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Distribution Uniformity of Multi Stream Multi Trajectory Rotary Nozzles Spaced Below Recommended Distance

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Introduction

Urban landscape irrigation is an important water use issue in California. The overarching-issue in California is *"that Section 2 of Article X of the California Constitution specifies that the right to use water is limited to the amount reasonably required for the beneficial use to be served and the right does not and shall not extend to waste or unreasonable method of use."* This issue is in clear focus as we now know California has a very limited water supply to meet the needs of a growing population. This limited water supply has multiple advocates within California for agriculture, environmental, and urban interest including landscape water users.

Recent legislative action based on extensive input from government, water agency, landscape, and environmental interest, resulted in AB 1881 Model Water Efficient Landscape Ordinance, and SB X7-7 Water Conservation Act of 2009.

In AB 1881 the Maximum Allowable Water Applied (MAWA) is based on irrigation efficiency of 0.71 and an average plant factor of 0.5 to determine the ET Adjustment Factor of 0.7. For sprinklers in a landscape irrigation system to have an efficiency of 0.71, the irrigation distribution uniformity (DU) must be very high.

High DU is critical to meet irrigation efficiency requirements of AB 1881. It states that irrigation efficiency "(IE) means the measurement of the amount of water beneficially used divided by the amount of water applied. Irrigation efficiency is derived from measurements and estimates of irrigation system characteristics and management practices. The minimum average irrigation efficiency for purposes of this ordinance is 0.71. Greater irrigation efficiency can be expected from well-designed and maintained systems." An irrigation system that has high DU of 0.80 and irrigation management efficiency of 95% has an estimated irrigation efficiency of 0.76 (if IE = DU x Irrigation Management Efficiency). In this case the estimated IE of 0.76 exceeds the required IE of 0.71 when the assumed sprinkler DU is 0.80.

Irrigation designers and contractor-installation methods may use various criteria for the sprinkler spacing and nozzle radius adjustments. The following objectives and nozzles spacing and adjustments were selected to measure the DU in outdoor conditions.

Study Objective

Measure the low quarter irrigation distribution uniformity (DU_{LQ}) of Multi Stream Multi Trajectory (MSMT) rotary nozzles using manufacturer's published data and at smaller spacings than the generally accepted maximum spacing for head to head coverage. The effect on DU_{LQ} of adjusting and not adjusting the radius screw on the nozzle for head to head (HTH) coverage will also be measured. An additional calculation was added later (as requested by CLCA) which is low half irrigation distribution uniformity (DU_{LH}).

Methods and Procedures

The spacing of the nozzles for this study was based on the maximum radii listed in the manufacturer's specifications. The tests were all run at 40 psi with pressure adjusted at the point of connection for the testing system. Pressure variation in the system was 5% or less. Nozzles were mounted on 6-inch risers with shrub adapters; there were no in-stem pressure regulators for the nozzles. The testing system (Figure 1) had 9 nozzles on a square spacing: 4 - 90 degree arc nozzles; 4 – 180 degree arc nozzles; and one 360 degree arc nozzle. Nozzles with arc adjustments were adjusted as needed for the testing system. This testing system which was constructed on turfgrass is also shown in Figures 2 and 3 (see page 11).

Square Configuration

T - Pressure Regulator
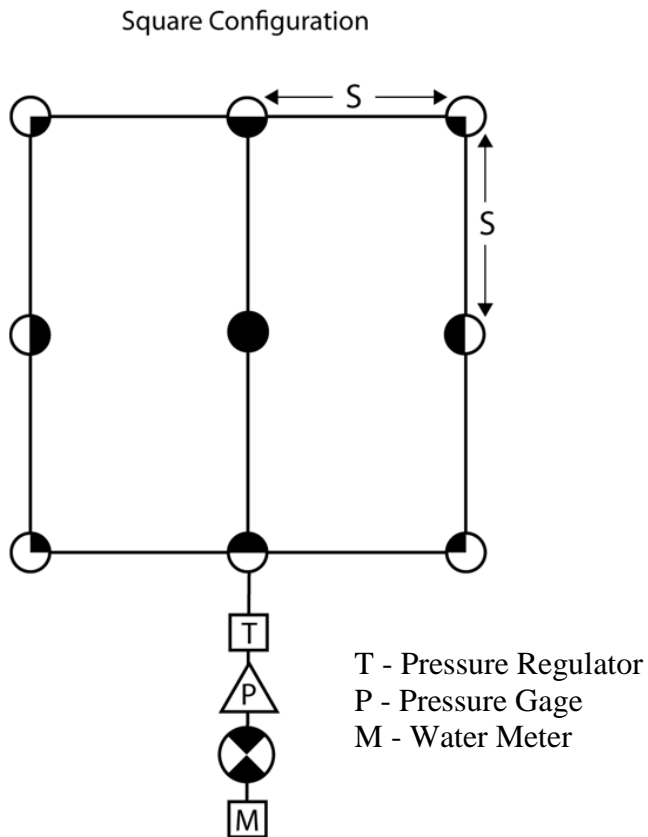P - Pressure Gage
M - Water Meter

Figure 1. Testing system used is similar to configuration of nozzles and point of connection as shown here and referenced in Colasurdo (2010) and IA (2012).

Three Multi Stream Multi Trajectory (MSMT) nozzles common in professionally installed systems were selected for this study. The first treatment factor (**spacing or spacing treatment**) was nozzle spacing distances in conjunction with adjusting and not adjusting the radius screw on the nozzle for head to head coverage (five levels) (Table 1). The second treatment factor was nozzle (**nozzle or nozzle treatment**) (three levels); they were labeled nozzle A, nozzle B, and nozzle C for this study. Distances between nozzles and between catch cans for the three test spacings are shown in Table 2.

Table 1. Five spacing and nozzle adjustment treatments.

Spacing treatment	Nozzle spacing description	Abbreviated description[z]	Replications
1	Maximum Spacing, HTH	Max.	4
2	Minus10% of HTH, unadjusted	10% unadj.	4
3	Minus 25% of HTH, unadjusted	25% unadj.	4
4	Minus 10% of HTH, adjust radius to HTH	10% adj.	4
5	Minus 25% of HTH, adjust radius to HTH	25% adj.	4

[z] See Table 2 for HTH (Head To Head) spacing; unadj. = nozzle radius unadjusted at reduced spacing; adj. = nozzle radius adjusted for head to head coverage.

Table 2. Nozzle treatments, maximum nozzle spacing, nozzle treatment spacing, and catch can spacing.

Nozzle treatment	Max. nozzle spacing, ft	Spacing % less than Max.	Nozzle treatment spacing, ft	Total outside dimension of test system,[z] ft	Catch can[y] inset from nozzle, ft	Catch can spacing, ft
A	18	0	18.0	36.0	2.0	6.4
A	18	-10	16.2	32.4	2.0	5.7
A	18	-25	13.5	27.0	2.0	4.6
B	21	0	21.0	42.0	2.0	7.6
B	21	-10	18.9	37.8	2.0	6.8
B	21	-25	15.8	31.5	2.0	5.5
C	20	0	20.0	40.0	2.0	7.2
C	20	-10	18.0	36.0	2.0	6.4
C	20	-25	15.0	30.0	2.0	5.2

[z] Distance between 90 degree arc nozzles in Figure 1.
[y] Catch cans were Cal Poly type.

The maximum spacings tested correspond to the maximum radius listed in product literature for nozzles B and C, and a spacing of maximum plus1 foot for nozzle A for pressures of 40 psi. The spacing of maximum minus 10% selected for this study was based on conversations with irrigation designers who use this criterion in some designs. The spacing of maximum minus 25% as the second spacing selected was based on a common metric in the industry for the screw on the nozzle to adjust the radius to 25% less than the maximum recommended radius.

The five spacing treatments with four replications were run for each nozzle as listed in Table 1. To ensure independence between replications, a separate set of nozzles for the entire testing system was used for each replication. As an illustration, replication I of nozzle A used the first set of nozzles for the five spacing treatments, while replication II of nozzle A used the second set of

nozzles for the five spacing treatments. The order of tests was: Maximum Spacing, HTH **(Max.)**, nozzle A, replications I to IV; nozzle B, replications I to IV; and then nozzle C, replications I to IV. This sequence of nozzle and replication tests was then used for the following spacing treatments in this order: Minus10% of HTH, unadjusted **(10% unadj.)**, Minus 25% of HTH, unadjusted **(25% unadj.)**, Minus 25% of HTH, adjust radius to HTH **(25% adj.)**, and Minus 10% of HTH, adjust radius to HTH **(10% adj.)**. A total of 60 individual tests were conducted.

Thirty six catch cans were used for each test. Catch can locations were changed each time the nozzle spacing was changed (see Table 2 for details). The 10% and 25% unadj. spacing treatments may have had overspray beyond the boundary of sprinkler heads. However, the catch cans for these treatments were only inside the boundary; catch can spacings are noted in Table 2. The nozzle height was the approximately the same as the top of the catch cans and the risers were visually aligned to vertical. The runtime was 15 minutes for all nozzles and spacing treatments. Wind speed measurements were taken near nozzle height and testing was terminated when wind speed exceeded 3 mph using a Kestrel 4000 Pocket weather tracker.

DU_{LQ} and DU_{LH} from 60 individual tests from the testing system were statistically analyzed. The experimental design was a 3 x 5 factorial completely randomized, in 4 replications, with nozzle (N) at 3 levels (A,B, and C) and spacing (S) at 5 levels (Max., 10% unadj., 25% unadj., 10% adj., and 25% adj.). A standard fixed effect model analysis of variance (ANOVA) procedure was used to test main effects and interaction and subsequently pre-determined single degrees of freedom contrasts (SAS 9.2). Because the N x S interaction was significant, ANOVA was conducted by N using a completely randomized design for 5 levels of the S treatment factor. Additionally, means were compared by using a Fisher's protected LSD test. It should be noted that Univariate procedure showed that DU_{LQ} data were normally distributed.

Results and Discussion

Two points of interest for this study were first, what effect does a decrease in nozzle spacing from head to head spacing (Max.) have on DU? Secondly, when the spacing is decreased, what effect does adjusting or not adjusting the radius screw have on DU? It should be noted that spacing treatments included both the treatments for physical distance between nozzles and the treatments of adjusting radius of the nozzle for head to head coverage (see Table 1).

Statistical analyses showed that spacing and nozzle treatments significantly affected DU_{LQ} and DU_{LH} and that the spacing x nozzle interaction also was significant (Tables 3 and 4, ANOVA effects). Due to the significant interaction, analysis of spacing treatments for individual nozzles was justified (Tables 3 and 4, Spacing treatment). The grand overall mean for DU_{LQ} for all spacing and nozzle treatments was 0.65 (Table 3, Overall column and Overall nozzle row) while the same for DU_{LH} was 0.78 (Table 4, Overall column and Overall nozzle row). The overall DU_{LQ} for the Max. spacing was 0.54 which was significantly lower than the overall DU_{LQ} for all other spacing treatments; 0.62, 0.66, 0.70, 0.72, 10% unadj., 25% unadj., 10 adj. and 25% adj., respectively (Table 3). Additionally, the overall DU_{LH} for the Max. spacing was 0.71 which was significantly lower than the overall DU_{LH} for all other spacing treatments; 0.76, 0.79, 0.81, 0.82, 10% unadj., 25% unadj., 10 adj. and 25% adj., respectively (Table 4). The DU for the Max. spacing was lower than expected for these types of nozzles which may be due to test conditions.

Contrasts for DU_{LQ}. In context of the present study, contrasts are **predetermined** comparisons among selected spacing treatments which help refine information provided from a table providing spacing treatment means for individual nozzles and the overall, as shown in the upper portion of Table 3.

1. *(Max. vs. (10% and 25% unadj.))*: The DU_{LQ} for (10% and 25% unadj.) was significantly higher than Max. for the overall and for Nozzles B and C. This difference was not significant for nozzle A.

2. (Max. vs. (10% and 25% adj.)): The DU_{LQ} for (10% and 25% adj.) was significantly higher than Max. for the overall and for all nozzles.

3. (10% unadj. vs. 10% adj.): The DU_{LQ} for 10% adj. was significantly higher than 10% unadj. for the overall and for nozzles A and B. This difference was not significant for nozzle C. The overall DU_{LQ} for 10% adj. and 10% unadj. was 0.70 and 0.62, respectively.

4. (25% unadj. vs. 25% adj.): The DU_{LQ} for 25% adj. was significantly higher than 25% unadj. for the overall and for nozzles A and C. This difference was not significant for nozzle B. The overall DU_{LQ} for 25% adj. and 25% unadj. was 0.72 and 0.66, respectively.

5. *(10% adj. vs. 25% adj.)* The DU_{LQ} for 25% adj. was not significantly different than 10% adj. for the overall and for nozzle B. For nozzle A, 10% adj. was significantly higher than 25% adj.; for nozzle C, 25% adj. was significantly higher than 10% adj. Considering the above, a general difference between 25% adj. and 10% adj. is inconclusive and specific to nozzle type.

6. *(10% adj. and unadj.) vs. (25% adj. and unadj.)*: The DU_{LQ} for (25% adj. and unadj.) was significantly higher than (10% adj. and unadj.) for the overall and nozzles B and C. For nozzle A, DU_{LQ} was significantly higher for (10% adj. and unadj.) than (25% adj. and unadj.).

Contrasts for DU_{LH} (see Table 4).

1. *(Max. vs. (10% and 25% unadj.))*: The DU_{LH} for (10% and 25% unadj.) was significantly higher than Max. for the overall and for Nozzles B and C. This difference was not significant for nozzle A.

2. (Max. vs. (10% and 25% adj.)): The DU_{LH} for (10% and 25% adj.) was significantly higher than Max. for the overall and for all nozzles.

3. (10% unadj. vs. 10% adj.): The DU_{LH} for 10% adj. was significantly higher than 10% unadj. for the overall and for nozzles A and B. For nozzle C, 10% unadj. was significantly higher than 10% adj. The overall DU_{LH} for 10% adj. and 10% unadj. was 0.81 and 0.76, respectively.

4. (25% unadj. vs. 25% adj.): The DU_{LH} for 25% adj. was significantly higher than 25% unadj. for the overall and for nozzle A. This difference was not significant for nozzles B and C. The overall DU_{LH} for 25% adj. and 25% unadj. was 0.82 and 0.79, respectively.

5. *(10% adj. vs. 25% adj.)*: The DU_{LH} for 25% adj. was not significantly different than 10% adj. for the overall and nozzles A and B. For nozzle C, 25% adj. was significantly higher than 10% adj. Considering the above, a general difference between 25% adj. and 10% adj. is not substantiated and specific to nozzle type.

6. *(10% adj. and unadj.) vs. (25% adj. and unadj.)*: The DU_{LH} for (25% adj. and unadj.) was significantly higher than (10% adj. and unadj.) for the overall and nozzles B and C. For nozzle A, DU_{LH} was significantly higher for (10% adj. and unadj.) than (25% adj. and unadj.).

Table 3. The effect of spacing, radius adjustment, and nozzle on low quarter irrigation distribution uniformity (DU_{LQ}).

Spacing treatment	Nozzle[z]			
	A	**B**	**C**	**Overall**
25% adj.	0.75 b[y]	0.74 a	0.67 a	**0.72 a**
10% adj.	0.81 a	0.76 a	0.52 c	**0.70 ab**
25% unadj.	0.59 cd	0.78 a	0.62 ab	**0.66 b**
10% unadj.	0.64 c	0.65 b	0.57 bc	**0.62 c**
Max.	0.58 d	0.58 b	0.45 d	**0.54 d**
Overall nozzle	**0.68 B[x]**	**0.71 A**	**0.56 C**	**0.65**
ANOVA effects (*P*)				
Spacing (S)	***	***	***	***
Nozzle(N)				***
S x N				***
Contrast (*P*)				
Max. vs. (10% and 25% unadj.)	NS	***	***	***
Max. vs. (10% and 25% adj.)	***	***	***	***
10% unadj. vs. 10% adj.	***	**	NS	***
25% unadj. vs. 25% adj.	***	NS	*	***
10% adj. vs. 25% adj.	*	NS	***	NS
(10% adj. and unadj.) vs. (25% adj. and unadj.)	*	*	***	**

[z] Nozzle spacing, feet: Max, 10%, & 25% respectively, Nozzle A: 18, 16.2, 13.5; B: 21, 18.9, 15.8; C: 20, 18, 15.
[y] Mean separation by Fisher's protected LSD test, *P* = 0.05. Means within the same column followed by the same letter are not significantly different.
[x] Mean separation by Fisher's protected LSD test, *P* = 0.05. Means within the same row followed by the same letter are not significantly different.

[NS,*,**,***] Nonsignificant, or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

Table 4. The effect of spacing, radius adjustment, and nozzle on low half irrigation distribution uniformity (DU$_{LH}$).

Spacing treatment	Nozzle[z]			
	A	**B**	**C**	**Overall**
25% adj.	0.83 a[y]	0.84 a	0.80 a	**0.82 a**
10% adj.	0.86 a	0.86 a	0.70 c	**0.81 ab**
25% unadj.	0.73 b	0.87 a	0.76 ab	**0.79 b**
10% unadj.	0.76 b	0.78 b	0.74 b	**0.76 c**
Max.	0.73 b	0.73 b	0.67 c	**0.71 d**
Overall nozzle	**0.78 B**[x]	**0.82 A**	**0.73 C**	**0.78**
ANOVA effects (*P*)				
Spacing (S)	***	***	***	***
Nozzle(N)				***
S x N				***
Contrast (*P*)				
Max. vs. (10% and 25% unadj.)	NS	***	***	***
Max. vs. (10% and 25% adj.)	***	***	***	***
10% unadj. vs. 10% adj.	***	**	*	***
25% unadj. vs. 25% adj.	***	NS	NS	**
10% adj. vs. 25% adj.	NS	NS	***	NS
(10% adj. and unadj.) vs. (25% adj. and unadj.)	*	*	***	**

[z] Nozzle spacing, feet: Max, 10%, & 25% respectively, Nozzle A: 18, 16.2, 13.5; B: 21, 18.9, 15.8; C: 20, 18, 15.
[y] Mean separation by Fisher's protected LSD test, *P* = 0.05. Means within the same column followed by the same letter are not significantly different.
[x] Mean separation by Fisher's protected LSD test, *P* = 0.05. Means within the same row followed by the same letter are not significantly different.

[NS,*,**,***] Nonsignificant, or significant at $P \leq 0.05$, 0.01, 0.001, respectively.

Summary

This study's primary objective was to measure the effects of spacing and nozzle radius adjustment on the DU for Multi Stream Multi Trajectory (MSMT) rotary nozzles. There are irrigation design and field situations where sprinkler spacings do not match conventional head to head spacing. A previous study (Colasurdo 2010) on spray nozzles reported that DU values were not consistently highest at the Max. spacing compared to smaller and greater spacings.

In this study, DU was basically higher at both 10% (adj. or unadj.) and 25% (adj. or unadj.) spacings than at the Max. spacings selected for this study for three nozzles.

A secondary objective was to determine the effect of adjusting or not adjusting the nozzles on DU when spacings were decreased from Max. Basically, data show adjusting the radius screw to achieve HTH coverage for smaller spacings resulted in a higher DU.

Several test procedures of this study should be noted. First, when nozzles are spaced at 25% unadj. there was overspray. This may be objectionable when nozzles are installed on landscape perimeters or other situations where overspray water is not used by plants. Overspray may occur to a lesser extent at 10% unadj.

It should be reemphasized that all nozzles were tested at 40 psi and wind speed did not exceed 3 mph. Results may be different if field conditions vary.

When nozzle spacings are less than the maximum spacing the precipitation rate does increase (data not shown). In the field this would need to be considered in irrigation scheduling.

Future research could explore if these trends in DU are similar in actual landscapes where nozzle spacing may include a range of sprinkler head spacings.

Figure 2. Test system with nozzles and catch cans. Point of connection for the system with pressure regulator, water meter and pressure gauge is in the forefront

Figure 3. Sprinkler nozzles on shrub adapters mounted on movable platforms to setup the required nozzle spacings

References

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