1.0. The higher the uniformity, more water saving can be achieved which the reason spray nozzle uniformity is of concern for water conservation advocates, and government agencies.

California Assembly Bill 1881, the California Model Water Ordinance enacted January 1, 2010 demonstrates the state's commitment to saving water. The ordinance's purpose is to encourage local agencies and water purveyors to use incentives that promote the efficient use of water. The ordinance applies to new construction and the remodel of existing landscapes greater than 2500 square feet requiring a landscape permit. The ordinance establishes a formula that limits the amount of water a landscape can consume annually. Local water purveyors are given the authority to penalize properties that use more than their allowance. The allowance or MAWA – Maximum Applied Water Allowance has a DU value embedded in its formula-Irrigation Efficiency. Irrigation systems can be completely uniform but not be efficient if the landscape manager over waters. Unlike DU, irrigation efficiency includes proper irrigation scheduling and extra water use such as watering in fertilizer, or establishing new plants. However, a system can never have poor uniformity and obtain high irrigation efficiency.

The Model Water Ordinance uses an irrigation efficiency of .71 which is based on certain assumptions of DU for irrigation systems. Since systems with spray nozzles typically have lower DU values than systems with rotors, it may be more difficult to design and manage a spray system to meet an irrigation efficiency of .71.

The Irrigation Association (IA) Certified Landscape Irrigation Auditor Training Manual (September 2010) has a DU quality rating for spray nozzles. The I.A. states that .65 -.75 is achievable, .55 -.65 is the target, and .45 -.55 is the historical range of DU values. When Baum conducted a study on 15' x15' outdoor plots irrigating with spray nozzles under controlled conditions their spray head DU results were .49 (Baum et al., 2005).

The study also audited residential spray landscapes with results for spray systems averaging .41 to .58. This study noted that for spray nozzles there was some relationship to sprinkler brand and pressure to their uniformity results. Low pressure had an effect of across all brands. Furthermore their test pointed to spacing as a key for good rotor performance

Materials and Methods

The purpose of this study was to determine the effects on distribution uniformity when increasing and decreasing spacing between spray nozzles for 12' and 15' nozzles (Table 1). An above ground irrigation system was designed and built to change spacing between nozzles from 8.4 feet to 19.5 feet, which allowed spacing to vary +/- 30% from the normal recommended spacing. The design was closed loop to keep pressure loss to a minimum. The system operated 9 spray nozzles: four quarter, four half, and one full circle nozzle in a square spacing design (Figures 1 and 2).

Table 1. Nozzle designation and recommended operating distance spacing at 30 psi.

12 A	Brand A	12 foot throw
12 B	Brand B	12 foot throw
12C	Brand C	12 foot throw
15A	Brand A	15 foot throw
15B	Brand B	15 foot throw
15C	Brand C	15 foot throw

The nozzles in this study were TORO Precision spray, Hunter Pro-Spray, and Rain Bird MPR series. These nozzles were considered representative of nozzles for use in the sprinkler spacings considered in this study.

Thirty psi is the recommended operating pressure for all nozzle brands tested. The system operated between 29 and 31 psi with variations between first and last sprinkler within 10% of operation pressure. A water meter provided a check on flow.

Figure 1 Irrigation system for testing nozzles with catch can grid.

Nozzle spacing set up

All spacing's were set at the distances listed in table 2. When a group of tests began nozzles were randomly picked from the package. Once the replications were complete at the tested spacing the nozzles were placed in a baggie and used in one more replication for a total of 10 to 12 cycles per nozzle. This ensured that the same nozzle completed a group of test, but that there was variation through the study.

Table 2. Nozzle spacing for all tests.

Nozzle	% Difference from Recommended Spacing	Spacing feet		Nozzle	% Difference from Recommended Spacing	Spacing feet
15' A,B&C	0	15		12' A,B&C	0	12
15' A,B&C	+10	16.5		12' A,B&C	+10	13.2
15' A,B&C	+20	18		12' A,B&C	+20	14.4
15' A,B&C	+30	19.5		12' A,B&C	+30	15.6
15' A,B&C	-10	13.5		12' A,B&C	-10	10.8
15' A,B&C	-20	12		12' A,B&C	-20	9.6
15 'A,B&C	-30	10.5		12' A,B&C	-30	8.4

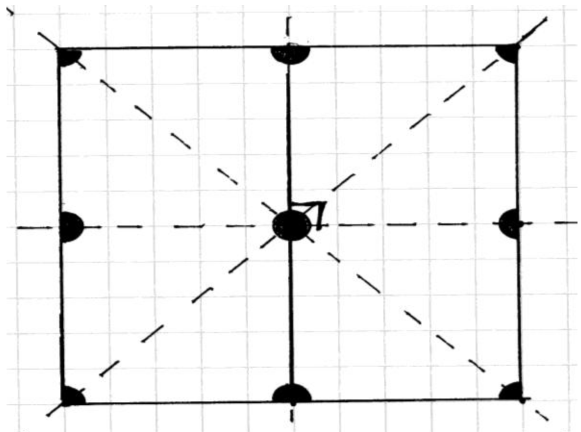

Figure 2 Sprinkler layout with four quarter, four half and one full circle nozzle.

Catch Can Placement

The catch can grid was made with 36 cups, exceeding the Irrigation Association recommendations of 24 cans. Devices were placed low enough to not obstruct the spray pattern. The grid began two feet in from the four quarter circle nozzles. There were six rows with six catch cans in each row (Figure 1).

Data collection

Brands A and C run time was 4 minutes and brand B run time was 5 minutes for each test. An average wind speed for the duration of test was recorded. If the average wind was above 5 mph testing ceased. Testing was between the hours of 9 AM to 1 PM. Pressure was checked during each test and recorded.

A test at each spacing was replicated a minimum of 5 times, sometimes six. All six brand nozzles were used for a maximum of 12 tests and retired for new nozzles. Fourteen different spacing's were tested with a total test count of 222.

Statistical Calculations

The study was designed to test two factors: spray nozzle brand and nozzles spacing on the dependant variable, distribution uniformity. An analysis of variance was performed on the main effects (nozzle brands and spacing) using PROC GLM of SAS (SAS ver. 9.2, Carey N.C.). When significant F test were observed, mean separator tests were performed with L.S.D. or L.S. means in the PROC GLM module.

Results and Discussion

There were significant differences between nozzle brands and spacings for both the 12' and 15' nozzles (Tables 3). These differences were the expected results considering differences in types of nozzles and nozzle spacings of +/- 30% from recommended spacing.

Table 3. Two Way Analysis of Variance (ANOVA) for DU of the 12' and 15' nozzles. Analysis of variables: nozzle, spacing, and interaction nozzle and spacing.

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Nozzle Brands (12' radius)	2	.29505586	.14752793	67.80	<.0001
Spacing	6	.038852841	.006421402	2.95	0.0112
Nozzle *Spacing	12	.25153970	.02096164	9.63	<.0001
Nozzle Brands (15' radius)	2	.13244505	.06622252	17.58	<.0001
Spacing	6	.07479862	.01246644	3.31	.0055
Nozzle *Spacing	12	.13127273	.01093939	2.90	.0020

The mean DU for all 12' nozzles was .62 and for 15' nozzles the mean DU was .60. All data is based on a test configuration of four half, four quarter and one full circle nozzles arranged in a square pattern.

Between all 12' nozzles, DU values ranged from .64 to .60 for the spacings tested (Table 4). However, there is no significant difference in DU with respect to spacing in +/-30% of recommended spacing of 12'. The seven spacings were 8.4', 9.6', 10.8', 13.2', 14.4', and 15.6'.

Between all 15' nozzles, DU values have no significant difference when spaced at 15' when compared to 10.5', 12', 13.5', 16.5', and 18' (Table 4). The 15' nozzles placed at 19.5' had a significantly lower DU of .55 than the DU for the recommended 15' spacing.

Table 4. Distribution uniformity averaged across all nozzle types for various spacing. Pairwise comparisons were made using LS Means between the 15' and 12' nozzles at the recommended spacing and all spacing between +/- 30% of recommended spacing. N= 15 to 18 for each spacing; α=.05

12' DU Mean .61 vs.	Spacing, Feet (% diff)	Pr>t	15' DU Mean .61 vs.	Spacing, feet	Pr>t
.64	8.4 (-30%)	.0596	.62	10.5 (-30%)	.7923
.63	9.6 (-20%)	.1866	.63	12 (-20%)	.4486
.63	10.8 (-10%)	.1866	.62	13.5 (-10%)	.8891
.60	13.2 (+10%)	.4590	.58	16.5 (+10%)	.1276
.60	14.4 (+20%)	.4358	.58	18 (+20%)	.1202
.60	15.6 (+30%)	.3781	.55	19.5 (+30%)	.0050

The high efficiency nozzle 12B and 15B had significantly higher Mean DU values than the other two traditional spray nozzle designs which included data for all spacings 8.4 – 15.6 feet for the 12 foot nozzle, and 9.6 – 19.5 feet for the 15 foot nozzle (Tables 5 and 6).

Table 5. Comparison of distribution uniformity by nozzle brand for 12' nozzles (Critical value of LSD =.0284, α=.05)

t-grouping	Mean DU	N	Nozzle
A	.65	37	12 B
B	.64	37	12 C
C	.55	37	12A

Table 6. Comparison of distribution uniformity by nozzle brands for 15' nozzles (Critical value of LSD =.0284, α=.05)

t-grouping	Mean DU	N	Nozzle
A	.65	37	15 B
B	.58	37	15 A
B	.57	37	15C

The 12B nozzles had an overall DU mean of .65 for all spacings +/-30% of recommended spacing. The Irrigation Association (IA) would rank this DU as "achievable". This was the highest DU in the test of all nozzles. Nozzle 12A had an overall test mean of .55 and12C had an overall test mean of .64. These DU values were in "target" range of the IA ratings.

The DU results for nozzle 15B had an overall test mean of .65. 15A had an overall test mean of .58, and 15C had an overall test mean of .57. These 15' nozzles had DU values the I.A. consider in the target and achievable categories.

When spacing and nozzle interact, the results were unexpected. In the 12' nozzle category none of the nozzles performed their best when placed at the recommended spacing of 12'. 12 A's best spacing was 15.6' with a DU of .60. 12B's best spacing was the shortest tested distance, 8.4 feet, with a DU of .74. 12C's best spacing was 9.6',

In the 15' nozzle category none of the nozzles performed their best when placed at the recommended spacing of 15'. The 15' nozzle has the highest DU at the 12' spacing or shorter. 15A's best performing spacing was 10.5' with a DU of .66.

15B had the highest DU at 12’. However 15B could operate 10.5’ to 18’ with no significant change in DU. Similar to 12B, 15B experienced a decline in DU when the spacing was +30% of recommended spacing.

Nozzle 15C best spacing was 12’. This nozzle at 12’ had DU values that were not significantly different than DU at spacings of 10.5’ – 16.5’. This study demonstrates that each nozzle has a range of spacings where DU values are not significantly different.

Baum et al. study (2005) did not report high DU results; low pressure was considered the reason for poor uniformity in this study. Baum et al.(2005) test plots also reported low DU under controlled conditions, which may have occurred because only quarter nozzles were used. This study tested the DU of a system, where there is an equal representation of half and quarter sprays. Generally it is perceived that spray nozzles do not yield higher DU values than rotors. This study had higher DU averages than Latief et al. (2008) tests. The tests were very similar, but their test experienced significant pressure fluctuations. The pressure during this study remained stable between 29 psi to 31 psi, and DU values were higher compared to their results. Pressure may be more significant to DU performance than distance between nozzles or geometric spray patterns.

Precipitation Rate

Precipitation rate does not impact uniformity; however it can impact irrigation efficiency. California’s Model Water Ordinance gives a water allocation based on .71 irrigation efficiency. Some water will always be applied to compensate for uniformity differences. More water may be used for other management practices such as applying fertilizer. The precipitation rate graphs (Figures 9 &10) demonstrate the closer the spacing the higher the precipitation rate. When nozzle 12 B was spaced at 8.4’ its application rate doubled over that at 12’. Run times must be adjusted based on the precipitation rate to apply a correct irrigation water requirement.

Precipitation rates for both 12’ and 15’ foot nozzles show a decrease, as expected, as sprinkler spacing increased (Figures 3 & 4). The precipitation rates for sprinkler spacings less the recommended spacing (less than 12’ or 15’), may not correspond with precipitation rates measured in the field since the radius of throw would be adjusted to prevent overspray outside the intended irrigated area. In this study, the radius of throw was not adjusted.

However, for spacings above the recommended spacing, the precipitation rates could be used to determine appropriated irrigation schedules. The measured precipitation rates in this case are reasonably close to calculated values based on nozzle flow.

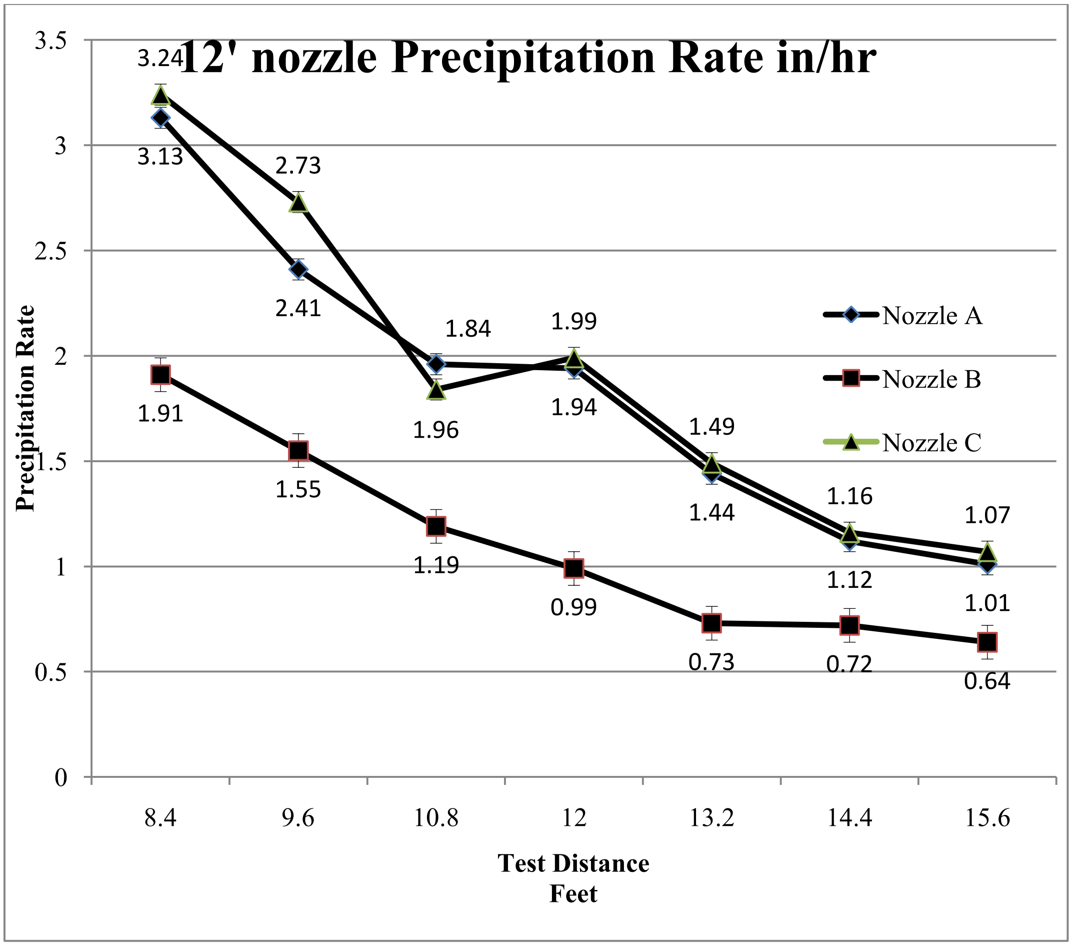

Figure 3. 12’ Nozzle precipitation rate.

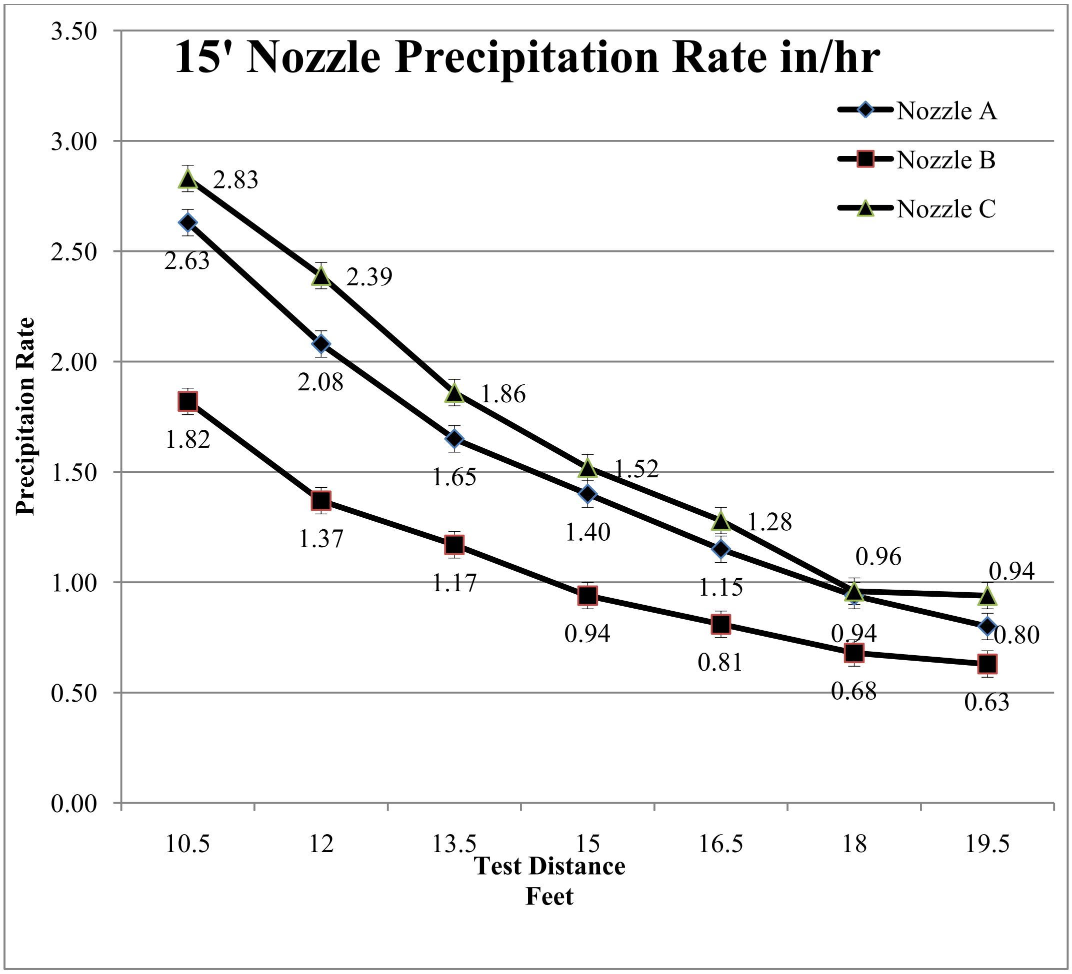

Figure 4. 15' Nozzle precipitation rate.

Conclusions

1. The mean DU for all nozzles and spacings tested was .61.
2. The mean DU for all **12'** nozzles was .62 and for 15' nozzles was .60.
3. The highest DU values for all nozzles were at spacings other than the recommended spacing.
4. There are several spacings for each nozzle where DU in not significantly different than its highest DU for that brand.
5. Brand B had higher DU values than other nozzles tested.
6. Precipitation rates change with spacing and must be accounted for in irrigation scheduling.

Recommendations for future study:

1. Determine the effect of adjusting the nozzle radius on DU.
2. Test at lower and higher pressure than manufacturers recommend pressures.

3. Test the effect of spacing above 30% of manufactures recommended throw on DU.
4. Optimum distance between nozzles should be field tested to determine if results are consistent over a range of conditions.

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