Assessment of Application Efficiency and Uniformity of Fixed Spray and Multi-Stream, Multi-Trajectory Sprinklers

Final Project Report

4 April 2013

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INTRODUCTION

A study was initiated at the request of Rain Bird Corporation to compare the performance of selected Rain Bird sprinkler heads and the Model O-T-12-Q head manufactured by The Toro Company. The project agreement calls for each set of head comparisons to be performed in both the summer and winter with performance assessed using standard measures of application efficiency (AE) and distribution uniformity (DU). The summer comparisons were completed between 16 May 2012 and 10 August 2012. The winter comparisons were completed between 24 January and 22 March 2013. This final project report summarizes the results of both the summer and winter comparisons and provides an assessment of how meteorological conditions, particularly wind, impacted the performance of each sprinkler head.

METHODS

The study was conducted at the University of Arizona Karsten Turf Research Facility located in Tucson, AZ. The Karsten Facility is located in the alluvial valley of the Rillito River at an elevation of 2440' above sea level. The specific experimental site consisted of eight 12'x12' blocks (plots) of Midiron bermudagrass turf. Each plot has its own irrigation system complete with separate control valve and meter. Sprinklers are installed at the corners of each plot in a square spacing arrangement with adjacent heads separated by a distance of 12'. A total of 32 casings were installed in each plot to hold irrigation catch cups. All casings were installed to allow catch cups to be placed at turf level. Sixteen round casings constructed of 4" diameter PVC pipe were installed in a centered and evenly spaced square grid within the plot area (Fig. 1). The separation distance between adjacent round casings was 3'. Sixteen rectangular casings constructed of short lengths of vinyl gutter were installed along the perimeter of the plot to facilitate collection of water applied to the edge of each plot (Fig. 1). Catch cups were inserted into the casings prior to each irrigation run. The circular cups were the funnel-shaped cups manufactured by the CalPoly Irrigation Training and Research Center. Rectangular food storage containers (6"x 4.5"; Up and Up Brand) served as the perimeter catch cups.

The meters for each plot were calibrated at the beginning of the study and each time a different set of sprinklers were compared. The calibration procedure involved attaching a hose to one of the

irrigation risers while capping the remaining risers. The system was then operated for a set period of time with the water passing through the system collected in a large plastic carboy. The weight increase in the filled carboy was converted to volume units and then compared to the difference in meter readings obtained before and after each run. Meter adjustment factors were derived by dividing the volume collected during a run by the volume indicated by the meter.

Each set of sprinkler heads was compared on a minimum of ten mornings during the summer of 2012 and winter of 2013 . Table 1 lists the sprinklers evaluated in each comparison and the time frame during which the comparisons were conducted. All sprinklers were installed in 4" Rain Bird Model 1800 SAMPRS bodies. Preliminary tests were conducted for each set of sprinklers to determine the precipitation rate. Run times were then set such that each set of heads applied approximately 0.50" of water. The Toro sprinkler had a much lower precipitation rate (~1.05"/hr) in comparison to the Rain Bird sprinklers (~1.9"/hr) and thus required a longer run time to apply 0.50" of water. For a given comparison event, irrigation of all plots (both sprinklers) was initiated at the same time. The termination time of irrigation varied due to the differences in precipitation rate of the opposing sprinklers. At the completion of each run, the volume of water in each cup was determined by transferring the water collected into a graduated cylinder and recording the resulting volume. Catch cup volumes were then converted to depth by dividing by the surface area of the cup. All comparisons were run during the morning hours in the summer of 2012. Some afternoon comparisons were included in the winter of 2013 to avoid subfreezing conditions and to better assess the performance of the sprinklers during periods with higher wind speeds.

Sprinkler performance was evaluated by measuring distribution uniformity (DU) and application efficiency (AE). Distribution uniformity was computed using the 16 circular catch cups located within each plot. Specific DU computations included the low quarter distribution uniformity (LQDU) and low half distribution uniformity (LHDU). The LQDU is determined by computing the average of the lowest 25% of catch volumes (depths) then dividing this value by the average volume (depth) of all cups. The LHDU is determined by computing the average of the lowest 50% of catch volumes (depths) then dividing this value by the average volume (depth) of all cups. The scheduling

coefficient (SC) was also computed for each comparison using the 16 circular catch cups. The SC was computed by dividing the average depth of water collected in the 16 catch cups by the smallest depth of water collected in a single cup (of 16 catch cups).

Application efficiency was determined using two difference computation procedures. The first procedure (AE16) involved taking the average depth of the 16 circular catch cups and dividing by the equivalent depth of water that passed through the water meter (meter volume converted to depth based on plot area of 144 sq. ft.). The second computation procedure (AE32) used all 32 catch cups to estimate the depth of water reaching the turf surface. In this procedure the total area of the plot was divided into 21 rectangular areas with catch cups located at the four corners of each area (Fig. 2). The average depth of water applied to each rectangle was computed by taking the average of the four corner catch cups. The four small corner areas of the plot had just three catch cups since the sprinkler head was located on the fourth corner (Fig. 2). For these corners, the depth of water collected at the head was estimated by averaging the catch values of the two closest cups. This estimated value was then averaged with the three cup values to estimate the depth of water received in the small corners. Depth estimates for the 25 rectangles were then multiplied by their respective areas (9, 4.5 or 2.25 sq. ft.), summed and divided by the total plot area (144 sq. ft.) to obtain the average amount of water reaching the plot surface. This value was then divided by the actual depth of water applied (as determined from the meter) to determine AE32.

Experimental design was randomized complete block with two treatments (irrigation heads) and four reps. All data were analyzed using the appropriate statistical procedure as provided by SAS (SAS Institute, Cary, NC).

A weather station was installed upwind of the plots to provide data on temperature, humidity, wind speed and wind direction during each evaluation period. Temperature and humidity were monitored at 5' (1.5 m) above ground level (agl) with a Vaisala Model HMP45C combination temperature and relative humidity sensor. Wind speed and direction were monitored at 6.6' (2.0 m) agl using a RM Young Model 03002Wind Sentry Set. All sensors were connected to a Campbell Scientific Inc.

Model 10X datalogger programmed to scan sensors at 0.2 Hz and output parameter means every 15 sec. The meteorological data were downloaded to a portable computer, then imported into spreadsheet software where the data were summarized over the specific run times of each evaluation.

RESULTS & DISCUSSION

Comparison of Rain Bird HE1201 & Toro OT12Q

The two distribution uniformity parameters (LQDU and LHDU), the two assessments of application efficiency (AE16 and AE32) and the scheduling coefficient (SC) were used to assess the overall performance of the opposing spray heads in each comparison study. The summer evaluation comparing the performance of the Toro OT12Q and Rain Bird HE1201 spray heads was conducted between 16 May and 13 June 2012 while the winter comparison was conducted between 5 and 22 February 2013. Wind speed on individual summer comparison dates ranged from ranged from 0.0 m/s to 4.1 m/s (0.0 to 9.2 mph) and averaged 1.6 m/s (3.6 mph). Wind speed on the individual winter comparison dates ranged from 0.5 to 2.3 m/s (1.1 to 5.1 mph) and averaged 1.4 m/s (3.1 mph).

The Rain Bird HE1201 produced significantly higher values of LQDU, LHDU, AE16 and AE32 when compared against the Toro OT12Q head, regardless of season (Tables 2-3; Fig. 3-10) . When averaged across the 13 individual summer comparison dates, irrigation with the Rain Bird HE 1201 resulted in LQDU, LHDU, AE16 and AE32 values of 0.52, 0.72, 0.81 and 0.78, respectively. In contrast, the resulting summer values of LQDU, LHDU, AE16 and AE32 from plots irrigated with the Toro QT12Q head were 0.40, 0.64, 0.62 and 0.60, respectively. For the winter comparisons, the LQDU, LHDU, AE16 and AE32 from plots irrigated with the HE1201 averaged 0.75, 0.85, 0.77 and 0.79, respectively. The resulting winter values of LQDU, LHDU, AE16 and AE32 obtained with the Toro QT12Q heads were 0.65, 0.80, 0.75 and 0.72, respectively. Wind flow during individual comparison events greatly impacted the results. The Toro spray head produced a smaller droplet size in comparison to the Rain Bird head and was more vulnerable to drift under moderate and high wind conditions. This drift problem resulted in lower values of LQDU (Fig. 11 & 12) and LHDU and reduced values of AE16 (Fig. 13 & 14) and AE32, particularly at higher wind speeds. The lower

values of AE16 and AE32 provide clear evidence that a significant amount of water simply drifted off the plots irrigated with the Toro head. Figures 15 & 16 provide the relationships between wind speed and water collected in the perimeter catch cups. The depth of water collected was significantly lower in plots irrigated with the Toro head. It is interesting to note that the relationship between perimeter catch and wind speed appear to differ from summer to winter as do several other performance parameters. One possible explanation for this difference could rest in the evaporative potential of the atmosphere. Vapor pressure deficit (VPD), a measure of the difference from saturation of the water vapor pressure in the atmosphere, represents the best means of estimating the evaporative power of the air. The VPD during the summer and winter comparisons averaged 2.98 kPa and 0.87 kPa, respectively. One should expect the higher VPDs in summer to produce more spray evaporation during irrigation events with the overall effects greatest in plots irrigated with the Toro head due to the much smaller droplet size. The differing response of the Toro head to wind speed in Figures 15 & 16 support the evaporation hypothesis. It is also interesting to note the improvements in AE16 and AE32 for the Toro head in winter as compared to summer. Considerably more water was reaching the catch cans in winter relative to summer, again suggesting the Toro head is more prone to evaporation due to the smaller droplet size. A similar response was not observed from plots irrigated with the Rain Bird HE1201 heads which produce larger droplets and should be less prone to evaporation.

The SCs for the Rain Bird and Toro heads were not significantly different during the summer comparison period. The summer SC values proved to be quite variable from one comparison to another due in large part to the variation in wind speed. Very large SCs were measured on the windy days with the highest SCs resulting on the days with the most extreme winds. There were fewer high wind periods during the winter comparison period, resulting in more realistic and usable SCs. The SCs for the Rain Bird HE1201 and Toro OT12Q heads during winter averaged 1.57 and 2.42, respectively, with the differences in SC significant from a statistical standpoint.

Comparison of Rain Bird 12Q & Toro OT12Q

The second evaluation compared the Rain Bird 12Q spray head with the Toro OT12Q. The summer and winter evaluations were conducted from 29 June to 13 July 2012 and 5 to 22 March 2013, respectively. Wind speed on individual summer comparison dates ranged from ranged from 0.4 m/s to 2.1 m/s (0.9 to 4.7 mph) and averaged 1.1 m/s (2.5 mph). Wind speed on the individual winter comparison dates ranged from 0.6 to 2.9 m/s (1.3 to 6.5 mph) and averaged 1.6 m/s (3.6 mph) across all comparisons.

Neither head proved superior across all performance parameters during both comparisons (Tables 4 & 5). Irrigation uniformity, as indicated by the LQDU (Fig. 17 & 18; Tables 4 & 5) was significantly higher in plots irrigated with the Toro head in both summer (0.62 for Toro vs. 0.58 for Rain Bird) and winter (0.59 for Toro vs. 0.56 for Rain Bird). However, when uniformity was assessed using LHDU (Fig. 19 & 20; Tables 4 & 5) the results were mixed. In summer, both heads produced similar values for LHDU (0.77 for Toro vs. 0.78 for Rain Bird) while in winter, the Toro head produced significantly higher values of LHDU (0.77 for Toro vs 0.74 for Rain Bird).

Offsetting results emerged from the evaluation of AE as well. The Toro head produced significantly higher values of AE16 than the Rain Bird head in both summer (0.80 for Toro vs. 0.73 for Rain Bird) and winter (0.71 for Toro vs. 0.66 for Rain Bird)[Fig. 21 & 22; Tables 4 & 5]. However, when the perimeter cups were included in the AE computation (AE32), the Rain Bird head produced a significantly higher values in both seasons (0.79 for Rain Bird vs. 0.76 for Toro in summer; 0.70 for Rain Bird vs. 0.68 for Toro in winter). The factor leading to the reversal in AE performance was the water collected along the perimeter of the plots. The catch along the perimeter of the plots irrigated with the Rain Bird head was 57% and 37% higher than the perimeter catch in the Toro plots during the summer and winter, respectively (Tables 4 & 5). When these perimeter cups were included in the computation of water reaching the turf surface, more water remained on the plots irrigated with the Rain Bird 12Q spray head.

Winds were generally light during the summer evaluation and light to moderate during the winter

evaluation. Wind did not greatly impact measured values of LQDU during either period. A decrease in LQDU with wind speed was observed with the Toro head in summer (Fig. 25), but this trend was not detected in the winter evaluation (Fig. 26). Wind did not greatly impact the LQDU in plots irrigated with the Rain Bird 12Q head in either season. The relationship between AE16 and wind speed proved to be similar for both heads with the exception that AE16 obtained from the plots irrigated with the 12Q heads appeared less sensitive to wind during the summer (Fig. 27 & 28). Both sprinkler heads performed better during the summer as compared to the winter. Light winds during the summer evaluation contributed to this improvement as did the higher VPD values. The VPD during the summer averaged 1.62 kPa, approximately 25% lower than the average VPD during the winter comparison (2.06 kPa).

Plots irrigated with Toro OT12Q head generated significantly lower values for the SC than plots irrigated with the 12Q. This result is not surprising given that the OT12Q produced significantly higher values of LQDU in both seasons. The resulting summer and winter SCs for the OT12Q plots were 2.60 and 2.56, respectively. The SC values for the 12Q head were 4.58 and 3.75 for the summer and winter.

Comparison of Rain Bird U12Q & Toro OT12Q

The final evaluation compared the performance of the Rain Bird U12Q spray head and the Toro OT12Q. The summer comparisons were completed between 31 July and 10 August 2012 with the winter comparison completed between 24 January and 1 February 2013. Wind speeds were quite low during the summer comparisons and ranged from 0-1.1 m/s (0 - 2.5 mph) with an average value of 0.7 m/s (1.6 mph). Winds were generally higher during the winter comparisons with a range and average of 0.5 - 4.4 m/s (1.1 - 9.8 mph) and 1.7 m/s (3.7 mph), respectively.

This evaluation also produced mixed results with the Rain Bird U12Q head exhibiting an advantage in LQDU (0.75 for Rain Bird vs. 0.70 for Toro in summer; 0.66 for Rain Bird vs. 0.62 for Toro in winter; Figures 31 & 32; Tables 6 & 7) and LHDU in winter (0.79 for Rain Bird vs. 0.77 for Toro; Figures 33 & 34; Tables 6 & 7), but falling short of the Toro head with respect to AE. AE based on

the middle catch cups (AE16) was significantly higher for the Toro head in both seasons (0.85 for Toro vs. 0.75 for Rain Bird in summer; 0.74 for Toro vs. 0.61 for Rain Bird in winter; Figures 35 & 36). The magnitude of the Toro advantage declined when all catch cups were included in the computation (AE32), but remained significant for both seasons (0.81 for Toro vs. 0.78 for Rain Bird in summer; 0.71 for Toro vs 0.67 for Rain Bird in winter; Figures 37 & 38).

The two seasonal comparisons produced mixed results with respect to the SC. During the summer the SCs for the U12Q and OT12Q were 1.56 and 2.19 with the differences significant from a statistical point of view. However, during the windier winter period the SCs for the U12Q and OT12Q were 2.85 and 3.15, respectively with the differences non-significant.

The impact of wind on sprinkler head performance was again evident in this evaluation. Wind negatively impacted LQDU and LHDU in plots irrigated with both heads, particularly when wind speeds were above 1.0 m/s (2.2 mph). These is some evidence that winds have a more negative effect on uniformity in plots irrigated with the OT12Q (see Figures 39 & 40). Wind negatively impacted AE in plots irrigated with both heads. During the summer evaluation, the reduction in both AE16 and AE32 with wind speed was approximately 2 times greater (based on slopes of regression lines) for the U12Q head which was inconsistent with the fact that DU was not impacted in these same plots. However, this apparent greater wind sensitivity (of U12Q head) disappeared during the winter evaluation when wind speeds were higher (similar slopes of AE vs. wind speed). Finally, it is important to note that the difference in AE32 between the two head is much smaller than the difference in AE16. The reason for this improvement is the much larger catch in the perimeter cups in the plots irrigated with the U12Q head (Figures 43 & 44).

The Toro OT12Q head clearly benefitted from the light winds and humid conditions (VPD = 1.22 kPa) encountered during the summer evaluation period. Both drift and evaporation (from head to turf) would be low under these conditions and the higher measured values of AE in the Toro plots reflect this fact. However, the Toro head continued to perform better with respect to AE during the winter period when the comparisons were conducted under humid (VPD =0.89 kPa) and windy

conditions. It is therefore not clear from this study whether the U12Q might produce similar results if the comparisons were conducted during periods with low humidity which is the norm for Arizona during the spring, early summer and fall.

SUMMARY COMMENTS

The study setup and experimental procedures worked well during the both the summer and winter evaluation periods. The data sets acquired were of high quality with limited noise which allowed for effective statistical assessment of all performance parameters with perhaps the exception of the SC (see below). The following brief paragraphs summarize the key findings and conclusions resulting from this study:

1. The Rainbird HE1201 sprinkler head proved superior to the Toro OT12Q when evaluated across all four performance parameters (LQDU, LHDU, AE16 and AE32). The Toro head produces a much smaller droplet size when compared to the HE1201 and is vulnerable to greater losses due to spray drift (off the target area) and evaporation when operated under windy and/or dry conditions. The evaluation also revealed that the Toro head does not apply as much water to the perimeter area as does the Rain Bird HE1201 head, especially under windy and dry conditions.

2. A clear performance advantage did not emerge from the evaluations comparing the Rainbird 12Q and U12Q sprinkler heads with the Toro OT12Q. In comparisons with the Rain Bird U12Q sprinkler head, the Toro OT12Q head produced higher values for application efficiency, but generally lower values for uniformity. When the Toro OT12Q was compared with the Rain Bird 12Q the Toro head was generally superior with respect to uniformity and AE16, but was inferior with respect to AE32.

3. The scheduling coefficient (SC) proved to be very sensitive to wind flow. The SC was computed using the lowest catch volume of any middle catch cup. On windy days it was not uncommon to have a very low catch rate in one of these middle cups which resulted in SC values in excess of 5.0. It might be wise to evaluate the differences in SCs by restricting the analyses to days when the wind speeds were less than 2.2 m/s (5.0 mph). We note that the Irrigation Association is using the

Scheduling Multiplier (SM) as a means of adjusting for irrigation nonuniformity. The SM is computed using the LQDU (SM = 1/(0.4+0.6*LQDU) and might be a better means of assessing the water use/savings one could expect from using the various sprinklers.

4. Both wind and humidity (VPD) impacted the performance of the sprinkler heads evaluated in this study. We attempted to develop an evaporative index from wind speed and VPD that would provide a better means of assessing the sensitivity of various sprinklers to drift and evaporation. A summary of these efforts is not included in this report as these efforts have proven inadequate at present. We will continue to work on this issue in the future and will submit an additional report if an appropriate and robust evaporative index emerges from these efforts.

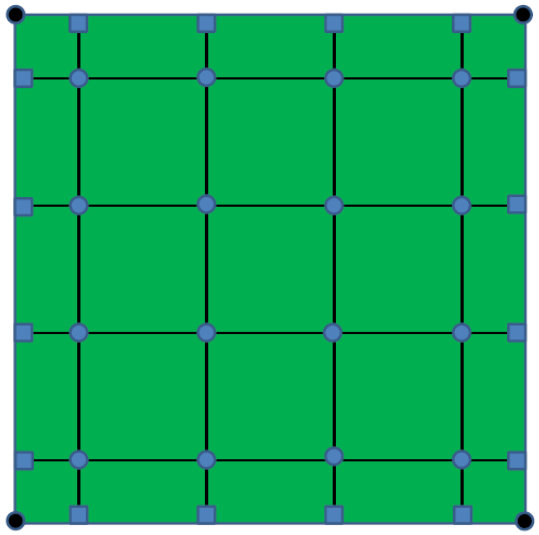

Figure 1. Location of catch cups on each study plot. Circular cups were used for the 16 interior cups. Rectangular cups were used along the perimeter of the plot. Black dots depict location of sprinkler heads.

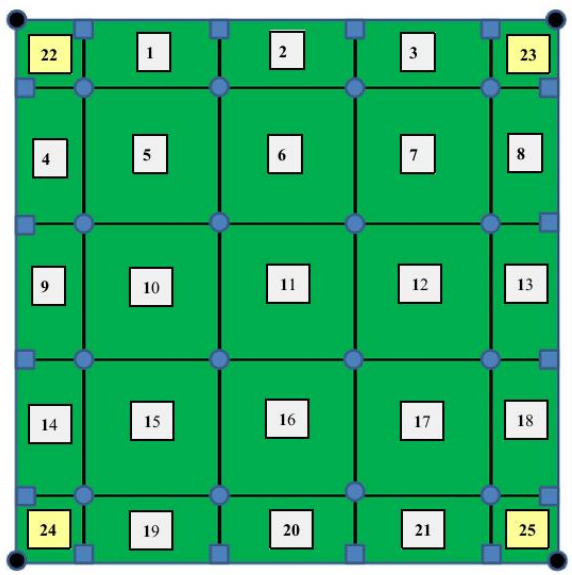

Figure 2. Graphic depicting the 25 rectangular areas used to estimate AE32. The amount of water reaching rectangular areas 1 through 21 was determined by averaging the catch from the four cups located at the corners of each area. The catch at the head (black dot) in rectangles 21 through 25 was estimated by taking the average of the two closest cups. This estimate was then added to the cup values obtained from the three remaining corners. This sum was then divided by four to obtain the estimate for these corner rectangles. Depth estimates for all 25 rectangles were then multiplied by their respective areas (9, 4.5 or 2.25 sq. ft.), summed and divided by the total plot area (144 sq. ft.) to obtain the average amount of water reaching the plot surface.

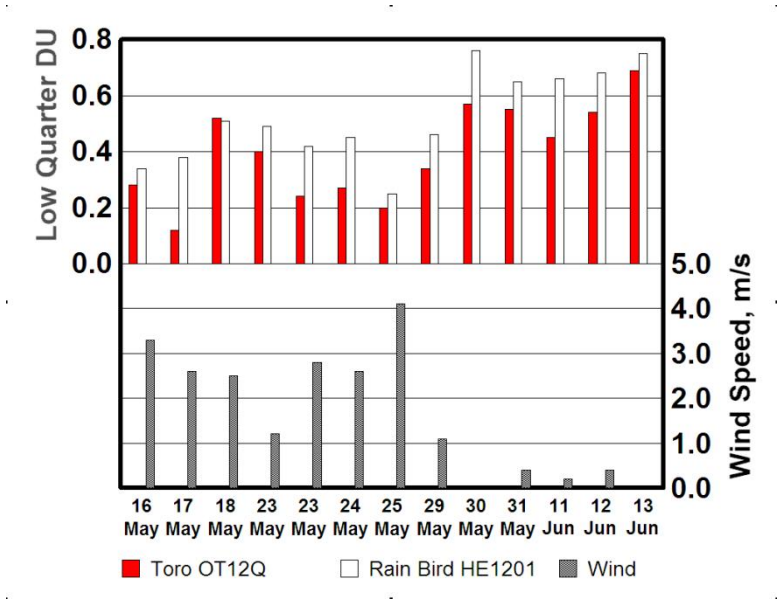

Figure 3. Low quarter distribution uniformity (LQDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the summer of 2012 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

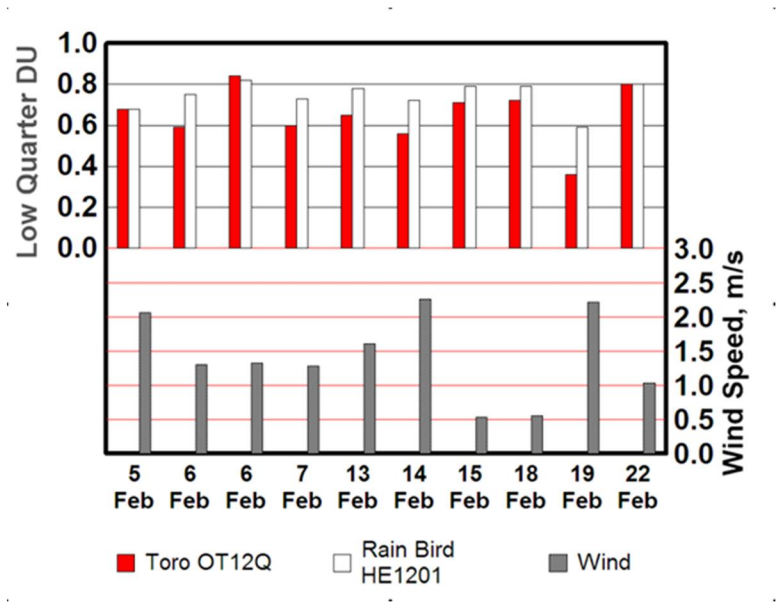

Figure 4. Low quarter distribution uniformity (LHDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the winter of 2013 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

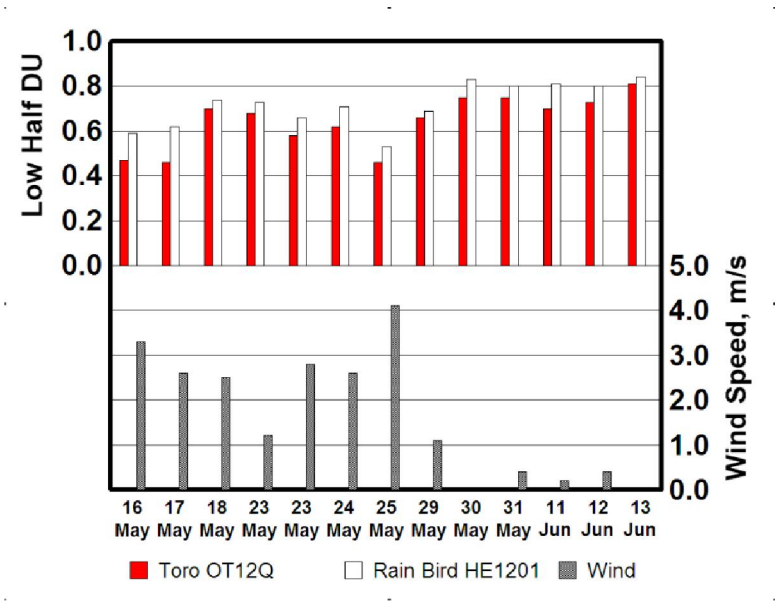

Figure 5. Low half distribution uniformity (LHDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the summer of 2013 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

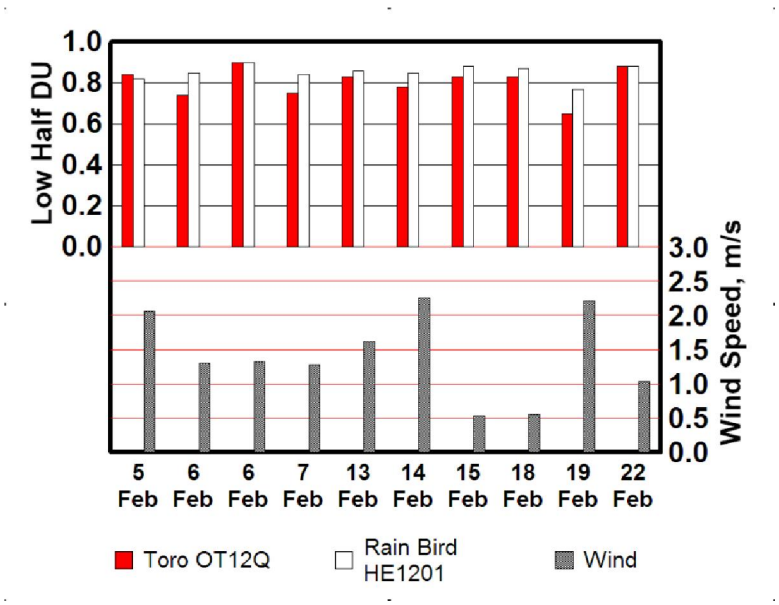

Figure 6. Low half distribution uniformity (LHDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the winter of 2013 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

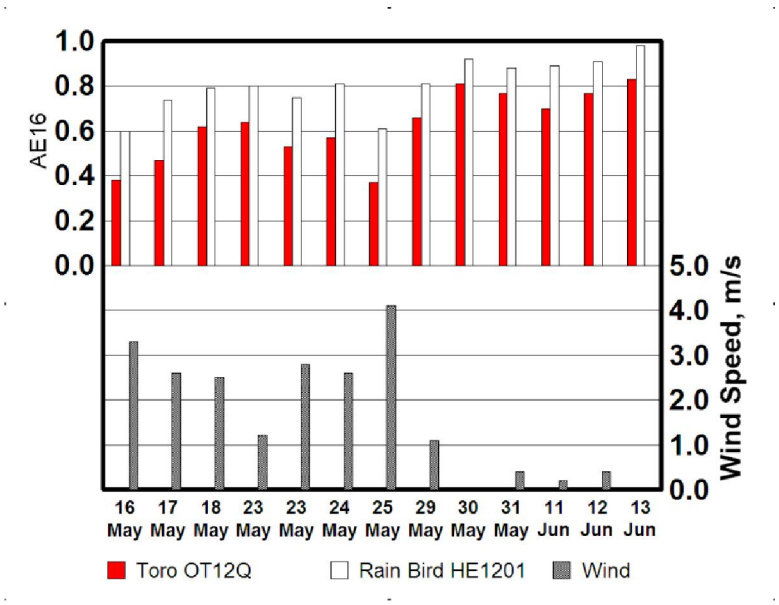

Figure 7. Application efficiency (AE16) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the summer of 2012 (upper). AE16 is computed using the 16 interior catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

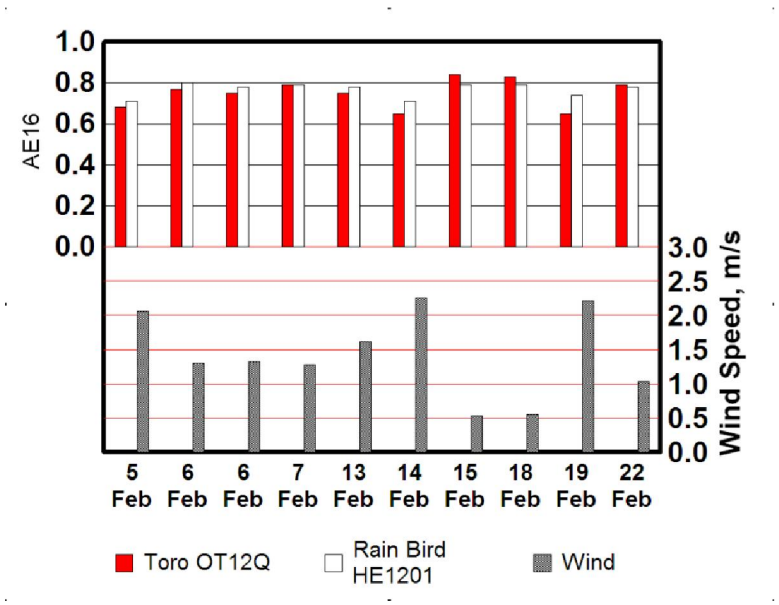

Figure 8. Application efficiency (AE16) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the winter of 2013 (upper). AE16 is computed using the 16 interior catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

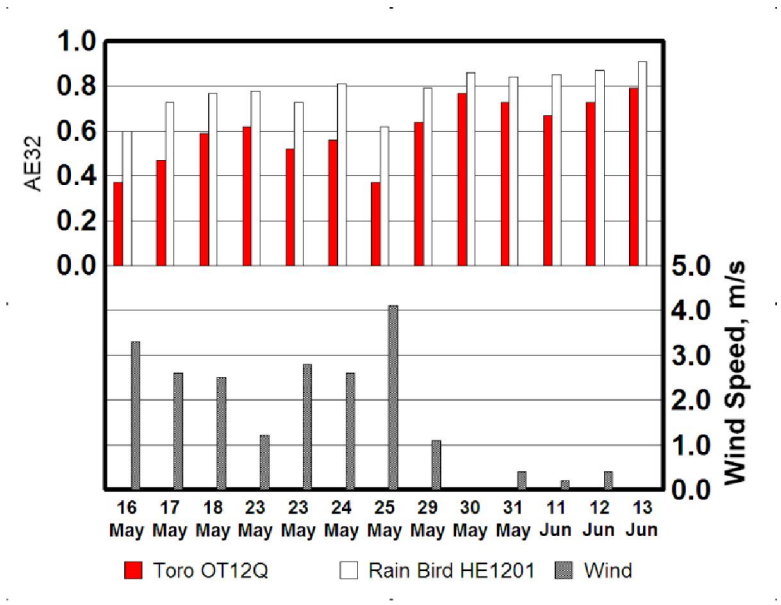

Figure 9. Application efficiency (AE32) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the summer of 2012 (upper). AE32 is computed using all 32 catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

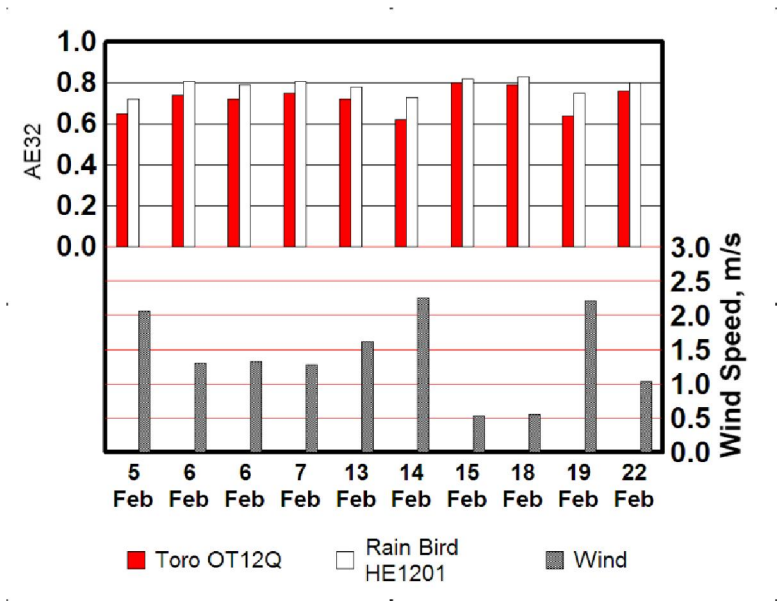

Figure 10. Application efficiency (AE32) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the winter of 2013 (upper). AE32 is computed using all 32 catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

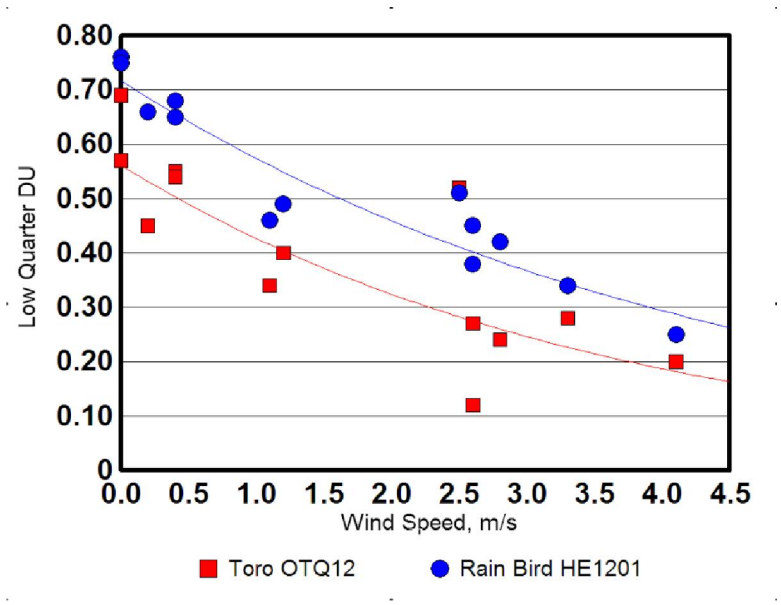

Figure 11. Low quarter distribution uniformity (LQDU) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird HE1201 sprinkler heads during the summer 2012. Plotted curves represent best fit exponential relationship for each sprinkler head.

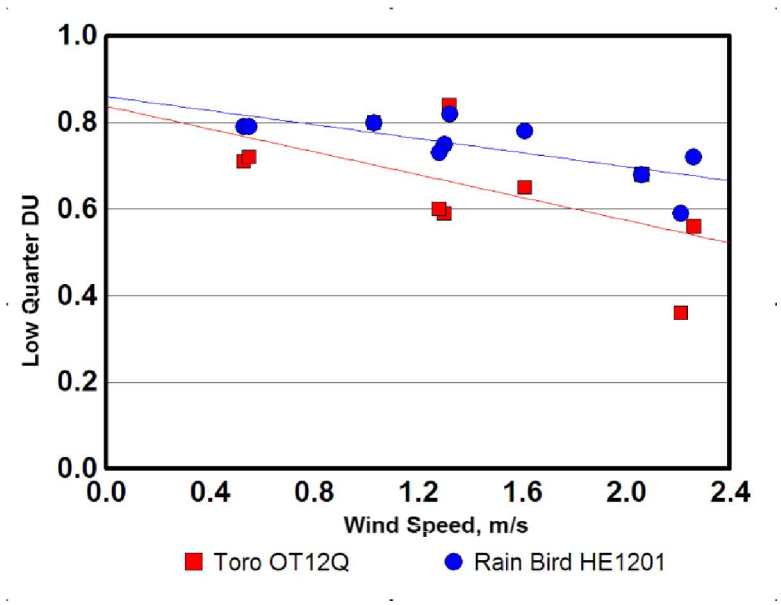

Figure 12. Low quarter distribution uniformity (LQDU) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird HE 1201 sprinkler heads during the winter of 2013. Lines represent best fit linear relationship for each sprinkler head.

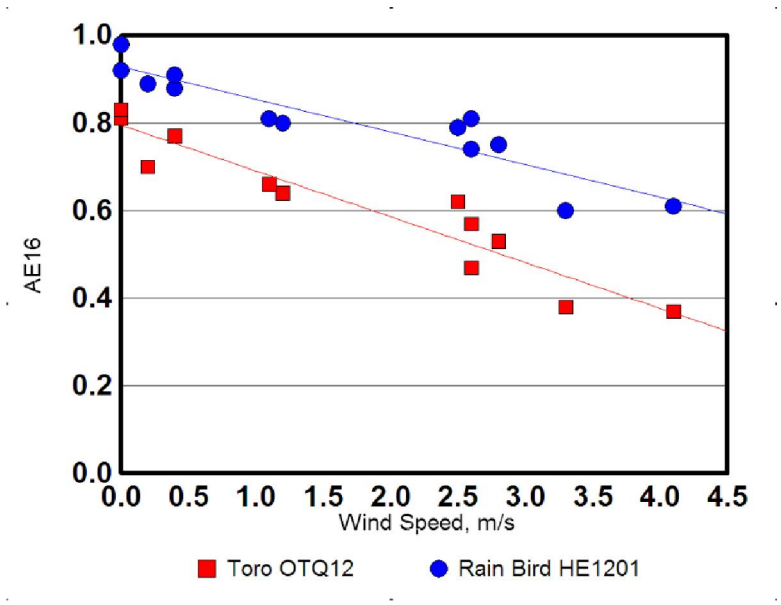

Figure 13. Application efficiency computed from the 16 interior catch cups (AE16) plotted as a function of wind speed for turf plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the summer of 2012. Lines represent the best fit linear relationship for each sprinkler head.

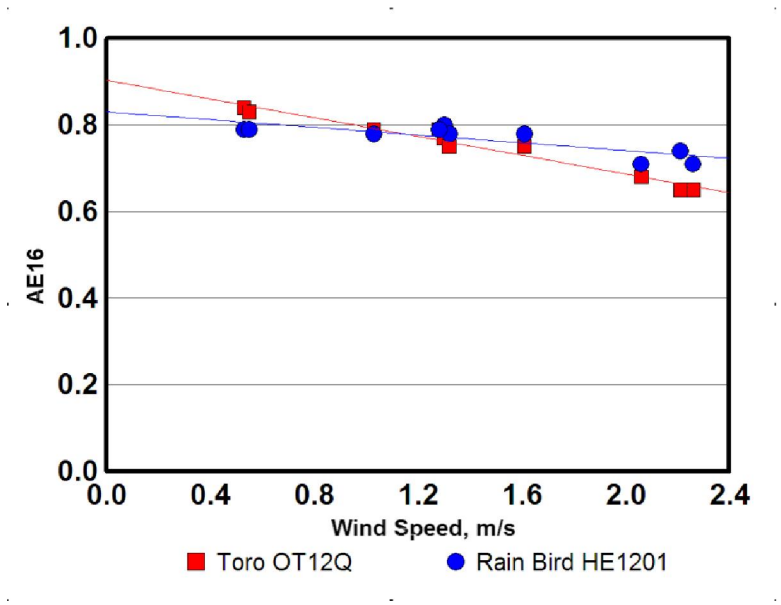

Figure 14. Application efficiency computed from the 16 interior catch cups (AE16) plotted as a function of wind speed for turf plots irrigated with the Toro OT12Q and Rain Bird HE1201 sprinkler heads during the winter of 2013. Lines represent the best fit linear relationship for each sprinkler head.

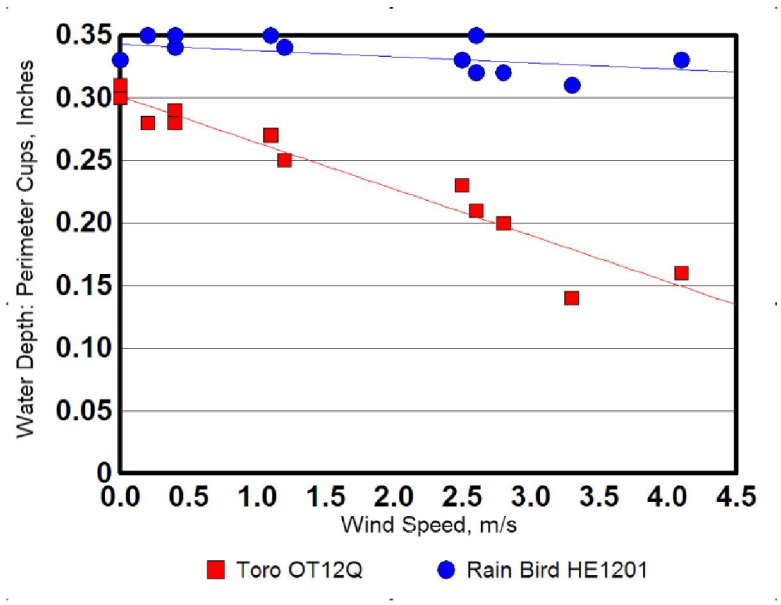

Figure 15. Depth of water collected in perimeter catch cups plotted as a function of wind speed for plots irrigated with the Toro OT12Q and Rain Bird HE 1201 sprinkler heads during the summer of 2012. Lines represent best fit linear relationship for each sprinkler head.

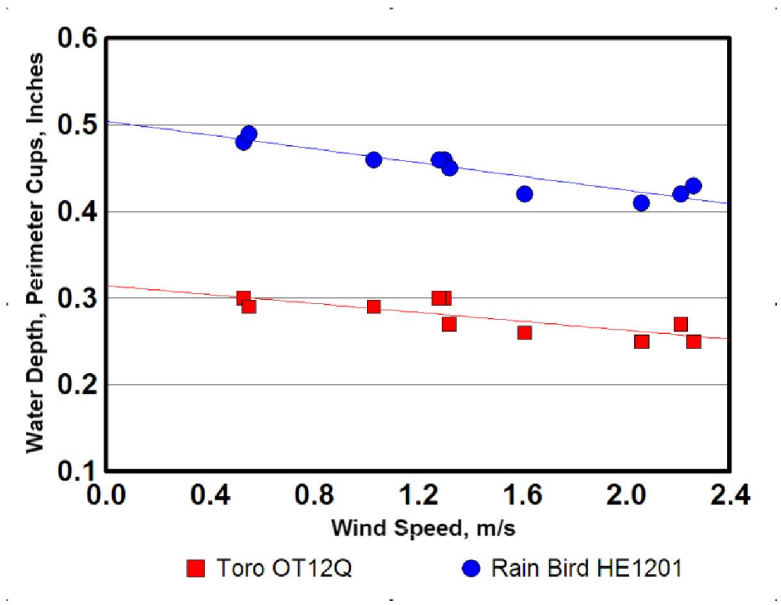

Figure 16. Depth of water collected in perimeter catch cups plotted as a function of wind speed for plots irrigated with the Toro OT12Q and Rain Bird HE 1201 sprinkler heads during the winter of 2013. Lines represent best fit linear relationship for each sprinkler head.

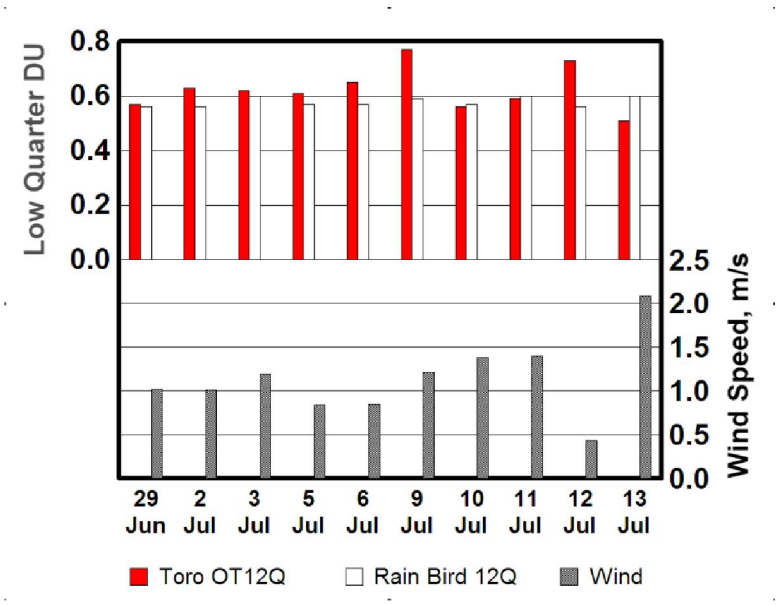

Figure 17. Low quarter distribution uniformity (LQDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the summer of 2012 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

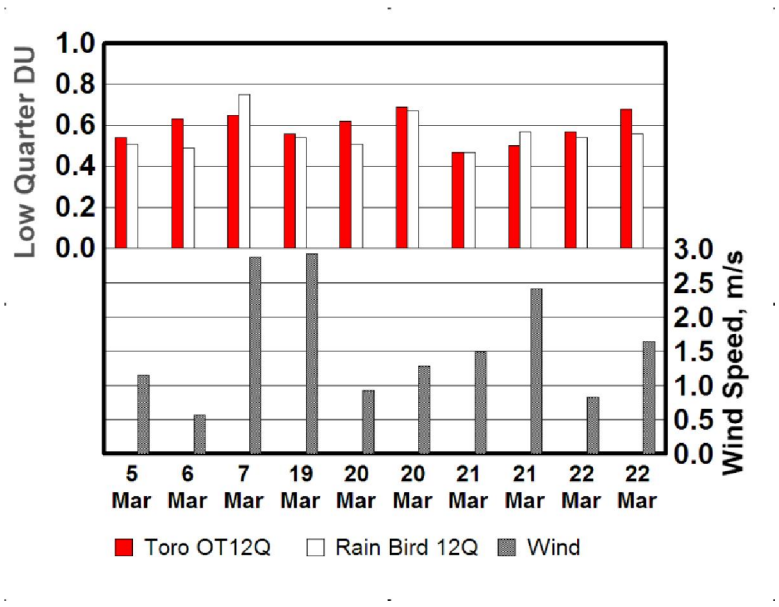

Figure 18. Low quarter distribution uniformity (LQDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the winter of 2013 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

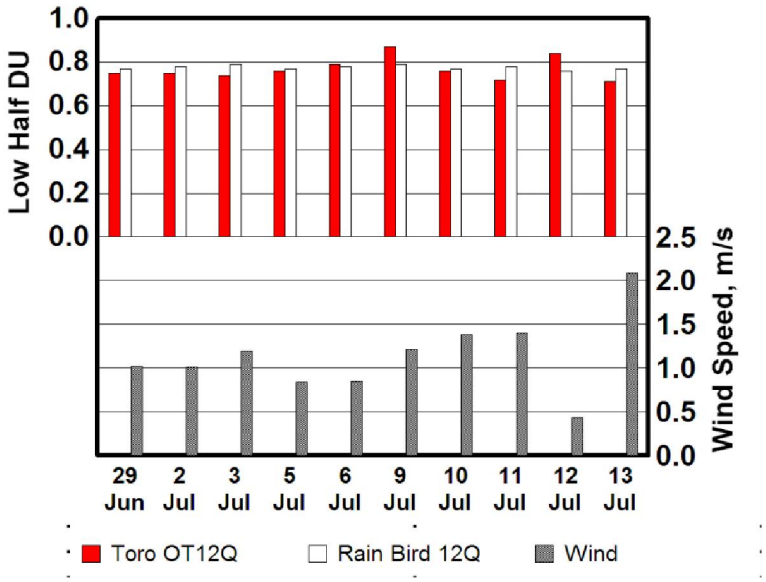

Figure 19. Low half distribution uniformity (LHDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the summer of 2012 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

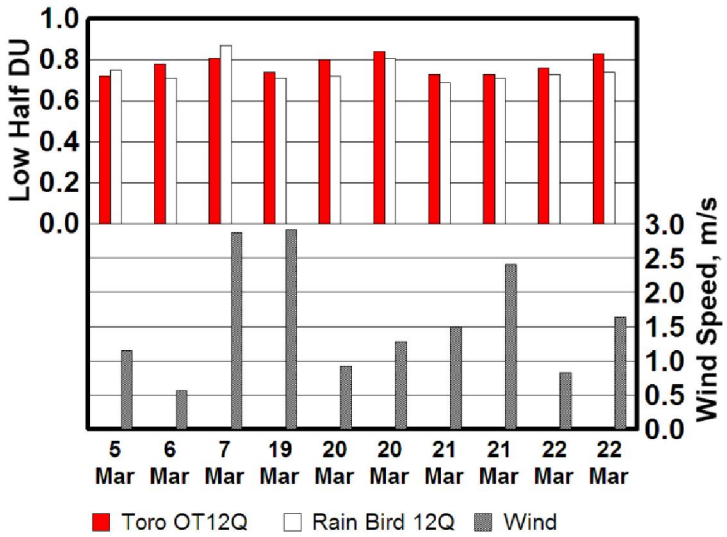

Figure 20. Low half distribution uniformity (LDDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the winter of 2013 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

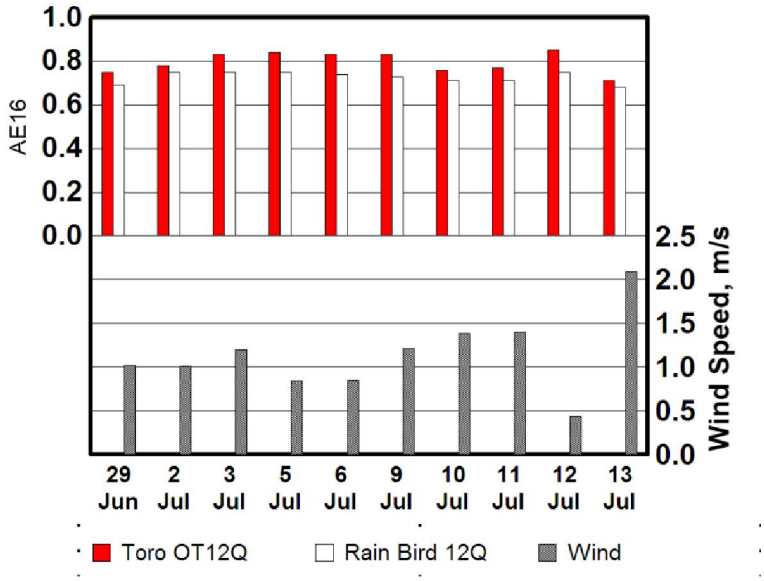

Figure 21. Application efficiency (AE16) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the summer of 2012 (upper). AE16 is computed using the 16 interior catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

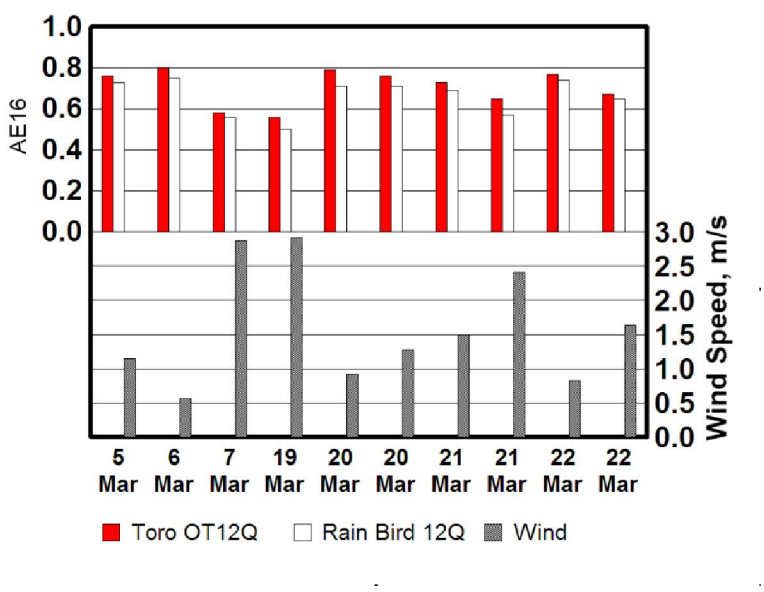

Figure 22. Application efficiency (AE16) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the winter of 2013 (upper). AE16 is computed using the 16 interior catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

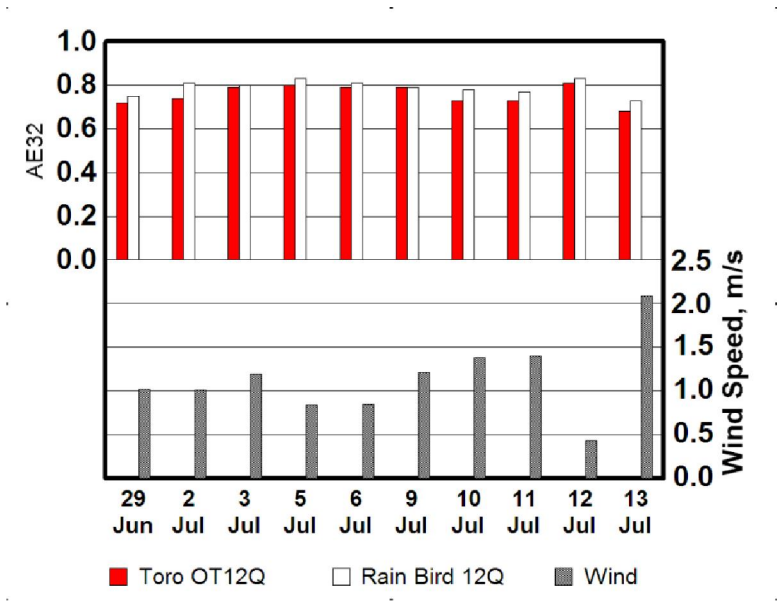

Figure 23. Application efficiency (AE32) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the summer of 2012 (upper). AE32 is computed using all 32 catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

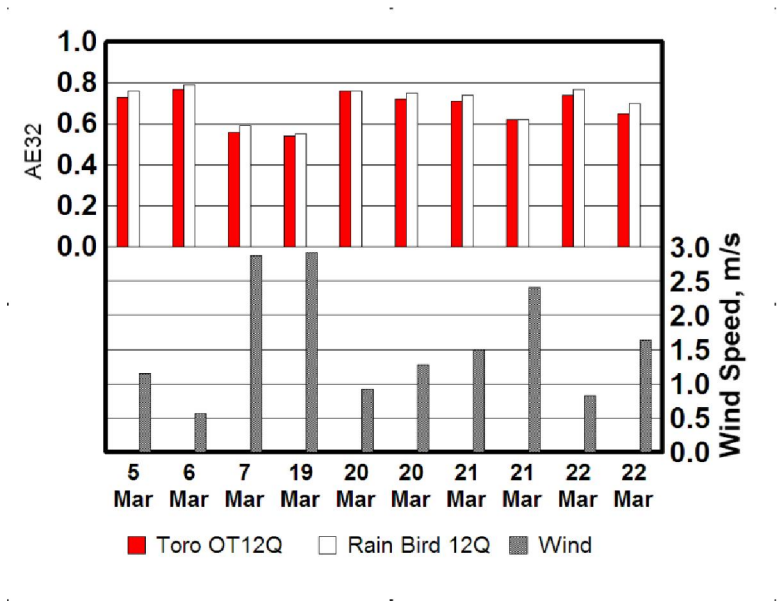

Figure 24. Application efficiency (AE32) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the winter of 2013 (upper). AE32 is computed using all 32 catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

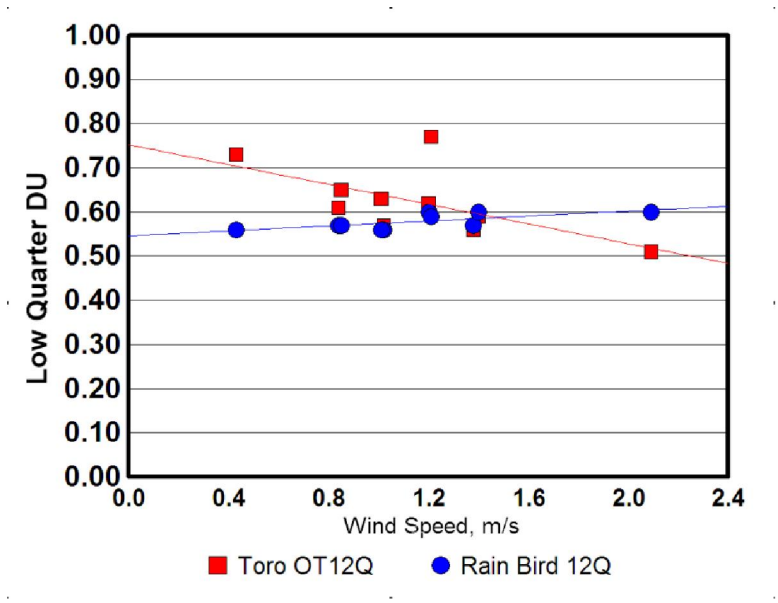

Figure 25. Low quarter distribution uniformity (LQDU) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird 12Q sprinkler heads during the summer of 2012. Lines represent best fit linear relationship for each sprinkler head.

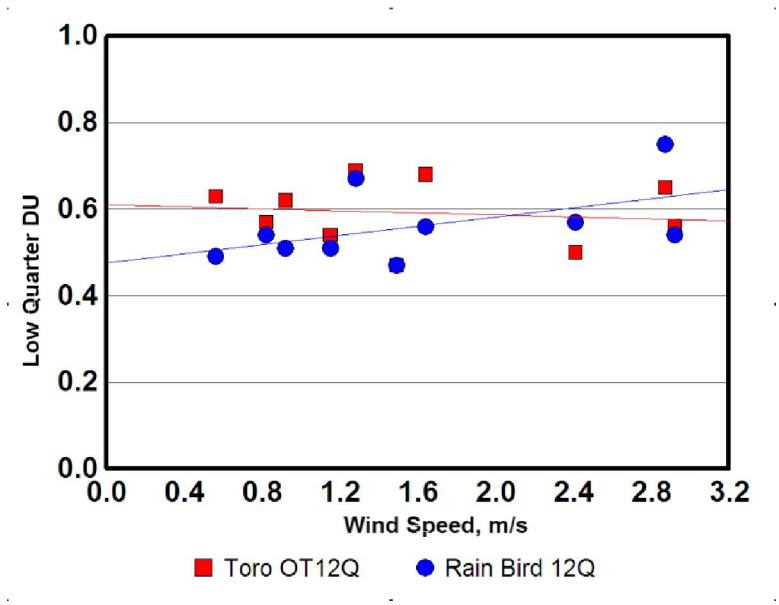

Figure 26. Low quarter distribution uniformity (LQDU) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird 12Q sprinkler heads during the winter of 2013. Lines represent best fit linear relationship for each sprinkler head.

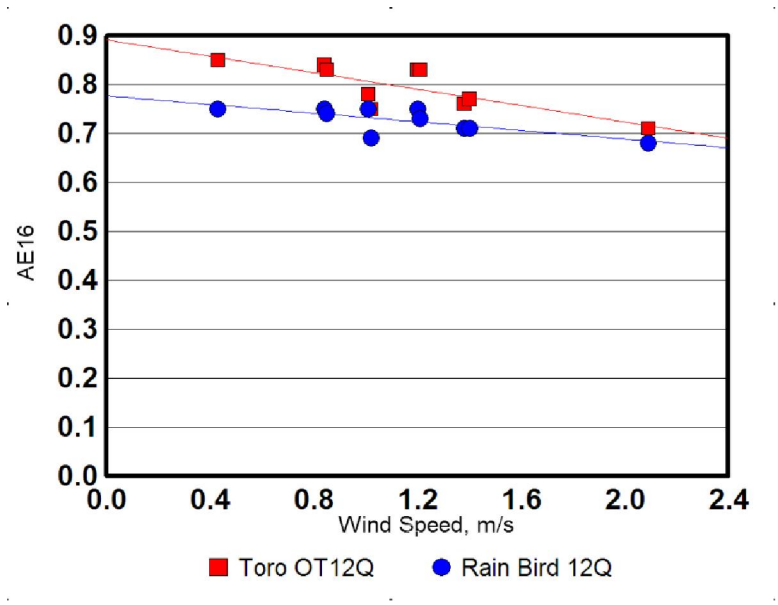

Figure 27. Application efficiency computed from the 16 interior catch cups (AE16) plotted as a function of wind speed for turf plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the summer of 2012. Lines represent the best fit linear relationship for each sprinkler head.

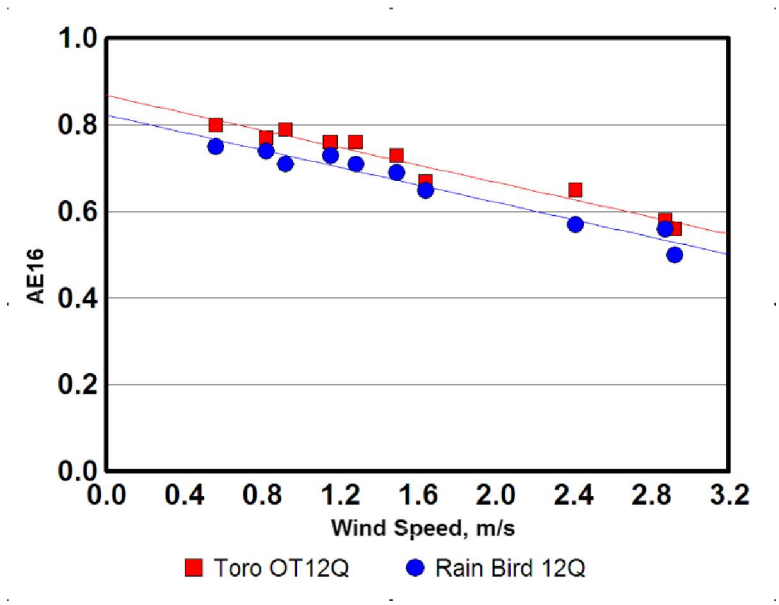

Figure 28. Application efficiency computed from the 16 interior catch cups (AE16) plotted as a function of wind speed for turf plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the winter of 2013. Lines represent the best fit linear relationship for each sprinkler head.

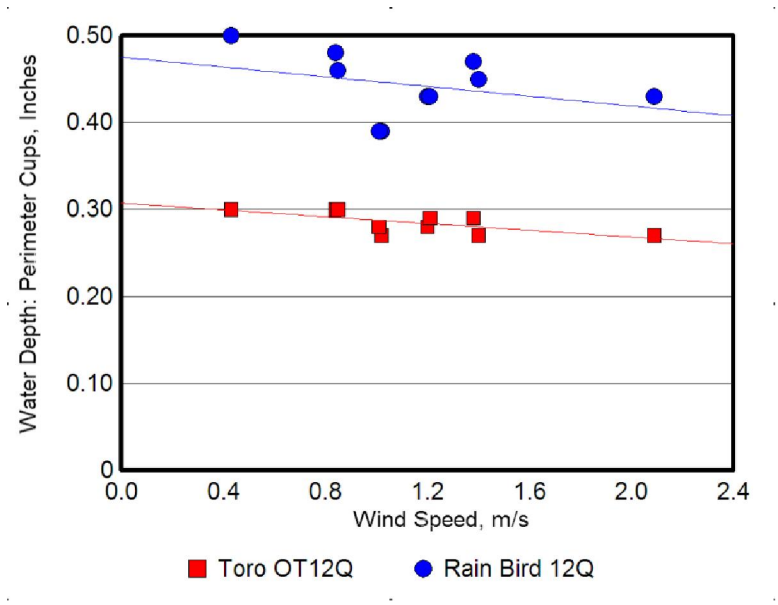

Figure 29. Depth of water collected in perimeter catch cups plotted as a function of wind speed for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the summer of 2012. Lines represent best fit linear relationship for each sprinkler head.

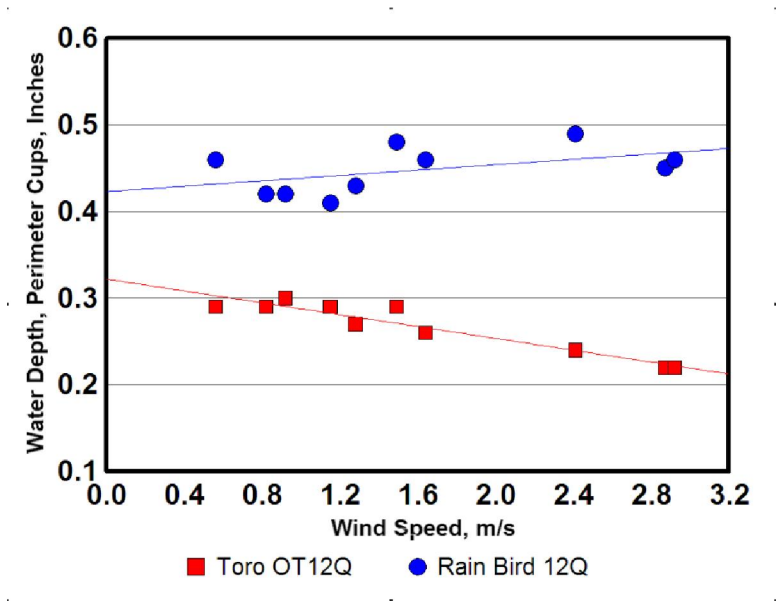

Figure 30. Depth of water collected in perimeter catch cups plotted as a function of wind speed for plots irrigated with the Toro OT12Q and Rain Bird 12Q sprinkler heads during the winter of 2012. Lines represent best fit linear relationship for each sprinkler head.

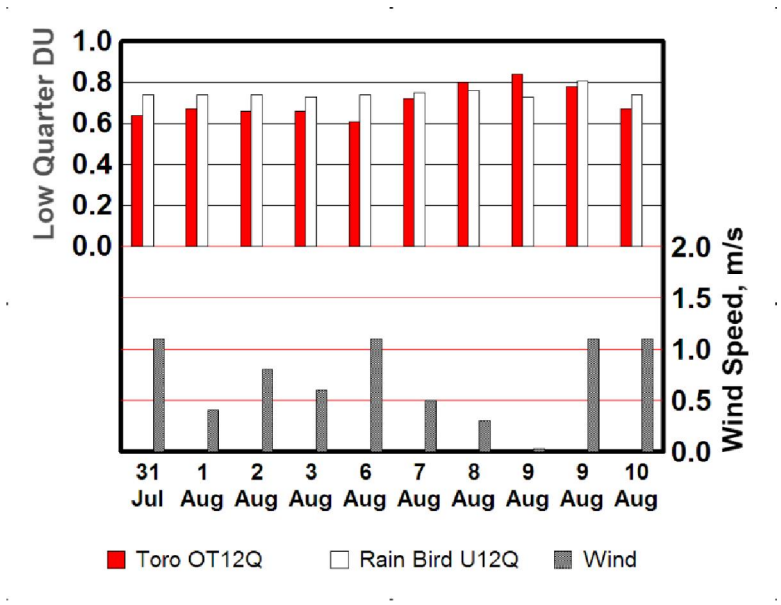

Figure 31. Low quarter distribution uniformity (LQDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the summer of 2012 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

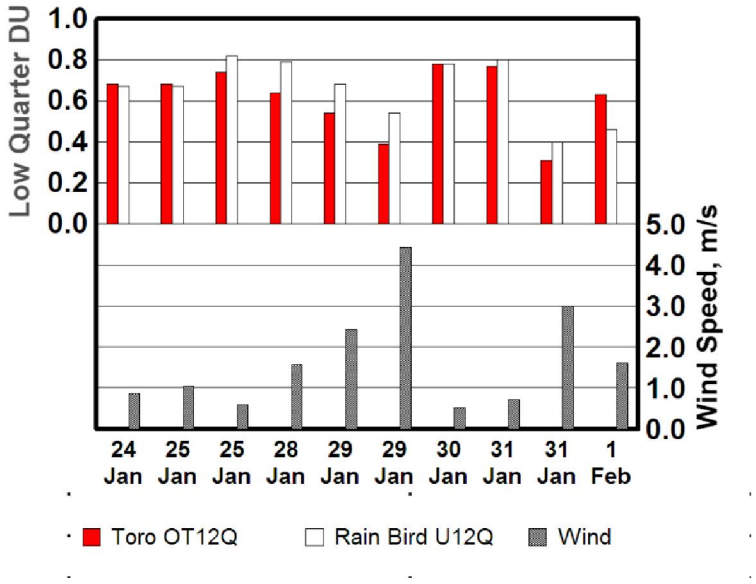

Figure 32. Low quarter distribution uniformity (LQDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the winter of 2013 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

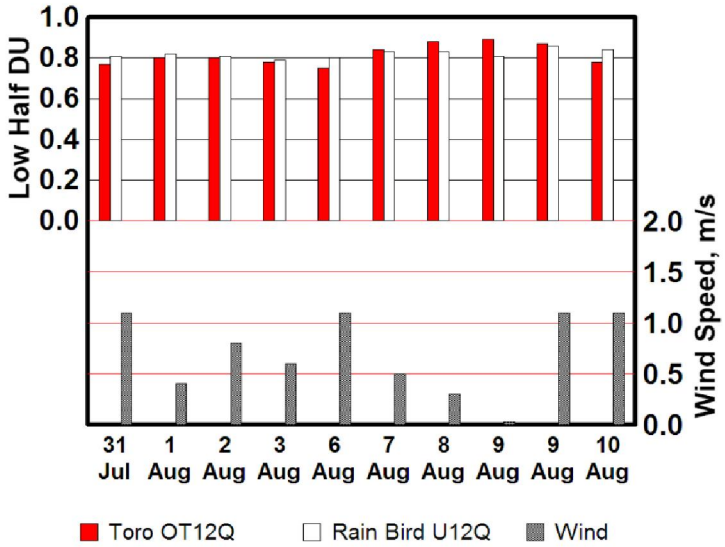

Figure 33. Low quarter distribution uniformity (LHDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the summer of 2012 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

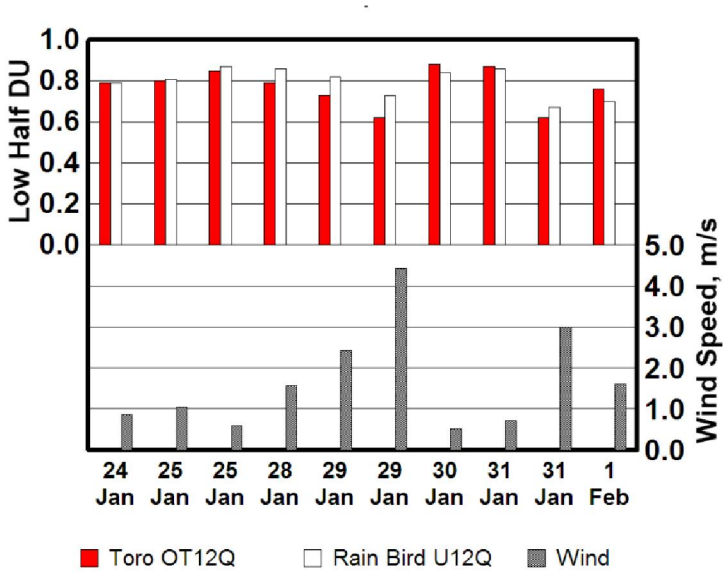

Figure 34. Low quarter distribution uniformity (LHDU) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the winter of 2013 (upper). Mean wind speed during each evaluation is plotted in the lower half of the graph.

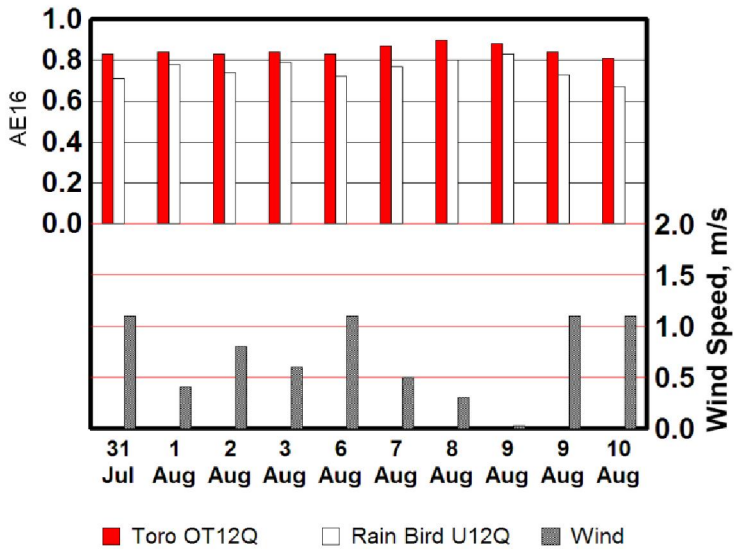

Figure 35. Application efficiency (AE16) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the summer of 2012 (upper). AE16 is computed using the 16 interior catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

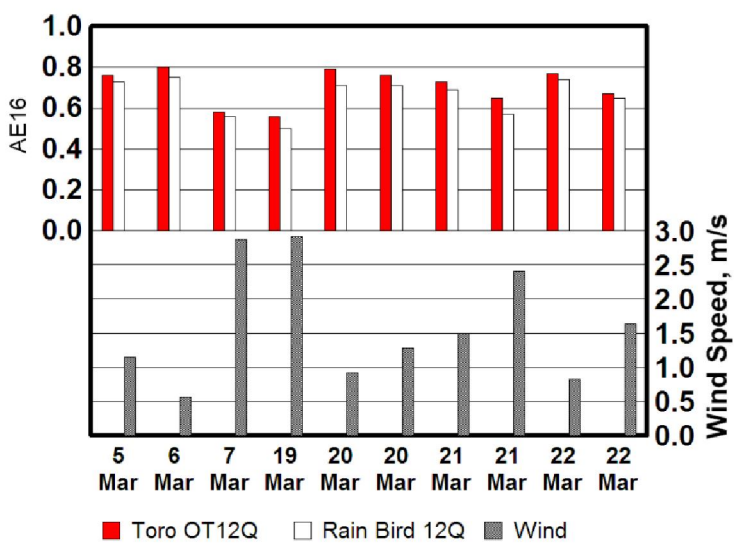

Figure 36. Application efficiency (AE16) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the winter of 2013 (upper). AE16 is computed using the 16 interior catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

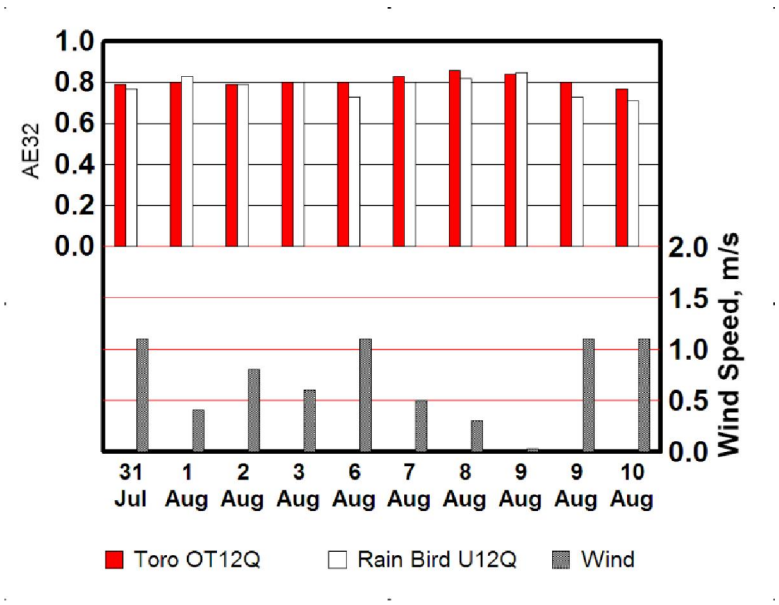

Figure 37. Application efficiency (AE32) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the summer of 2012 (upper). AE32 is computed using all 32 catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

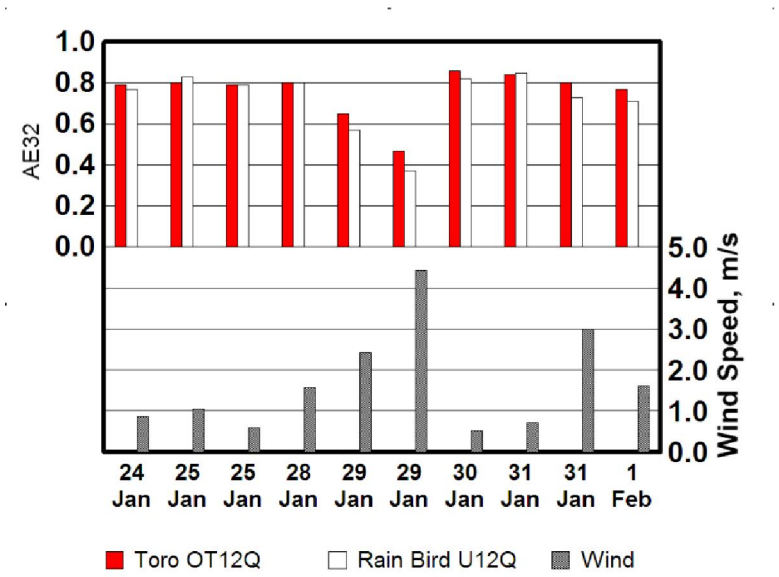

Figure 38. Application efficiency (AE32) by evaluation date for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the winter of 2013 (upper). AE32 is computed using all 32 catch cups. Mean wind speed during each evaluation is plotted in the lower half of the graph.

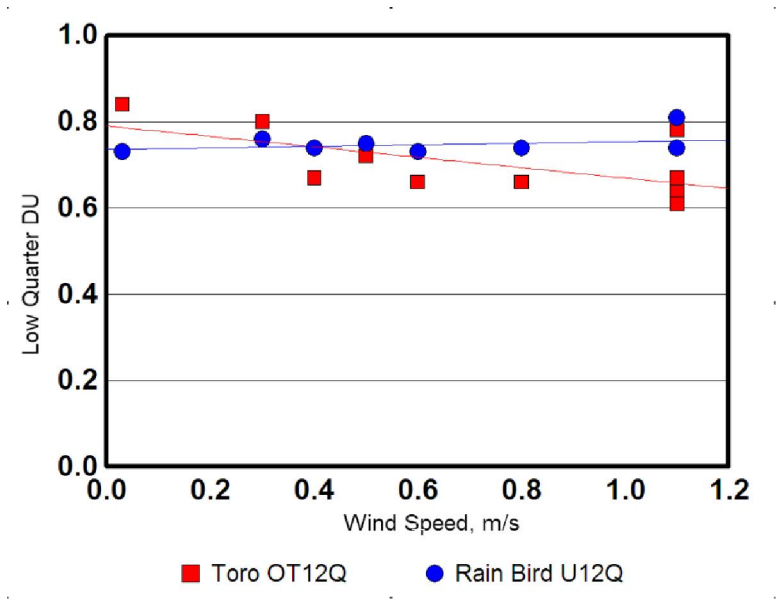

Figure 39. Low quarter distribution uniformity (LQDU) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird U12Q sprinkler heads during the summer of 2012. Lines represent best fit linear relationship for each sprinkler head.

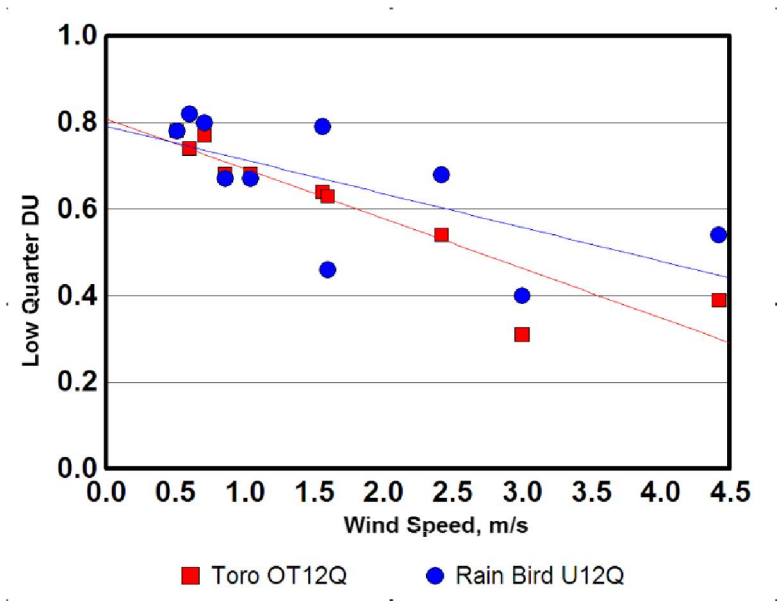

Figure 40. Low quarter distribution uniformity (LQDU) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird U12Q sprinkler heads during the summer of 2012. Lines represent best fit linear relationship for each sprinkler head.

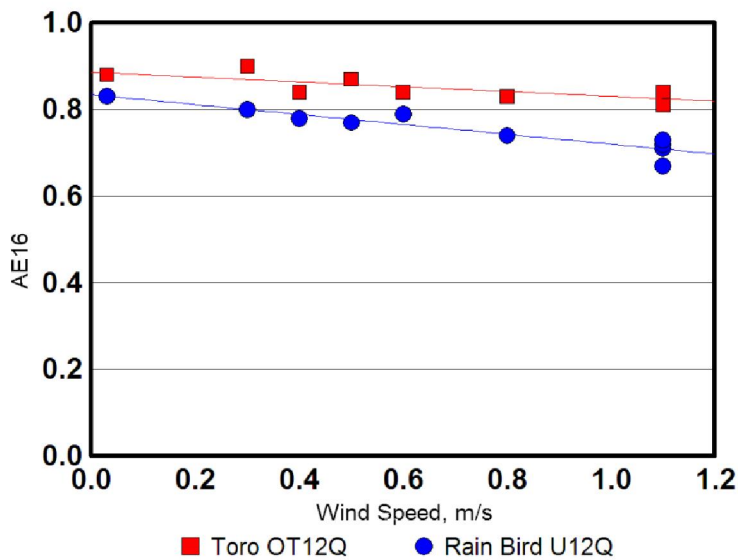

Figure 41. Application efficiency computed from the 16 interior catch cups (AE16) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird U12Q sprinkler heads during the summer of 2012. Lines represent best fit linear relationship for each sprinkler head.

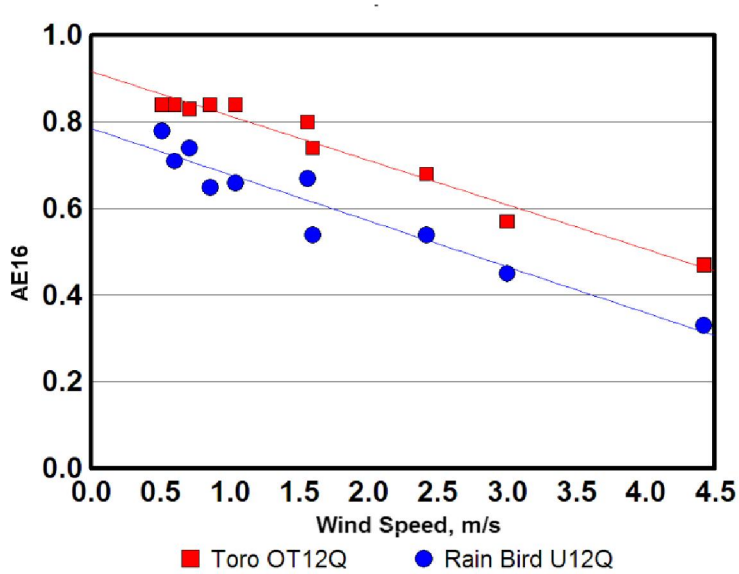

Figure 42. Application efficiency computed from the 16 interior catch cups (AE16) plotted as a function of wind speed for turf plots irrigated with the Toro OTQ12 and Rain Bird U12Q sprinkler heads during the winter of 2013. Lines represent best fit linear relationship for each sprinkler head.

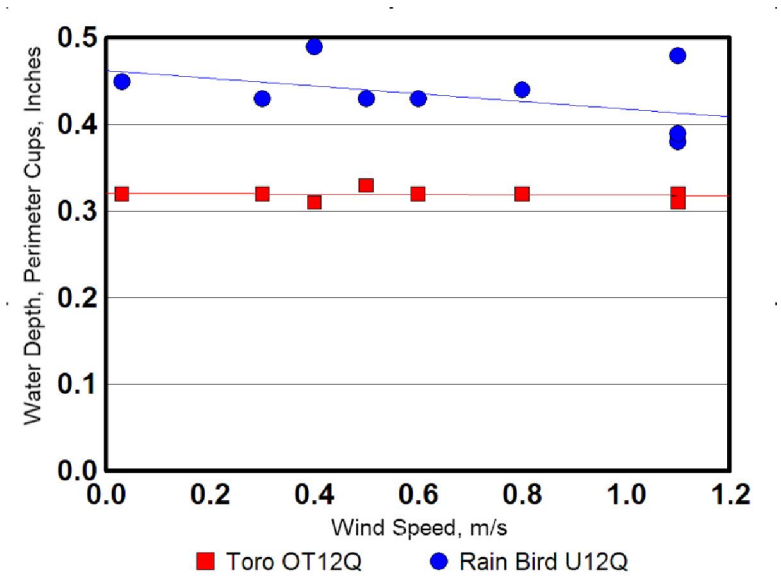

Figure 43. Depth of water collected in perimeter catch cups plotted as a function of wind speed for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the summer of 2012. Lines represent best fit linear relationship for each sprinkler head.

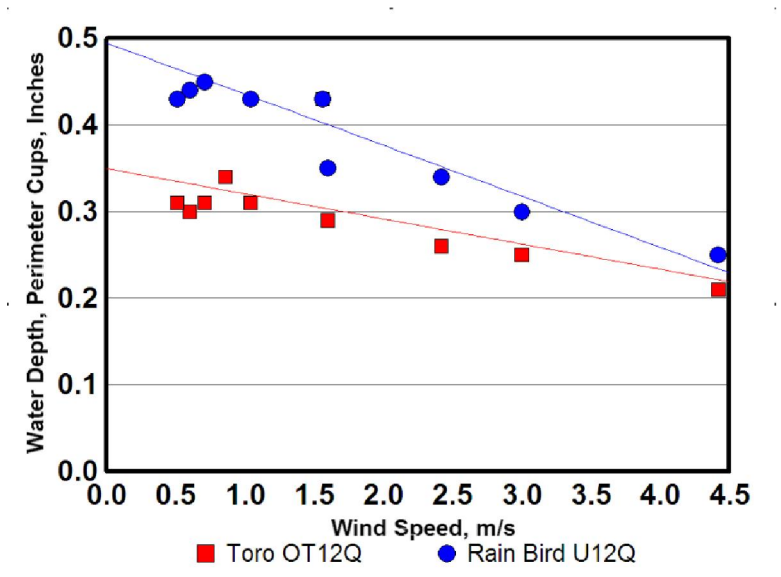

Figure 44. Depth of water collected in perimeter catch cups plotted as a function of wind speed for plots irrigated with the Toro OT12Q and Rain Bird U12Q sprinkler heads during the winter of 2013. Lines represent best fit linear relationship for each sprinkler head.

Table 1. Listing of the sprinkler heads evaluated in this study and the time span of each evaluation.

Rain Bird Product		Competitive Comparison Product		Time of Evaluation
Model	Description	Model	Description	
HE1201	12' High Efficiency Variable Arc Spray Nozzle	Toro O-T-12-Q	Toro Precision Series 12 Q Spray Nozzle	Summer: 16 May - 13 June 2012 Winter: 5 Feb - 22 Feb 2013
12Q	MPR 12Q Spray Nozzle	Toro O-T-12-Q	Toro Precision Series 12 Q Spray Nozzle	Summer: 29 Jun - 13 Jul 2012 Winter: 5 Mar - 22 Mar 2013
U12Q	U-Series 12 Q Spray Nozzle	Toro O-T-12-Q	Toro Precision Series 12 Q Spray Nozzle	Summer: 13 Jul - 10 Aug 2012 Winter: 24 Jan - 1 Feb 2013

Table 2. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity, application efficiency and scheduling coefficient by date for plots irrigated using the Toro OT12Q (TO) and Rain Bird HE1201 (RB) sprinkler heads during the summer of 2012. Distribution uniformity determined using only the 16 middle catch cups. Yes in the row labeled Stat Sig indicates means are significantly different at $p<0.05$.

Date	Time of Day			Applied		Water Collected						Distribution				Application Efficiency				Scheduling	
	Start	End		Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg.		Perimeter Cups (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg		Middle 16 Cups	
	Both	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB
16 May	1018a	1055a	1033a	0.46	0.47	0.17	0.28	0.17	0.28	0.14	0.31	0.28	0.34	0.47	0.59	0.38	0.60	0.37	0.60	8.80	6.34
17 May	736a	803a	751a	0.48	0.44	0.23	0.32	0.23	0.32	0.21	0.32	0.12	0.38	0.46	0.62	0.47	0.74	0.47	0.73	31.8	57.8
18 May	750a	817a	805a	0.48	0.46	0.29	0.37	0.28	0.36	0.23	0.33	0.52	0.51	0.70	0.74	0.62	0.79	0.59	0.77	4.75	2.98
23 May	645a	711a	700a	0.48	0.47	0.31	0.38	0.30	0.36	0.25	0.34	0.40	0.49	0.68	0.73	0.64	0.80	0.62	0.78	5.82	4.20
23 May	758a	825a	813a	0.46	0.43	0.24	0.32	0.24	0.31	0.20	0.32	0.24	0.42	0.58	0.66	0.53	0.75	0.52	0.73	10.2	8.59
24 May	724a	751a	739a	0.45	0.41	0.26	0.33	0.25	0.33	0.21	0.35	0.27	0.45	0.62	0.71	0.57	0.81	0.56	0.81	8.14	5.99
25 May	651a	718a	706a	0.49	0.47	0.18	0.29	0.18	0.29	0.16	0.33	0.20	0.25	0.46	0.53	0.37	0.61	0.37	0.62	30.5	23.7
29 May	717a	744a	732a	0.49	0.47	0.32	0.38	0.31	0.37	0.27	0.35	0.34	0.46	0.66	0.69	0.66	0.81	0.64	0.79	5.16	5.13
30 May	621a	648a	636a	0.49	0.49	0.40	0.46	0.38	0.42	0.30	0.33	0.57	0.76	0.75	0.83	0.81	0.92	0.77	0.86	2.65	1.55
31 May	636a	703a	651a	0.48	0.46	0.37	0.40	0.35	0.39	0.29	0.34	0.55	0.65	0.75	0.80	0.77	0.88	0.73	0.84	2.89	2.15
11 Jun	642a	709a	657a	0.50	0.48	0.35	0.43	0.33	0.41	0.28	0.35	0.45	0.66	0.70	0.81	0.70	0.89	0.67	0.85	4.40	2.20
12 Jun	633a	700a	648a	0.48	0.46	0.37	0.42	0.35	0.40	0.28	0.35	0.54	0.68	0.73	0.80	0.77	0.91	0.73	0.87	3.08	1.85
13 Jun	652a	719a	707a	0.49	0.48	0.41	0.47	0.39	0.43	0.31	0.33	0.69	0.75	0.81	0.84	0.83	0.98	0.79	0.91	2.00	1.64
Means				**0.48**	**0.46**	**0.30**	**0.40**	**0.29**	**0.36**	**0.24**	**0.33**	**0.40**	**0.52**	**0.64**	**0.72**	**0.62**	**0.81**	**0.60**	**0.78**	**8.28**	**8.60**
Stat Sig				**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**No**	

Table 3. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity, application efficiency and scheduling coefficient by date for plots irrigated using the Toro OT12Q (TO) and Rain Bird HE1201 (RB) sprinkler heads during the winter of 2013. Distribution uniformity determined using only the 16 middle catch cups. Yes in the row labeled Stat Sig indicates means are significantly different at $p<0.05$.

Date	Time of Day			Applied Water		Water Collected						Distribution Uniformity				Application Efficiency				Scheduling Coefficient	
	Start	End		Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg. (Inches)		Perimeter Cups (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg		Middle 16 Cups	
	Both	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB
5 Feb	154p	221p	209p	0.48	0.52	0.33	0.37	0.31	0.38	0.25	0.41	0.68	0.68	0.84	0.82	0.68	0.71	0.65	0.72	1.81	1.83
6 Feb	807a	834a	822a	0.48	0.52	0.37	0.42	0.35	0.43	0.30	0.46	0.59	0.75	0.74	0.85	0.77	0.80	0.74	0.81	2.87	1.53
6 Feb	135p	202p	150p	0.48	0.53	0.36	0.42	0.35	0.42	0.27	0.45	0.84	0.82	0.90	0.90	0.75	0.78	0.72	0.79	1.38	1.34
7 Feb	815a	842a	830a	0.47	0.53	0.37	0.42	0.36	0.42	0.30	0.46	0.60	0.73	0.75	0.84	0.79	0.79	0.75	0.81	2.71	1.52
13 Feb	153p	220p	208p	0.47	0.53	0.35	0.41	0.34	0.41	0.26	0.42	0.65	0.78	0.83	0.86	0.75	0.78	0.72	0.78	2.23	1.39
14 Feb	137p	204p	152p	0.47	0.53	0.30	0.38	0.29	0.39	0.25	0.43	0.56	0.72	0.78	0.85	0.65	0.71	0.62	0.73	2.83	1.56
15 Feb	839a	916a	854a	0.48	0.53	0.40	0.42	0.38	0.25	0.30	0.48	0.71	0.79	0.83	0.88	0.84	0.79	0.80	0.82	1.78	1.41
18 Feb	942a	1009a	957a	0.47	0.53	0.39	0.42	0.37	0.30	0.29	0.49	0.72	0.79	0.83	0.87	0.83	0.79	0.79	0.83	1.79	1.42
19 Feb	839a	916a	854a	0.47	0.53	0.30	0.39	0.30	0.40	0.27	0.42	0.36	0.59	0.65	0.77	0.65	0.74	0.64	0.75	5.37	2.26
22 Feb	934a	1001a	949a	0.47	0.52	0.37	0.41	0.36	0.42	0.29	0.46	0.80	0.80	0.88	0.88	0.79	0.78	0.76	0.80	1.44	1.46
Means				**0.47**	**0.53**	**0.36**	**0.41**	**0.34**	**0.41**	**0.28**	**0.45**	**0.65**	**0.75**	**0.80**	**0.85**	**0.75**	**0.77**	**0.72**	**0.79**	**2.42**	**1.57**
Stat Sig				**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**	

Table 4. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity, application efficiency and scheduling coefficient by date for plots irrigated using the Toro OT12Q (TO) and Rain Bird 12Q (RB) sprinkler heads during the summer of 2012. Distribution uniformity determined using only the 16 middle catch cups. Yes in the row labeled Stat Sig indicates means are significantly different at $p<0.05$.

Date	Time of Day			Applied Water		Water Collected						Distribution Uniformity				Application Efficiency				Scheduling Coefficient	
	Start	End		Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg. (Inches)		Edge Cups (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg		Middle 16 Cups	
	Both	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	T	RB	T	RB	T	RB	T	RB
29 Jun	634a	701a	649a	0.47	0.48	0.35	0.33	0.34	0.36	0.27	0.39	0.57	0.56	0.75	0.77	0.75	0.69	0.72	0.75	1.36	1.36
2 Jul	611a	638a	626a	0.47	0.45	0.36	0.34	0.35	0.36	0.28	0.39	0.63	0.56	0.75	0.78	0.78	0.75	0.74	0.81	1.29	1.36
3 Jul	608a	635a	623a	0.47	0.50	0.39	0.37	0.37	0.40	0.28	0.43	0.62	0.60	0.74	0.79	0.83	0.75	0.79	0.80	2.82	4.88
5 Jul	556a	623a	611a	0.47	0.49	0.39	0.38	0.39	0.41	0.30	0.48	0.61	0.57	0.76	0.77	0.84	0.75	0.80	0.83	2.39	4.15
6 Jul	607a	634a	622a	0.47	0.49	0.39	0.36	0.37	0.40	0.30	0.46	0.65	0.57	0.79	0.78	0.83	0.74	0.79	0.81	2.08	4.26
9 Jul	605a	632a	620a	0.47	0.49	0.39	0.36	0.37	0.39	0.29	0.43	0.77	0.59	0.87	0.79	0.83	0.73	0.79	0.79	1.54	4.54
10 Jul	609a	636a	624a	0.50	0.52	0.38	0.37	0.36	0.41	0.29	0.47	0.56	0.57	0.76	0.77	0.76	0.71	0.73	0.78	2.95	4.76
11 Jul	614a	641a	629a	0.47	0.51	0.37	0.37	0.34	0.39	0.27	0.45	0.59	0.60	0.72	0.78	0.77	0.71	0.73	0.77	2.98	4.76
12 Jul	554a	621a	609a	0.48	0.51	0.41	0.38	0.39	0.42	0.30	0.50	0.73	0.56	0.84	0.76	0.85	0.75	0.81	0.83	1.19	1.36
13 Jul	604a	631a	619a	0.48	0.51	0.34	0.35	0.33	0.37	0.27	0.43	0.51	0.60	0.71	0.77	0.71	0.68	0.68	0.73	1.42	1.32
Means				**0.48**	**0.50**	**0.38**	**0.36**	**0.36**	**0.39**	**0.28**	**0.44**	**0.62**	**0.58**	**0.77**	**0.78**	**0.80**	**0.73**	**0.76**	**0.79**	**2.60**	**4.58**
Stat Sig				**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**No**		**Yes**		**Yes**		**Yes**	

Table 5. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity, application efficiency and scheduling coefficient by date for plots irrigated using the Toro OT12Q (TO) and Rain Bird 12Q (RB) sprinkler heads during the winter of 2012. Distribution uniformity determined using only the 16 middle catch cups. Yes in the row labeled Stat Sig indicates means are significantly different at $p<0.05$.

Date	Time of Day			Applied Water		Water Collected						Distribution Uniformity				Application Efficiency				Scheduling Coefficient	
	Start	End		Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg. (Inches)		Perimeter Cups (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg		Middle 16 Cups	
	Both	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB
5 Mar	841a	906a	856a	0.47	0.48	0.36	0.35	0.35	0.36	0.29	0.36	0.54	0.51	0.72	0.75	0.76	0.73	0.73	0.76	2.99	3.12
6 Mar	824a	851a	839a	0.47	0.47	0.38	0.35	0.36	0.37	0.29	0.38	0.63	0.49	0.78	0.71	0.80	0.75	0.77	0.79	2.47	3.69
7 Mar	111p	138p	126p	0.47	0.48	0.27	0.27	0.26	0.28	0.22	0.32	0.65	0.75	0.81	0.87	0.58	0.56	0.56	0.59	1.73	1.82
19 Mar	129p	156p	144p	0.48	0.47	0.27	0.24	0.26	0.26	0.22	0.33	0.56	0.54	0.74	0.71	0.56	0.50	0.54	0.55	2.97	4.50
20 Mar	802a	829a	817a	0.48	0.47	0.38	0.34	0.37	0.36	0.30	0.39	0.62	0.51	0.80	0.72	0.79	0.71	0.76	0.76	2.37	4.58
20 Mar	1237p	104p	1252p	0.48	0.48	0.37	0.34	0.35	0.36	0.27	0.39	0.69	0.67	0.84	0.81	0.76	0.71	0.72	0.75	1.91	2.40
21 Mar	803a	830a	818a	0.49	0.48	0.35	0.33	0.34	0.35	0.29	0.38	0.47	0.47	0.73	0.69	0.73	0.69	0.71	0.74	3.11	4.58
21 Mar	117p	144p	132p	0.48	0.48	0.31	0.27	0.30	0.29	0.24	0.35	0.50	0.57	0.73	0.71	0.65	0.57	0.62	0.62	3.75	5.88
22 Mar	744a	811a	759a	0.49	0.48	0.38	0.35	0.36	0.37	0.29	0.39	0.57	0.54	0.76	0.73	0.77	0.74	0.74	0.77	2.57	4.08
22 Mar	927a	954a	942a	0.49	0.48	0.33	0.31	0.31	0.34	0.26	0.38	0.68	0.56	0.83	0.74	0.67	0.65	0.65	0.70	1.75	3.18
Means				**0.48**	**0.48**	**0.34**	**0.31**	**0.33**	**0.34**	**0.27**	**0.37**	**0.59**	**0.56**	**0.77**	**0.74**	**0.71**	**0.66**	**0.68**	**0.70**	**2.56**	**3.75**
Stat Sig				**No**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**	

Table 6. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity, application efficiency and scheduling coefficient by date for plots irrigated using the Toro OT12Q (TO) and Rain Bird U12Q (RB) sprinkler heads during the summer of 2012. Distribution uniformity determined using only the 16 middle catch cups. Yes in the row labeled Stat Sig indicates means are significantly different at $p<0.05$.

Date	Time of Day			Applied Water		Water Collected						Distribution Uniformity				Application Efficiency				Scheduling Coefficient	
	Start	End		Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg. (Inches)		Edge Cups (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg		Middle 16 Cups	
	Both	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB
31 Jul	614a	641a	629a	0.49	0.46	0.40	0.33	0.39	0.35	0.32	0.48	0.64	0.74	0.77	0.81	0.83	0.71	0.79	0.77	2.66	1.55
1 Aug	619a	646a	634a	0.49	0.47	0.41	0.36	0.39	0.39	0.31	0.49	0.67	0.74	0.80	0.82	0.84	0.78	0.80	0.83	2.04	1.69
2 Aug	613a	640a	628a	0.49	0.46	0.40	0.34	0.39	0.36	0.32	0.44	0.66	0.74	0.80	0.81	0.83	0.74	0.79	0.79	1.96	1.68
3 Aug	615a	642a	630a	0.49	0.47	0.41	0.37	0.39	0.38	0.32	0.43	0.66	0.73	0.78	0.79	0.84	0.79	0.80	0.80	2.54	1.57
6 Aug	614a	641a	629a	0.49	0.46	0.41	0.33	0.39	0.34	0.32	0.39	0.61	0.74	0.75	0.80	0.83	0.72	0.80	0.73	3.70	1.57
7 Aug	620a	647a	635a	0.49	0.46	0.43	0.36	0.41	0.37	0.33	0.43	0.72	0.75	0.84	0.83	0.87	0.77	0.83	0.80	2.19	1.53
8 Aug	607a	634a	622a	0.49	0.46	0.44	0.37	0.42	0.38	0.32	0.43	0.80	0.76	0.88	0.83	0.90	0.80	0.86	0.82	1.46	1.46
9 Aug	615a	642a	630a	0.49	0.47	0.43	0.39	0.41	0.40	0.32	0.45	0.84	0.73	0.89	0.81	0.88	0.83	0.84	0.85	1.29	1.58
9 Aug	749a	816a	804a	0.50	0.47	0.42	0.34	0.40	0.34	0.32	0.38	0.78	0.81	0.87	0.86	0.84	0.73	0.80	0.73	1.75	1.35
10 Aug	615a	642a	630a	0.49	0.46	0.40	0.31	0.38	0.33	0.31	0.39	0.67	0.74	0.78	0.84	0.81	0.67	0.77	0.71	2.30	1.59
Means				**0.49**	**0.46**	**0.42**	**0.35**	**0.40**	**0.36**	**0.32**	**0.43**	**0.70**	**0.75**	**0.82**	**0.82**	**0.85**	**0.75**	**0.81**	**0.78**	**2.19**	**1.56**
Stat Sig				**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**No**		**Yes**		**Yes**		**Yes**	

Table 7. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity, application efficiency and scheduling coefficient by date for plots irrigated using the Toro OT12Q (TO) and Rain Bird U12Q (RB) sprinkler heads during the winter of 2013. Distribution uniformity determined using only the 16 middle catch cups. Yes in the row labeled Stat Sig indicates means are significantly different at $p<0.05$.

Date	Time of Day			Applied Water		Water Collected						Distribution Uniformity				Application Efficiency				Scheduling Coefficient	
	Start	End		Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg. (Inches)		Edge Cups (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg		Middle 16 Cups	
	Both	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	TO	RB	T	RB	T	RB	T	RB	T	RB
24 Jan	844a	859a	911a	0.53	0.57	0.45	0.34	0.43	0.40	0.34	0.54	0.68	0.67	0.79	0.79	0.84	0.65	0.80	0.71	2.33	2.31
25 Jan	830a	845a	857a	0.48	0.47	0.40	0.30	0.38	0.33	0.31	0.43	0.68	0.67	0.80	0.81	0.84	0.66	0.80	0.71	1.97	2.04
25 Jan	141p	156p	208p	0.49	0.47	0.41	0.33	0.39	0.35	0.30	0.44	0.74	0.82	0.85	0.87	0.84	0.71	0.79	0.74	1.69	1.26
28 Jan	808a	823a	835a	0.47	0.47	0.37	0.31	0.36	0.29	0.43	0.43	0.64	0.79	0.79	0.86	0.80	0.67	0.76	0.72	2.07	1.45
29 Jan	821a	836a	848a	0.47	0.47	0.32	0.26	0.31	0.27	0.26	0.34	0.54	0.68	0.73	0.82	0.68	0.54	0.65	0.58	4.04	2.11
29 Jan	139p	154p	206p	0.47	0.47	0.22	0.16	0.22	0.18	0.21	0.25	0.39	0.54	0.62	0.73	0.47	0.33	0.47	0.37	4.69	3.01
30 Jan	1004a	1019a	1031a	0.49	0.47	0.41	0.37	0.39	0.37	0.31	0.43	0.78	0.78	0.88	0.84	0.84	0.78	0.80	0.80	1.84	1.37
31 Jan	943a	958a	1010a	0.49	0.48	0.41	0.35	0.39	0.37	0.31	0.45	0.77	0.80	0.87	0.86	0.83	0.74	0.79	0.77	1.80	1.39
31 Jan	140p	155p	207p	0.49	0.47	0.28	0.21	0.28	0.23	0.25	0.30	0.31	0.40	0.62	0.67	0.57	0.45	0.56	0.49	4.94	5.35
1 Feb	1004a	1019a	1031a	0.49	0.48	0.36	0.26	0.35	0.28	0.29	0.35	0.63	0.46	0.76	0.70	0.74	0.54	0.71	0.58	3.08	11.2
Means				**0.49**	**0.48**	**0.36**	**0.29**	**0.35**	**0.31**	**0.29**	**0.40**	**0.62**	**0.66**	**0.77**	**0.79**	**0.74**	**0.61**	**0.71**	**0.65**	**2.85**	**3.15**
Stat Sig				**No**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**No**	