DISCLAIMER

This project was conducted with financial assistance from a grant from the Metropolitan Water District of Southern California (Metropolitan), the U.S. Bureau of Reclamation, the Central Arizona Project, and the Southern Nevada Water Authority through Metropolitan's Innovative Conservation Program (ICP). The ICP provides funding for research to help document water savings and reliability of innovative water savings devices, technologies, and strategies. The findings of this project, summarized in this report, are solely from the project proponent.

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Final Executive Summary

Innovative Conservation Program

Project: 143543

Project PRS: Study of Pressure Regulated versus Non-Pressure Regulated Sprays and Rotors

Overview -

Metropolitan Water District of Southern California (MWD) awarded Rain Bird Corporation with an Innovative Conservation Program (ICP) grant to study the effects of spray and single-stream rotor (rotors) bodies with Pressure Regulating Stems (PRS) versus non-regulated sprays and rotors. This was a blind study conducted by the University of Arizona in Tucson, Arizona under the direction of Dr. Paul Brown, with the work being completed by Mr. Jeff Gilbert. The study was conducted through the university's Department of Soil, Water and Environmental Science at the Karsten Turf Research Facility.

The study evaluated 8 turf plots (4 with PRS and 4 without PRS) for precipitation rate (PR), application efficiency (AE) and distribution uniformity (DU) at 3 different operating pressures. 10 tests were run and flow measurements were collected at each pressure. The industry standard test for DU, using catch cans, was used and the DU was calculated for low quarter distribution uniformity (DU_{LQ}) and low half distribution uniformity (DU_{LH}). The university also conducted a test to measure application efficiency (AE), which determined the amount of water that stayed in the target zone versus the amount that drifted outside the zone. It should be noted that AE is often called "Sprinkler Operational Efficiency" by others, including the Irrigation Association.

Results - Rotors

Both the PRS rotors and the non-regulated rotors were tested at three pressures, measured in pounds per square inch (psi): 45 (the manufacturer's recommended psi), 60, and 75 psi. The results of the test showed that, at 75 psi, and a 90 degree pattern, the PRS rotors saved an average of .76 gallons per minute (GPM) per rotor, or 22% savings. At 65 psi, just 20 psi over the recommended pressure, the PRS rotor saved an average of .47 GPM, or 15%, for the quarter pattern. In theory, for a half pattern (180 degrees), estimated savings would be 1 gallon per minute per head. In addition, application efficiency (AE) and distribution uniformity (DU) significantly improved with PRS. This was a result of less misting and improved rotor performance. As expected, at 45 psi, the results were similar for both pressure-regulating and non-pressure regulating rotors.

The chart below shows the water savings for the rotor test, using what is referred to as 2.5 nozzles, which refers to the 2.5 GPM flow rate.

ROTOR PRS Water Savings Table Nozzle 2.5				
Inlet Pressure	Flow Rate No PRS	Flow Rate With PRS	Savings/Rotor	% Savings
[psi]	[GPM]	[GPM]	[GPM]	
45	2.42	2.43	0.00	0
55	2.80	2.60	0.20	7%
60	2.94	2.63	0.31	10%
65	3.10	2.63	0.47	15%
75	3.39	2.63	0.76	22%

Results - Sprays

The sprays study had similar results; however, there was a limitation with the testing. The actual pressure at the heads was not at the levels specified in the test protocol. Both the PRS and non-regulated sprays were supposed to be tested at three pressures: 30 (the manufacturer's recommended psi), 50 and 70 psi. Due to an error in the test setup, 70 psi was really only 55 psi, 50 psi was 35 psi, and 30 psi was 15 psi. Even at 55 psi, it was learned that there was an increase of water when the pressure was higher than the manufacturer's recommended operating pressure. It was also learned that pressure regulated sprays provided better uniform coverage than non-pressure regulating heads. In addition, pressure regulating sprays were more consistent in spraying the target area, even when wind increased.

Using the University of Arizona spray study, and correcting for the actual pressures observed, a Rain Bird engineer was able to develop a conservative model to determine savings at higher pressures. (Appendix A)

Based on GPM: Flow Rate Savings = .03 GPM for every 10 psi over 30 psi

Flow Rate Savings (GPM per head) = .06 GPM for every 20 psi over 30 psi

Thus, given an inlet pressure of 50 psi (20 psi over the desired 30 psi), the model would predict flow rate savings as 0.06 GPM (0.03 GPM * 2. And, if the system was 70 psi (40 psi over the desired 30 psi), the estimated savings would be 0.120 GPM (0.03 GPM * 4. At just 20 psi over the manufacturer's recommended operating pressure, there would be a savings of 0.077 gallons, which represents 11% saving. Since the study was based on a 90 degree pattern, estimated savings for the half pattern (180 degrees) would be multiplied by 2. Full pattern, or 360 degrees, would be multiplied by 4.

The chart below consider the theoretical water saved, as well as the percent saved using the 12 foot quarter (90 degree) nozzles, which are known as the 12Q nozzles.

SPRAY PRS Water Savings Table 12Q				
Inlet Pressure	Flow Rate No PRS	Flow Rate With PRS	Savings	% Savings
[psi]	[GPM]	[GPM]	[GPM]	
30	.65	.65	.00	0
40	0.6657	0.6303	0.035	5%
50	0.717	0.6403	0.077	11%
60	0.7583	0.6503	0.108	14%
70	0.794	0.6603	0.134	17%
80	0.824	0.6703	0.154	19%

Savings over Time -

The next set of charts looks at how these water saving translate to real water usage over time. First, the "Optimal" range is identified, which equates to the manufacturer's recommended operating pressure. The flow rates are measured in GPM and show savings based on the mid-range of the operating pressure for a range "Above" optimal, "Severely" above optimal and "Extremely" above optimal. This is then multiplied by a run time for rotors (25 minutes) and for spray (10 minutes). This savings chart assumes 10 heads running 1 irrigation cycle per day, 5 days per week. Daily savings calculated by dividing weekly savings by 7.

Rotor Savings with PRS over Time

Pressure	Daily	Weekly	Monthly	Yearly
Operating Pressure (PSI) Optimal – 45 psi	Gallons * 10 heads			
Above – 50 psi	36	250	1083	13,000
Severely – 60 psi	55	385	1667	20,020
Extremely – 80 psi	135	946	4097	49,205

Based on 25 minute run time, 1 cycle per day, 5 days per week. Savings based on 10 sprays.

Spray Savings with PRS over Time

Pressure	Daily	Weekly	Monthly	Yearly
Operating Pressure (PSI) Optimal – 30 psi	Gallons * 10 heads			
Above – 45 psi	5	38	166	1994
Severely – 60 psi	8	54	234	2808
Extremely – 80 psi	11	77	333	3996

Based on 10 minute run time, 1 cycle per day, 5 days per week. Savings based on 10 sprays.

Summary

The University of Arizona study finds that pressure regulation can save up to 11% for sprays over non-pressure regulating heads at only 20 psi above the recommended 30 psi and 15% for rotors at only 20 psi above the recommended 45 psi. This translates to 1 gallon per minute per head savings. This study revealed that pressure regulation adds benefits, such as water savings, over non-pressure regulated bodies. It was also discovered that the heads provided better uniformity and performed better in windy conditions.

Appendix A

This is the detailed explanation of how Rain Bird engineers calculated the savings and corrected for the low pressure at the head for the spray portion of the University of Arizona study.

High-Level Explanation:

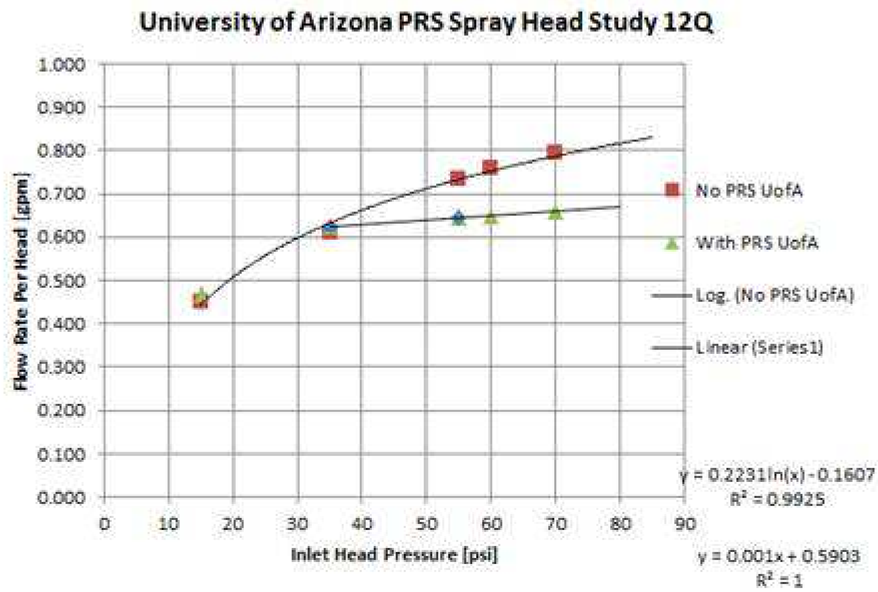
Using the data from the study, the flow rate at each spray head can be determined.
The actual input pressure used can be determined by knowing the pressure vs. flow characteristic for the spray head, i.e. we know the flow rate and nozzle size, so we can determine the input pressure.
This revealed the University of Arizona Spray PRS study had pressures at the head approximately 15 psi lower than the pressure measured upstream.
Flow rates were graphed for PRS and non-PRS results at corrected pressures and extrapolated using a least squares technique to determine the savings a higher input pressures.
Note that spray heads used in the study were taken back to Rain Bird after the study and verified to be working properly for PRS operation and flow vs. pressure.

Background:

The first study (sprays) measured input pressure far upstream of the system rather than at the base of the spray head.
A water meter in each plot measured the total water (gallons) input for each run.
By knowing the run time (15 min), number of heads (4 per plot), we know the flow rate for each spray head in the plot.
Matching the measured flow rates from the study to the known flow rates for the spray head with a 12Q nozzle, we can determine very accurately the real base pressure at the spray head.
This issue was corrected in the rotor study.

Water Savings:

Flow for PRS and non-PRS results from the study were graphed for corrected inlet pressures.
Note that the University of Arizona study flows were based on 10 runs and the average results were used.
A least squares curve fit was applied, along with a conservative extrapolation out to higher pressures, such as 70 psi.
The savings were then calculated by subtracting the flow of non-PRS and PRS results.
Note: Units from the study were taken back to Rain Bird and the PRS and flow were tested to ensure the heads were working properly.


University of Arizona PRS Spray Head Study 12Q
Flow Rate Per Head [gpm]
Inlet Head Pressure [psi]
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
10
20
30
40
50
60
70
80
90
No PRS UofA
With PRS UofA
Log. (No PRS UofA)
Linear (Series1)
y = 0.2231ln(x) - 0.1607
R² = 0.9925
y = 0.001x + 0.5903
R² = 1

Appendix B

Application Efficiency and Distribution Uniformity of Pressure-Regulated and Non-Pressure-Regulated Rotor Irrigation Heads Analysis

Submitted to Rain Bird Corporation
31 January 2015

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Introduction

System pressure can have a decided impact on the performance of an irrigation system. Failure to properly regulate pressure can impact key system performance parameters such as precipitation rate (PR), application efficiency (AE) and distribution uniformity (DU). Variable PRs can result in deficit irrigation and declining turf performance as well as excessive irrigation, saturated soils and runoff. Poor pressure control can impact both AE and DU by impacting the radius of throw (inadequate or excessive throw distances) and droplet size which greatly impacts spray drift. The objective of this study is to quantify the benefits of using pressure-regulated as compared to non-pressure-regulated rotors in a turf irrigation system operating at three different line pressures.

Methods

The study was conducted at the University of Arizona Campus Agricultural Center located in an alluvial valley at 713 m above sea level in Tucson, Arizona. The comparison of pressure-regulated (prs+) and non-pressure-regulated (prs-) rotors was conducted on eight 35'x35' blocks (plots) of bermudagrass turf. A separate irrigation system was constructed for each of the eight plots using 1" PVC pipe. The irrigation systems were constructed on the surface of the bermudagrass to avoid the costs and delays associated with installing buried systems. Each system was outfitted with a control valve, meter and pressure regulator to control line pressure. Rain Bird model 5000 irrigation rotors were installed at the corners of each plot (square 35' spacing). Each rotor was connected to the main irrigation pipe with a 2" PVC nipple that was equipped with valve stem to facilitate measurements of pressure at the base of the rotor. Four plots irrigated with prs+ rotors were outfitted with Rain Bird 5004PCR rotors and 2.5 nozzles. The remaining four plots irrigated with prs- rotors were outfitted with Rain Bird 5004PC rotors and 2.5 nozzles. Experimental units were set in out a randomized complete block design with four replicates.

The performance of the prs+ and prs- rotors were compared at system operating pressures of 45, 60 and 75 psi. The pressure regulator installed on the main water supply line for each plot was adjusted until the pressure at the base of the operating rotors reached the desired level. A total of 10 comparisons were completed for each level of operating pressure with system run time set to 20 minutes. Sprinkler performance was evaluated by measuring the total volume of water passing through the meters, application efficiency (AE) and distribution uniformity (DU). During each irrigation event, 16 circular catch cans were placed out on each plot in a 4x4 evenly spaced matrix to facilitate the computation of DU (Fig. 1). An additional 16 catch cans were placed along the perimeter of the plots to measure the amount of water applied to the edges of the plots. All catch cans were installed at the height of the irrigation rotors, or ~10" (~25 cm) above the surface. Specific DU computations were based on data collected from the 16 interior catch cans and included the low quarter distribution uniformity (LQDU) and low half distribution uniformity (LHDU). The LQDU was determined by computing the average of the lowest 25% of catch volumes (depths) then dividing this value by the average volume (depth) of all cans. The LHDU was determined by computing the average of the lowest 50% of catch volumes (depths) then dividing this value by the average volume (depth) of all cans.

Application efficiency was determined using two difference computation procedures. The first procedure (AE16) involved taking the average depth of the 16 interior catch cans and dividing by the equivalent depth of water that passed through the water meter (meter volume converted to depth based on plot area of 1225 sq. ft.). The second computation procedure (AE32) used all 32 catch cans to estimate the depth of water reaching the turf surface. In this procedure the total area of the plot was divided into 25 square areas with catch cans located at the four corners of each area (Fig. 1). The average depth of water applied to each square was computed by taking the average of the four corner catch cans. The four corner areas of the plot had just three catch cans since the sprinkler head was located on the fourth corner (Fig. 1). For these corners, the depth of water collected at the head was estimated by averaging the catch values of the two closest cans. This estimated value was then averaged with the three cup values to estimate the depth of water received in the corners. Depth estimates for the 25 squares were then summed and divided by 25 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 (prs+ and prs- rotors) and four reps. All data were analyzed using the appropriate statistical procedure as provided by SAS (SAS Institute, Cary, NC). Treatments means were compared using the least squares different test with $p<0.05$.

Irrigation meters were calibrated by connecting a hose to an irrigation riser that was then attached to one of the rotors. The irrigation system was then run for a set amount of time with the rotor inserted into a plastic carboy to collect the water. The weight of water collected in the carboy was converted to volume units and compared to the change in meter reading during system operation to develop meter correction factors, if required.

Meteorological data were collected from an automated weather station located just south of the study plots. The weather station collected air temperature, wind speed, relative humidity and wind direction at one-minute intervals. Meteorological sensors were installed at 2 m above ground level.

Results and Discussion

Use of prs+ rotors resulted in more consistent system precipitation rates and improved irrigation system performance, particularly at operating pressures of 60 and 75 psi. The prs+ and prs- rotors discharged similar volumes of water at 45 psi (Figure 2, Table 1). However, at 60 and 75 psi, the volume of water discharged by prs- rotors was significantly greater than that of the prs+ rotors (Figure 2, Tables 1-3). The total volume of water passing through the system meters increased by 21.1% and 39.9% for plots irrigated with prs- rotors as pressure increased from 45 psi to 60 and 75 psi, respectively. In contrast, the volume of water passing through the meters in plots irrigated with prs+ rotors increased just 8.1% and 8.3% for the same respective increases in pressure. Given that the measured flow in plots irrigated with prs+ rotors exhibited some increase in flow between 45 and 60 psi and no increase from 60 to 75 psi, it appears the prs+ pressure regulators were engineered to regulate pressure at levels slightly above 45 psi.

The more consistent discharge rate of prs+ rotors resulted in a more consistent water application rate as measured with catch cans (Figure 3 and Tables 1-3). The amount of water collected in the internal catch cans in plots irrigated with the prs+ rotors varied by ~5% as pressure increased from 45 psi to 75 psi. In contrast, the amount of water collected in plots irrigated with prs- rotors increased nearly 25% over the same range of pressure. Similar results emerged when data from the perimeter and internal catch cans were merged to estimate the amount of water applied to the entire plot area (Figure 4 and Tables 1-3). Water applied to the entire plot area increased ~5% and ~27% for plots irrigated with prs+ and prs- rotors, respectively, as operating pressure increased from 45 to 75 psi. It is important to note here that because the rotor comparison tests for each level of system pressure were conducted on different days, results obtained at different pressures cannot be compared in a statistical sense.

Use of the prs+ rotors resulted in higher AE as well. Application efficiencies computed using the 16 interior catch cans (AE16) were quite high and averaged above 0.90 for plots irrigated with prs+ rotors (Figure 5 and Tables 1-3). AE16 values for plots irrigated with prs- rotors were similar to AE16 values obtained from plots irrigated with prs+ rotors at 45 psi, but declined and were significantly lower than AE16 values obtained with prs+ rotors at 60 and 75 psi. AE16 values were 0.03 and 0.08 higher in plots irrigated with prs+ rotors as compared to plots irrigated with prs- rotors at system pressures of 60 and 75 psi, respectively. It is interesting to note that the AE16 values equal to or slightly greater than 1.0 were obtained during several comparison runs when system pressure was set to 45 psi (Table 1). In each case where this happened, temperatures were cool (<50F), relative humidity was high (>93%) and winds were generally light (<2 mph) -- conditions that would result in little or no evaporation and drift.

Similar results emerged when the amount of water applied to the whole plot was used to estimate application efficiency (AE32). Application efficiencies computed in this way were substantially lower that similar values computed using only the interior catch cans (AE16), ranging from 0.72 to 0.81 (Figure 6 and Tables 1-3). At all levels of operating pressure, AE32 values from plots irrigated with prs+ rotors were significantly higher than similar values obtained from plots irrigated with prs- rotors, even at 45 psi. The increases in AE32 obtained with prs+ rotors were 0.02, 0.02 and 0.06 for system pressures of 45, 60 and 75 psi, respectively.

Longer water throw distances and increased misting likely explain the reduction in AE16 and AE32 resulting from the use of prs- rotors at higher system operating pressures. Longer throw distances would result in more off-target (plot) water application that would not be recorded by the array of catch cans. Evidence for increased misting comes from visual observations during system operation and from the higher volume of water collected in the perimeter catch cans. The amount of water collected in the interior catch cans increased ~25% in plots irrigated with prs- rotors as pressure increased from 45 to 75 psi. Water collected in the perimeter catch cans from prs- plots increased ~36% over this same increase in pressure, suggesting more drift, caused by increased misting.

Distribution uniformity as measured from the interior catch cans was not as impacted by pressure regulation. Rotors with and without pressure regulation produced similar values of low quarter mean distribution uniformity (LQDU) at 45 and 60 psi (Figure 7 and Tables 1-3). Pressure regulation did result in a significantly higher LQDU when the system operating pressure was increased to 75 psi (Table 3). Pressure regulation did not significantly impact low half distribution uniformity at any of the three system operating pressures (Figure 8 and Tables 1-3). The fact that system pressure did not greatly impact distribution uniformity suggest both the prs+ and prs- rotors applied water in relatively uniform manner in the center of the plots where the interior 16 catch cans were located.

Local wind conditions negatively impacted irrigation system performance in plots irrigation with prs+ and prs- rotors, particularly at system operating pressures of 60 and 75 psi (Figures 9-20).

System performance parameters decreased linearly with wind speed over the range of wind speeds encountered during this study. Least squares regression lines were fit to the relationships between AE16, AE32, LQDU and LHDU and wind speed. The slopes of the resulting regression lines were evaluated to determine if they were different from zero (zero slope indicates no effect of wind). At system operating pressures of 45 psi, the only performance parameters impacted by wind speed were AE16 and AE32 from plots irrigated with the prs+ rotors. However, at system operating pressures of 60 psi, all performance parameters were significantly impacted by wind speed. Similar results emerged when performance parameters were evaluated for system operating pressures of 75 psi. The only performance parameter not significantly impacted by wind speed at 75 psi was LHDU obtained from plots irrigated with prs- rotors.

While Figures 9-20 clearly show that irrigation system performance was negatively impacted by wind speed at higher system operating pressures, the decline in performance, as indicated by the slopes of the regression lines, was similar with both prs+ and prs- rotors. The slopes of the regression lines relating system performance parameters to wind speed for plots irrigated with prs+ and prs- rotors were compared to determine if the slopes were different ($p<0.05$). None of the slopes were different indicating irrigation system performance declined similarly in response to increasing wind flow, regardless of whether the plots were irrigated with prs+ or prs- rotors.

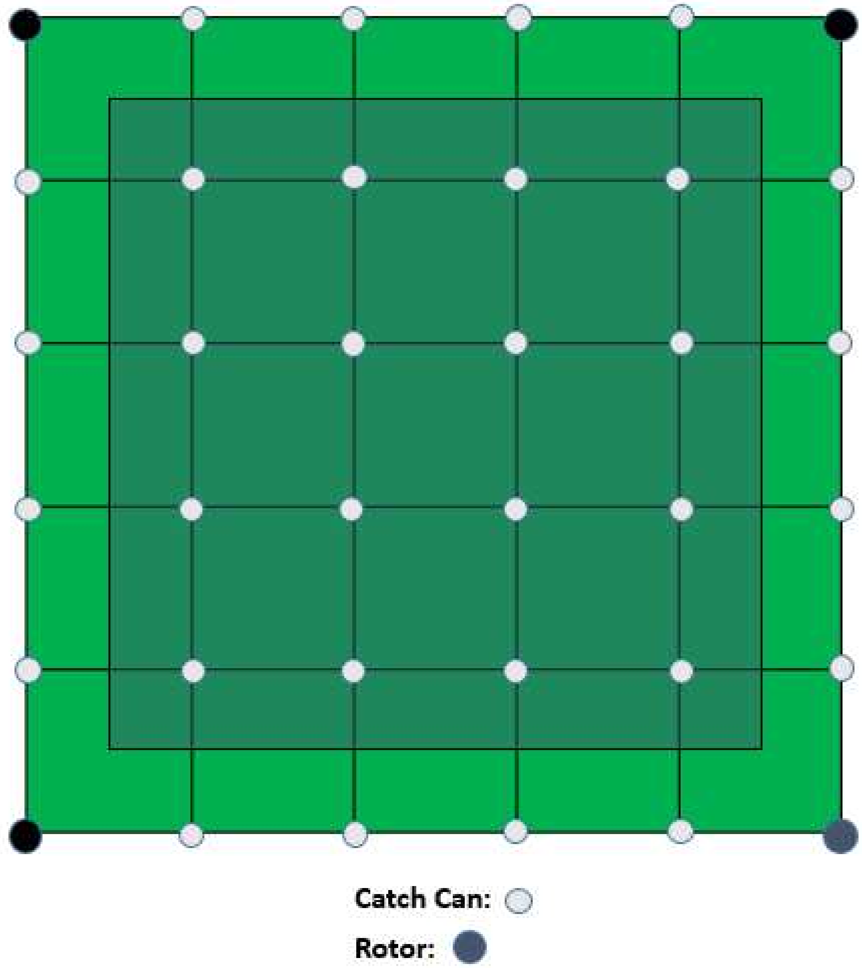

Figure 1. Plot schematic showing the location of the catch cans used to assess irrigation system performance. The 16 internal catch can reside within the darker shaded area.

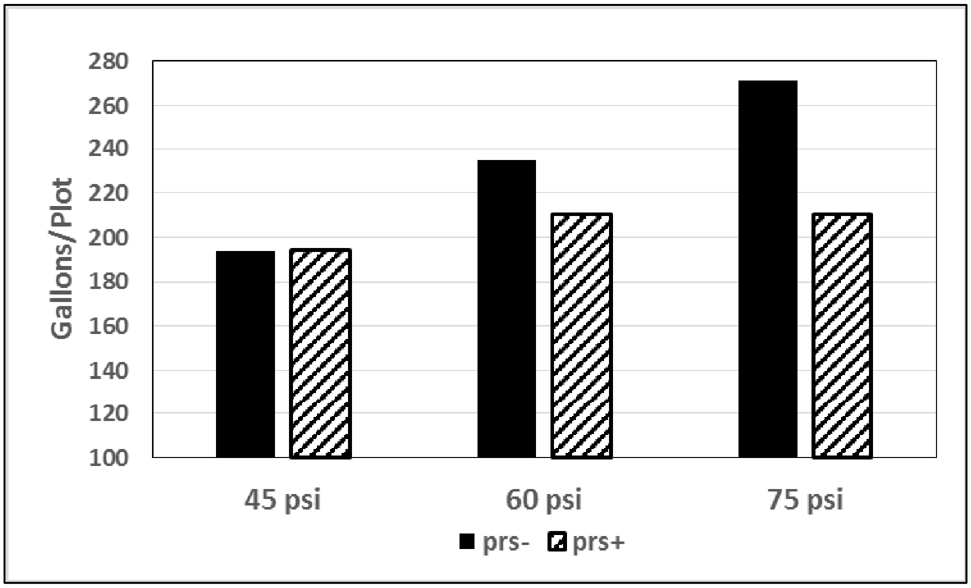

Figure 2. Total volume of water applied to plots irrigated with prs- and prs+ rotors at system operating pressures of 45, 60 and 75 psi.

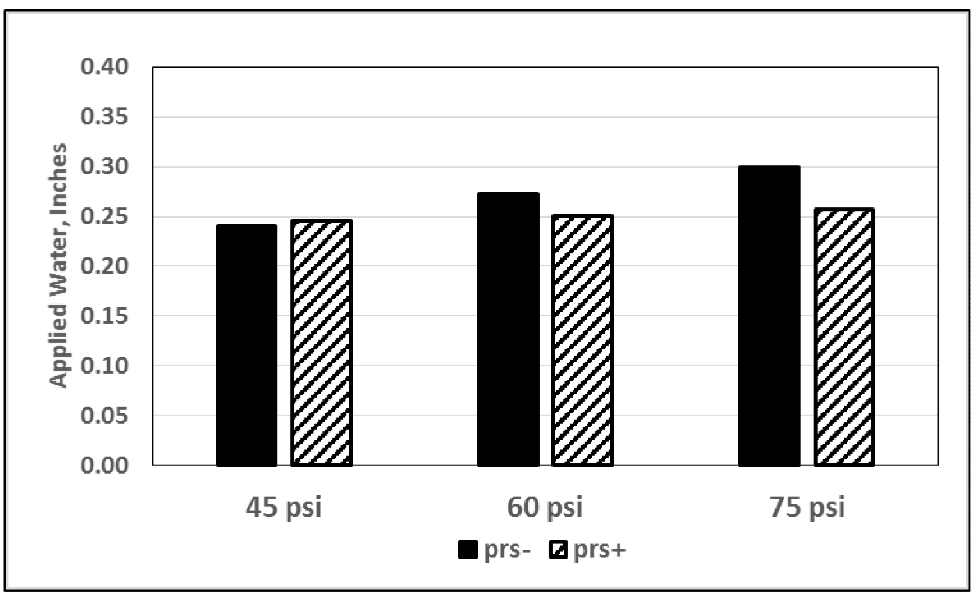

Figure 3. Depth of water applied to plots irrigated with prs- and prs+ rotors at system operating pressures of 45, 60 and 75 psi. Depth measured using the 16 interior catch cans.

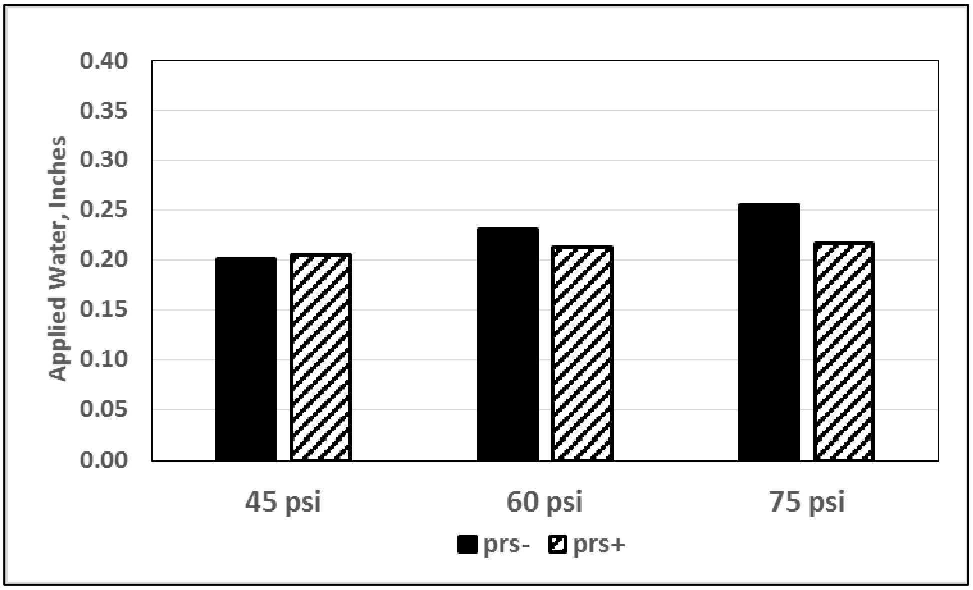

Figure 4. Depth of water applied to plots irrigated with prs- and prs+ rotors at system operating pressures of 45, 60 and 75 psi. Depth measured using the both interior and perimeter catch cans.

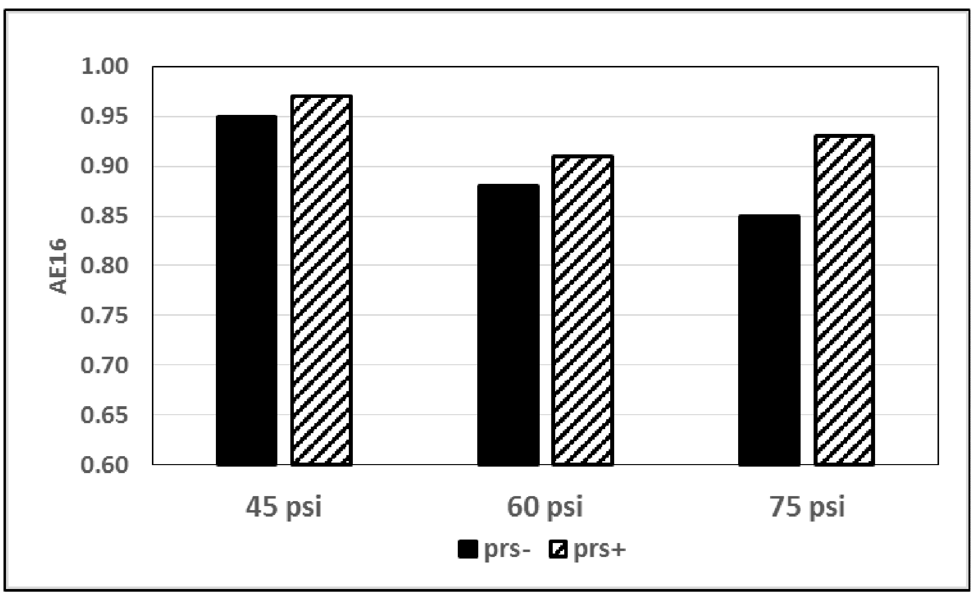

Figure 5. Application efficiency as determined from the 16 internal catch cans (AE16) for plots irrigated with prs- and prs+ rotors at system operating pressures of 45, 60 and 75 psi.

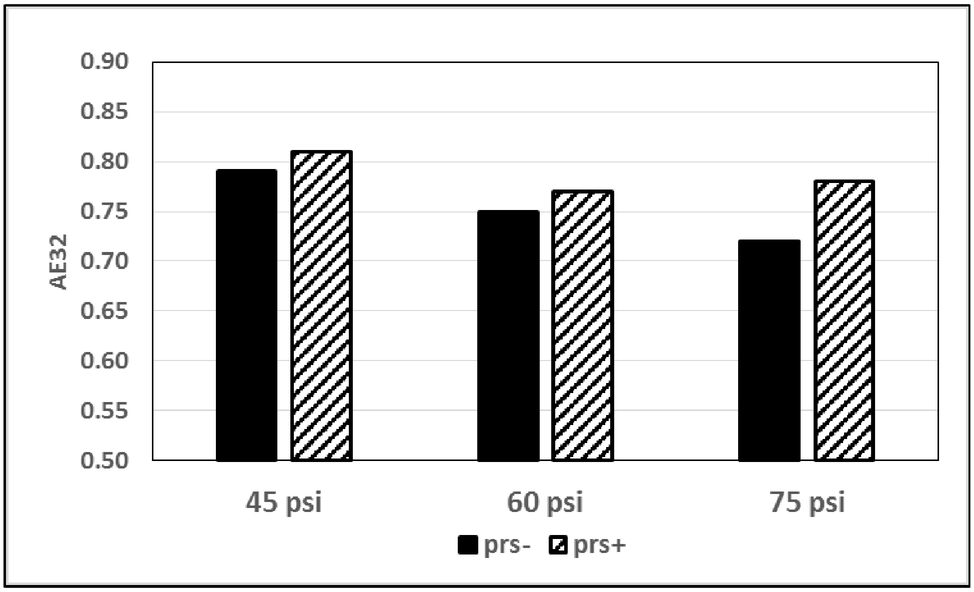

Figure 6. Application efficiency as determined from all 32 catch cans (AE32) for plots irrigated with prs- and prs+ rotors at system operating pressures of 45, 60 and 75 psi.

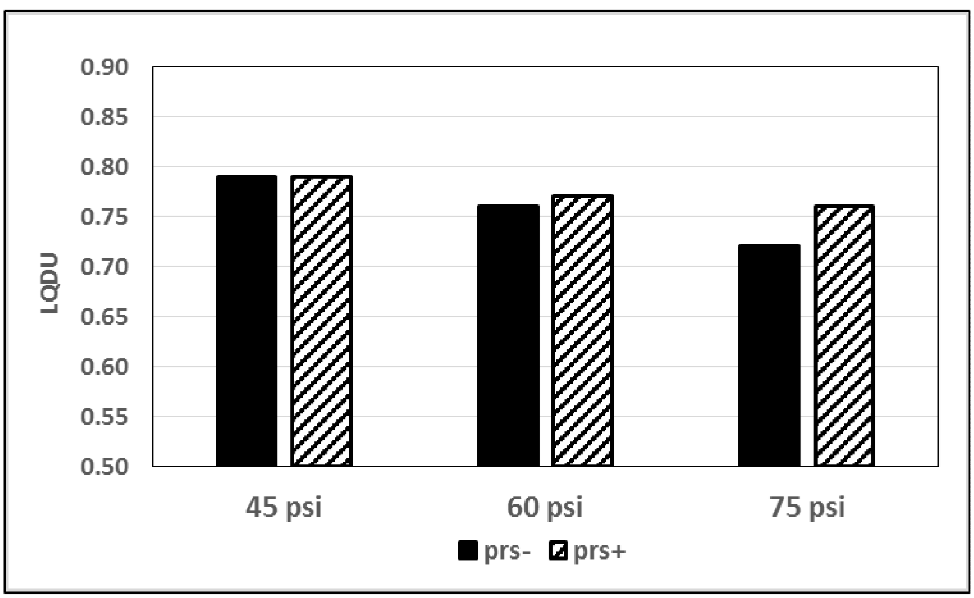

Figure 7. Low quarter mean distribution uniformity (LQDU) for plots irrigated with prs- and prs+ rotors at system operating pressures of 45, 60 and 75 psi.

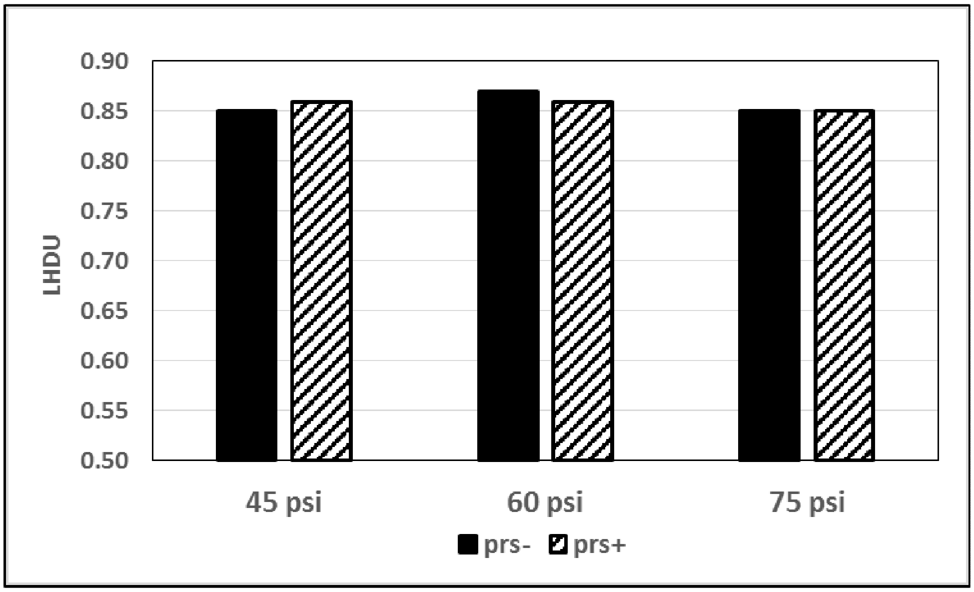

Figure 8. Low half mean distribution uniformity (LHDU) for plots irrigated with prs- and prs+ rotors at system operating pressures of 45, 60 and 75 psi.

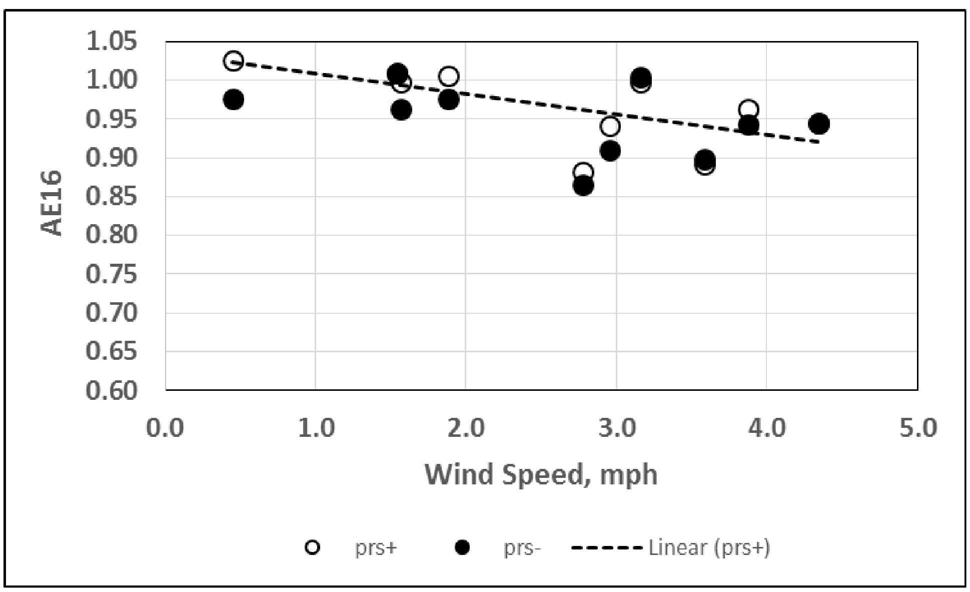

Figure 9. Application efficiency as determined from the 16 internal catch cans (AE16) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 45psi. Regression lines relating AE16 to wind speed are plotted if the line slopes are significantly different from zero.

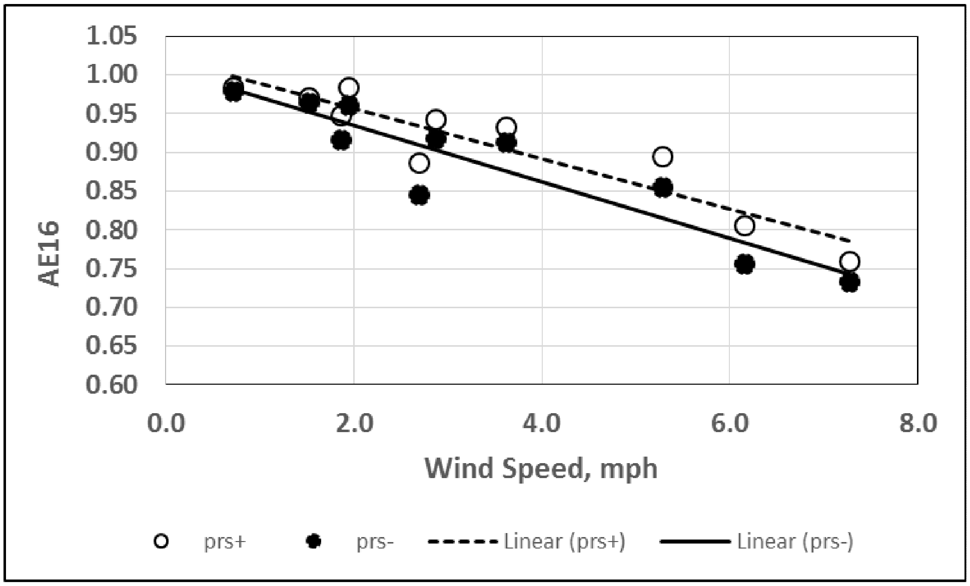

Figure 10. Application efficiency as determined from the 16 internal catch cans (AE16) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 60 psi. Regression lines relating AE16 to wind speed are plotted if the line slopes are significantly different from zero.

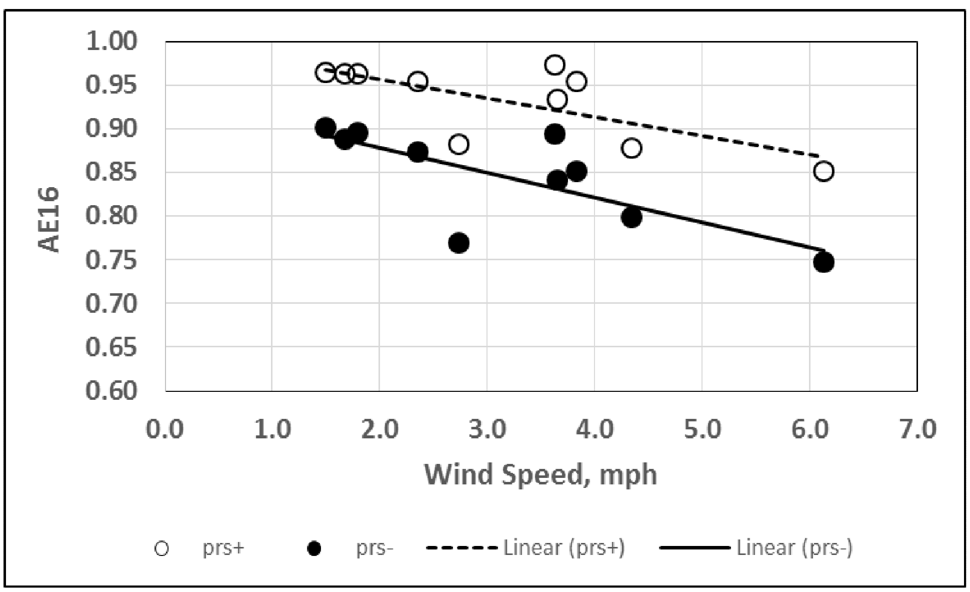

Figure 11. Application efficiency as determined from the 16 internal catch cans (AE16) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 75 psi. Regression lines relating AE16 to wind speed are plotted if the line slopes are significantly different from zero.

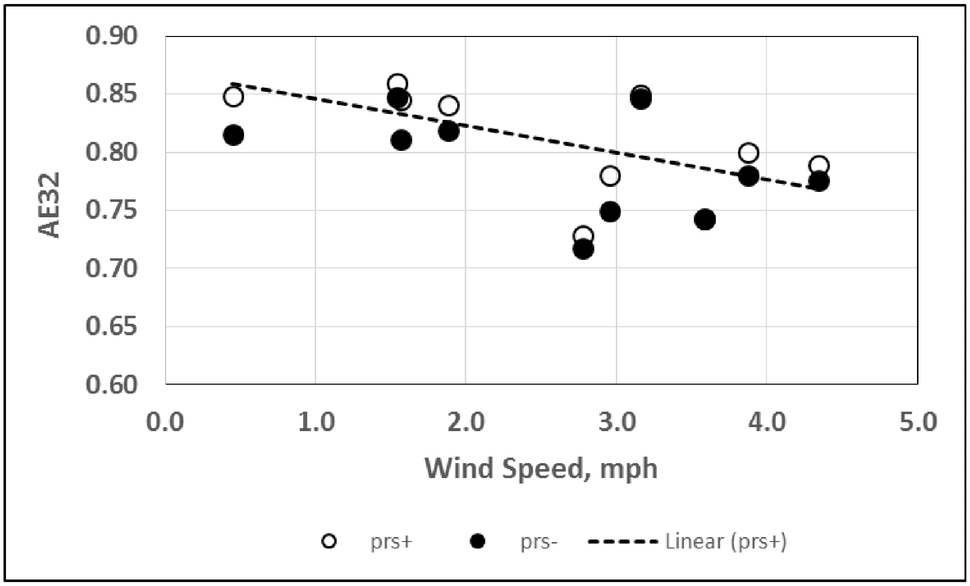

Figure 12. Application efficiency as determined from all 32 catch cans (AE32) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 45 psi. Regression lines relating AE32 to wind speed are plotted if the line slopes are significantly different from zero.

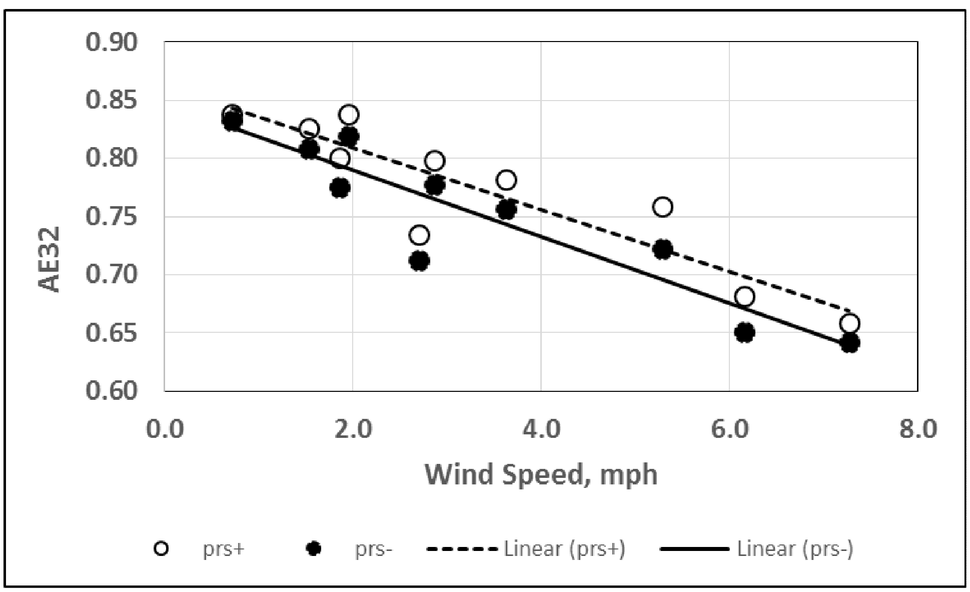

Figure 13. Application efficiency as determined from all 32 catch cans (AE32) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 60 psi. Regression lines relating AE32 to wind speed are plotted if the line slopes are significantly different from zero.

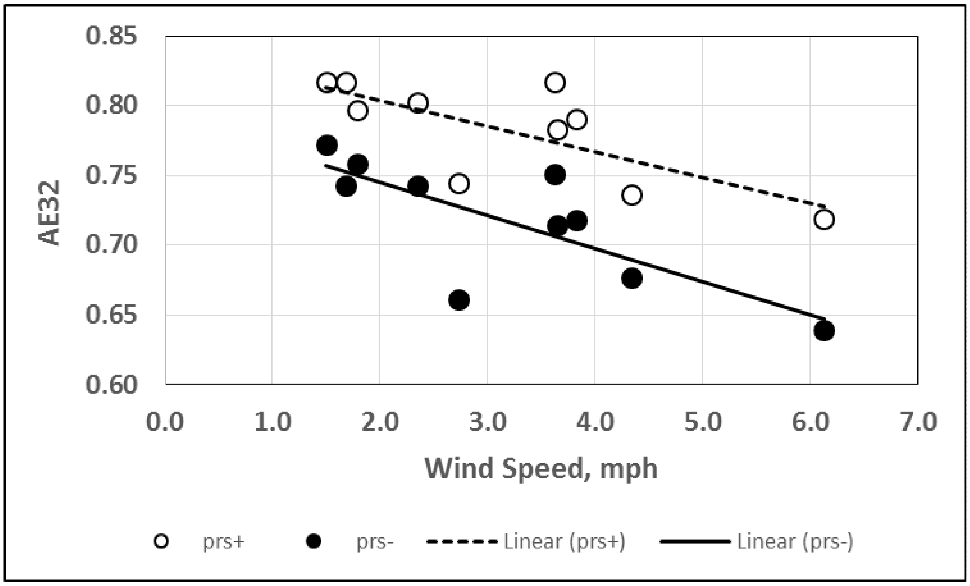

Figure 14. Application efficiency as determined from all 32 catch cans (AE32) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 75 psi. Regression lines relating AE32 to wind speed are plotted if the line slopes are significantly different from zero.

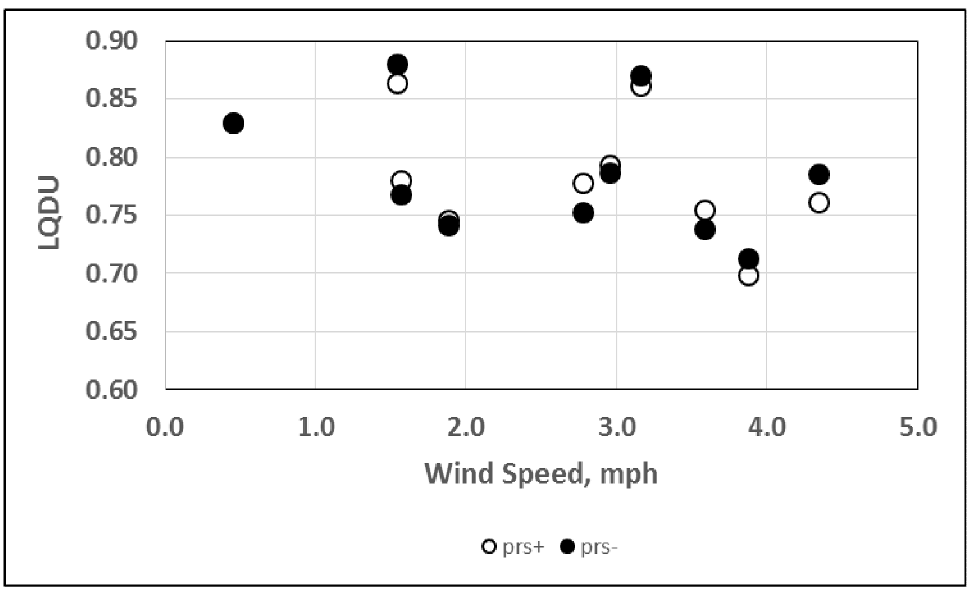

Figure 15. Low quarter mean distribution uniformity (LQDU) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 45 psi. Regression lines relating LQDU to wind speed are plotted if the line slopes are significantly different from zero.

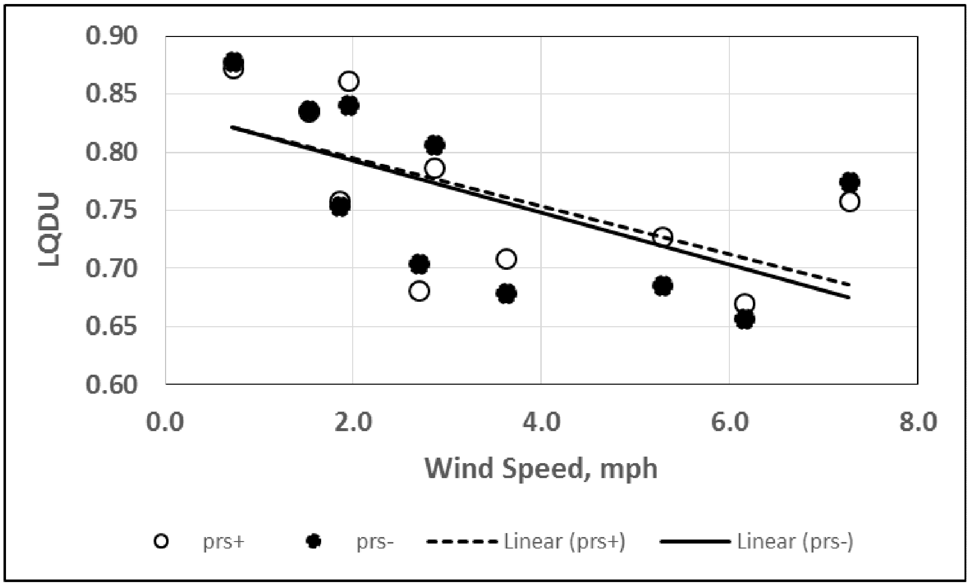

Figure 16. Low quarter mean distribution uniformity (LQDU) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 60 psi. Regression lines relating LQDU to wind speed are plotted if the line slopes are significantly different from zero.

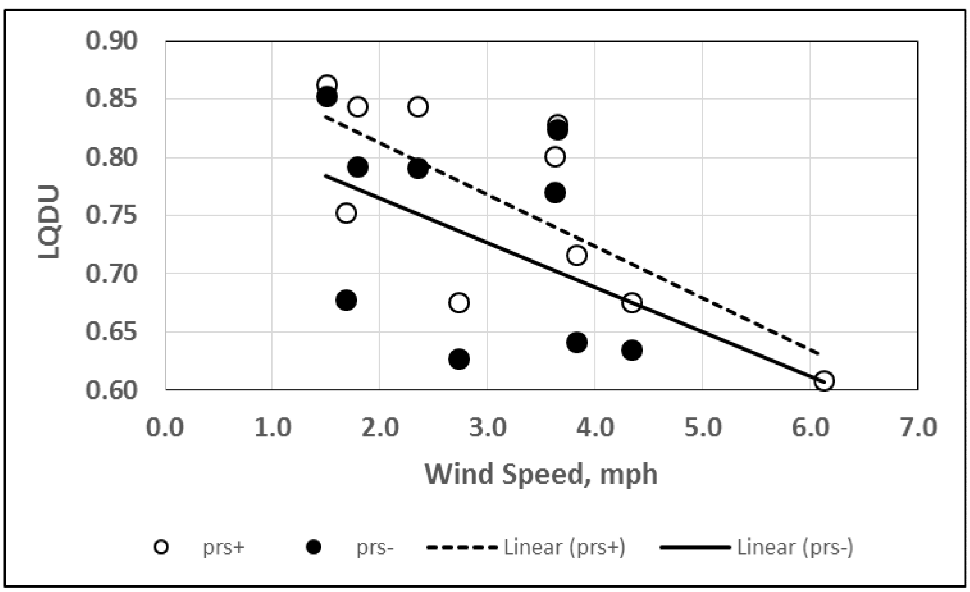

Figure 17. Low quarter mean distribution uniformity (LQDU) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 75 psi. Regression lines relating LQDU to wind speed are plotted if the line slopes are significantly different from zero.

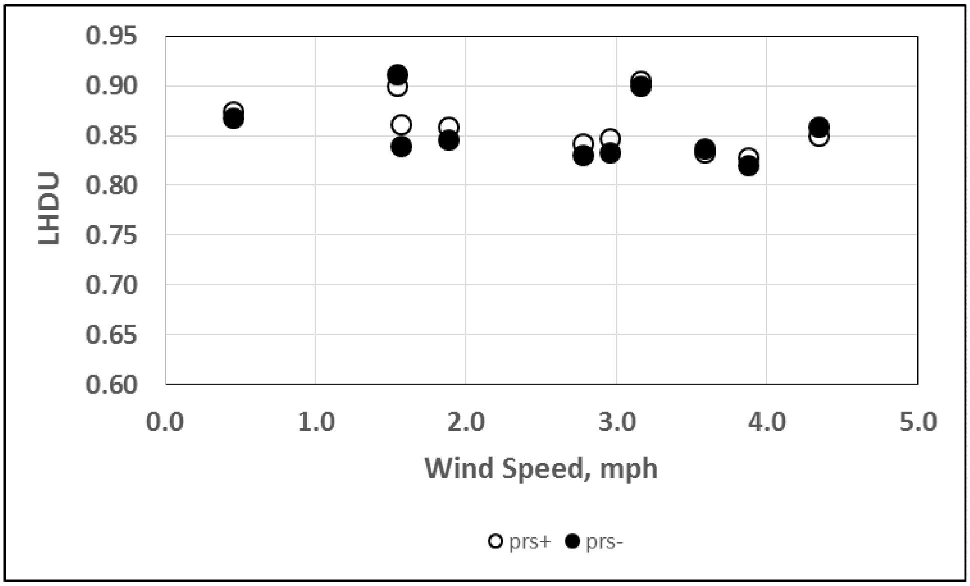

Figure 18. Low half mean distribution uniformity (LHDU) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 45 psi. Regression lines relating LHDU to wind speed are plotted if the line slopes are significantly different from zero.

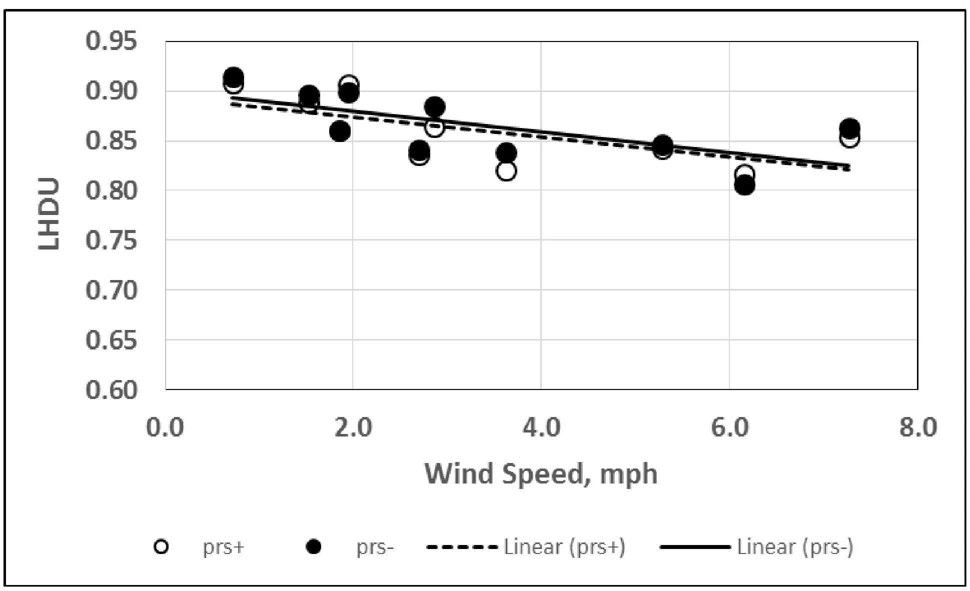

Figure 19. Low half mean distribution uniformity (LHDU) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 60 psi. Regression lines relating LHDU to wind speed are plotted if the line slopes are significantly different from zero.

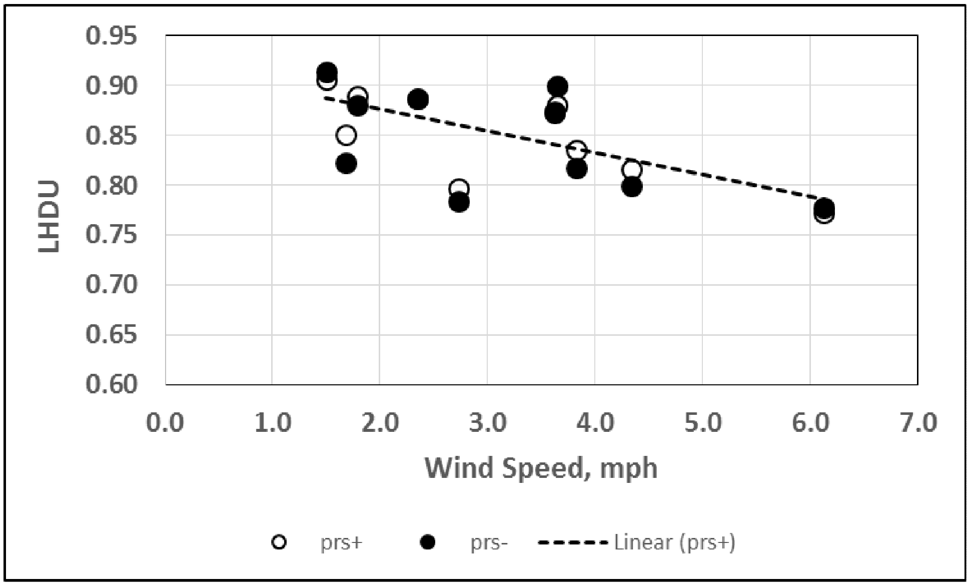

Figure 20. Low half mean distribution uniformity (LHDU) plotted as a function of wind speed for plots irrigated with prs- and prs+ rotors at system operating pressure of 75 psi. Regression lines relating LHDU to wind speed are plotted if the line slopes are significantly different from zero.

Table 1. Mean values of applied water (from meter), water collected in catch cans, distribution uniformity and application efficiency by date for plots irrigated with (+prs) and without (-prs) pressure regulated rotor with line pressure set at 45 psi. Distribution uniformity determined using only the 16 middle catch cans. Yes in the row labeled Stat Sig indicates overall means are significantly different at p<0.05.

Date	**Time**		**Applied Water**		**Water Collected**						**Distribution Uniformity**				**Application Efficiency**			
45psi	**On**	**Off**	**Water Applied (Gallons)**		**Middle 16 Cans (Inches)**		**32-Can Spatial Avg (Inches)**		**Edge Cans (Inches)**		**Low Quarter**		**Low Half**		**Middle 16 Cans**		**32-Can Spatial Avg**	
			-prs	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**
17 Dec	152p	212p	193.4	193.4	0.22	0.22	0.18	0.18	0.11	0.12	0.75	0.78	0.83	0.84	0.87	0.88	0.72	0.73
18 Dec	833a	853a	195.0	195.4	0.25	0.26	0.21	0.21	0.14	0.14	0.74	0.75	0.85	0.86	0.98	1.01	0.88	0.84
18 Dec	929a	949a	193.7	193.9	0.26	0.26	0.22	0.22	0.14	0.15	0.88	0.86	0.91	0.90	1.01	1.01	0.85	0.86
18 Dec	1026a	1046	193.9	195.8	0.26	0.26	0.21	0.22	0.14	0.15	0.87	0.86	0.90	0.91	1.00	1.00	0.85	0.85
19 Dec	834a	854a	194.6	192.2	0.25	0.26	0.21	0.21	0.13	0.13	0.83	0.83	0.87	0.87	0.98	1.03	0.82	0.85
22 Dec	815a	835a	195.2	195.4	0.25	0.25	0.21	0.22	0.14	0.15	0.77	0.78	0.84	0.86	0.96	1.00	0.81	0.85
22 Dec	913a	933a	195.0	192.6	0.23	0.24	0.19	0.20	0.12	0.12	0.79	0.79	0.83	0.85	0.91	0.94	0.75	0.78
22 Dec	1023a	1043	193.7	191.3	0.24	0.24	0.20	0.20	0.12	0.13	0.71	0.70	0.82	0.83	0.94	0.96	0.78	0.80
22 Dec	1234p	1254	190.7	193.5	0.22	0.23	0.19	0.19	0.12	0.12	0.74	0.75	0.84	0.83	0.90	0.89	0.74	0.74
22 Dec	140p	200p	193.4	199.6	0.24	0.25	0.20	0.21	0.12	0.13	0.79	0.76	0.86	0.83	0.95	0.95	0.78	0.79
Means			**193.9**	**194.4**	**0.24**	**0.24**	**0.20**	**0.21**	**0.13**	**0.13**	**0.79**	**0.79**	**0.85**	**0.86**	**0.95**	**0.97**	**0.79**	**0.81**
Stat Sig			**No**		**No**		**Yes**		**Yes**		**No**		**No**		**No**		**Yes**	

Table 2. Mean values of applied water (from meter), water collected in catch cans, distribution uniformity and application efficiency by date for plots irrigated with (+prs) and without (-prs) pressure regulated rotor with line pressure set at 60 psi. Distribution uniformity determined using only the 16 middle catch cans. Yes in the row labeled Stat Sig indicates overall means are significantly different at p<0.05.

Date	**Time**		**Applied Water**		**Water Collected**						**Distribution Uniformity**				**Application Efficiency**			
60psi	**On**	**Off**	**Water Applied (Gallons)**		**Middle 16 Cans (Inches)**		**32-Can Spatial Avg (Inches)**		**Edge Can (Inches)**		**Low Quarter**		**Low Half**		**Middle 16 Cans**		**32-Can Spatial Avg**	
			-prs	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**
23 Dec	858a	918a	231.8	207.8	0.26	0.24	0.22	0.20	0.14	0.13	0.70	0.68	0.84	0.84	0.85	0.89	0.71	0.73
23 Dec	1004a	1024a	228.1	207.9	0.27	0.26	0.23	0.22	0.16	0.15	0.81	0.79	0.89	0.86	0.92	0.94	0.78	0.80
23 Dec	1050a	1110a	228.2	207.8	0.22	0.21	0.19	0.18	0.14	0.13	0.77	0.76	0.86	0.85	0.73	0.76	0.64	0.66
12 Jan	114p	134p	236.4	210.6	0.23	0.22	0.20	0.19	0.14	0.13	0.66	0.67	0.81	0.82	0.76	0.81	0.65	0.68
13 Jan	852a	912a	237.1	211.0	0.28	0.26	0.24	0.22	0.16	0.15	0.75	0.76	0.86	0.86	0.92	0.95	0.78	0.80
13 Jan	1012a	1032a	237.0	211.6	0.30	0.27	0.25	0.23	0.17	0.16	0.84	0.86	0.90	0.91	0.96	0.99	0.82	0.84
13 Jan	1253p	113p	238.7	211.4	0.28	0.26	0.24	0.22	0.15	0.14	0.68	0.71	0.84	0.82	0.91	0.93	0.76	0.78
13 Jan	153p	213p	237.7	211.8	0.27	0.25	0.22	0.21	0.15	0.14	0.69	0.73	0.85	0.84	0.86	0.90	0.72	0.76
14 Jan	924a	944a	236.9	210.6	0.30	0.27	0.26	0.23	0.18	0.16	0.88	0.87	0.91	0.91	0.98	0.98	0.83	0.84
14 Jan	1048a	1108a	237.4	211.3	0.30	0.27	0.25	0.23	0.16	0.16	0.84	0.84	0.90	0.89	0.96	0.97	0.81	0.83
Means			**234.9**	**210.2**	**0.27**	**0.25**	**0.23**	**0.21**	**0.16**	**0.14**	**0.76**	**0.77**	**0.87**	**0.86**	**0.88**	**0.91**	**0.75**	**0.77**
Stat Sig			**Yes**		**Yes**		**Yes**		**Yes**		**No**		**No**		**Yes**		**Yes**	

Table 3. Mean values of applied water (from meter), water collected in catch cans, distribution uniformity and application efficiency by date for plots irrigated with (+prs) and without (-prs) pressure regulated rotor with line pressure set at 75 psi. Distribution uniformity determined using only the 16 middle catch cans. Yes in the row labeled Stat Sig indicates overall means are significantly different at $p<0.05$.

Date	**Time**		**Applied Water**		**Water Collected**						**Distribution Uniformity**				**Application Efficiency**			
75psi	**On**	**Off**	**Water Applied (Gallons)**		**Middle 16 Cans (Inches)**		**32-Can Spatial Avg (Inches)**		**Edge Can (Inches)**		**Low Quarter**		**Low Half**		**Middle 16 Cans**		**32-Can Spatial Avg**	
			-prs	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**	**-prs**	**+prs**
11 Dec	830a	850a	274.8	211.0	0.32	0.27	0.27	0.23	0.18	0.15	0.68	0.75	0.82	0.85	0.89	0.96	0.74	0.82
11 Dec	928a	948a	277.4	210.0	0.28	0.24	0.24	0.20	0.17	0.14	0.63	0.68	0.78	0.80	0.77	0.88	0.66	0.74
11 Dec	1026	1046a	275.2	209.6	0.31	0.26	0.26	0.22	0.18	0.14	0.64	0.72	0.82	0.84	0.85	0.95	0.72	0.79
11 Dec	200p	220p	275.1	211.5	0.30	0.26	0.26	0.22	0.18	0.14	0.82	0.83	0.90	0.88	0.84	0.93	0.71	0.78
12 Dec	758a	818a	271.2	212.2	0.28	0.24	0.24	0.20	0.16	0.13	0.63	0.68	0.80	0.82	0.80	0.88	0.68	0.74
12 Dec	910a	930a	271.0	210.6	0.32	0.27	0.27	0.23	0.18	0.15	0.77	0.80	0.87	0.87	0.89	0.97	0.75	0.82
12 Dec	1016	1036a	267.6	211.1	0.26	0.24	0.22	0.20	0.16	0.13	0.60	0.61	0.78	0.77	0.75	0.85	0.64	0.72
15 Dec	1028	1108a	260.2	202.7	0.30	0.26	0.26	0.22	0.18	0.14	0.79	0.84	0.88	0.89	0.90	0.96	0.76	0.80
15 Dec	129p	149p	267.5	210.1	0.32	0.26	0.27	0.22	0.19	0.15	0.85	0.86	0.91	0.91	0.90	0.96	0.77	0.82
16 Dec	122p	142p	272.8	211.9	0.31	0.26	0.27	0.22	0.18	0.15	0.79	0.84	0.89	0.89	0.87	0.95	0.74	0.80
Means			**271.2**	**210.6**	**0.30**	**0.26**	**0.25**	**0.22**	**0.17**	**0.14**	**0.72**	**0.76**	**0.85**	**0.85**	**0.85**	**0.93**	**0.72**	**0.78**
Stat Sig			**Yes**		**Yes**		**Yes**		**Yes**		**Yes**		**No**		**Yes**		**Yes**	

Appendix C

Application Efficiency and Distribution Uniformity of Pressure-Regulated and Non-Pressure-Regulated Spray Irrigation Heads Analysis

Submitted to Rain Bird Corporation
26 September 2014

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Introduction

System pressure can have a decided impact on the performance of an irrigation system. Failure to properly regulate pressure can impact key system performance parameters such as precipitation rate (PR), application efficiency (AE) and distribution uniformity (DU). Variable PRs can result in deficit irrigation and declining turf performance as well as excessive irrigation, saturated soils and runoff. Poor pressure control can impact both AE and DU by impacting the radius of throw (inadequate or excessive throw distances) and droplet size which greatly impacts spray drift. The objective of this study is to quantify the benefits of using pressure-regulated as compared to non-pressure-regulated spray heads and rotors in a turf irrigation system operating at three different line pressures. This progress report summarizes the performance data of irrigation systems operating at three line pressures and outfitted with regulated and non-regulated spray heads.

Methods

The study was conducted at the University of Arizona Karsten Turf Facility located in an alluvial valley at 713 m above sea level in Tucson, Arizona. The comparison of regulated and non-regulated spray heads was be conducted on eight 12'x12' blocks (plots) of bermudagrass turf. Each of the eight plots has its own irrigation system complete with separate control valve and meter, and sprinklers are installed at the corners of each plot (square spacing with 12' spacing). The irrigation systems of four randomly selected plots were outfitted with non-regulated Rain Bird 12 Q spray heads (-prs). Pressure-regulated 12Q sprinklers (+prs) were installed in the irrigation systems of the remaining four plots. A pressure regulator was be installed on the main line supplying water to the eight plots to facilitate the performance comparison of pressure-regulated and non-pressure-regulated spray heads at three different line pressure levels (30, 50 and 70 psi) using 15-minute run times. Ten comparisons were completed for each level of input pressure. Sprinkler performance was be evaluated by measuring application efficiency (AE) and distribution uniformity (DU). During each irrigation event, 16 circular catch cans were placed out on each plot in a 4x4 evenly spaced matrix to facilitate the computation of DU (Fig. 1). DU in the form of the low quarter and low half distribution uniformity was computed following each comparison run. An additional 16 square catch cans were placed along the perimeter of each plot to measure the amount of water applied at the edge of each plot (Fig. 1). Water collected in the perimeter cans was paired with volumes collected in adjacent circular catch cans to estimate the amount of water applied to the perimeter area of the plot using interpolation. This perimeter volume was added to the volume of water collected within the 4x4 matrix of circular catch cans to determine the total volume of water applied to the plot. Application efficiency was computed by: 1) dividing the total volume of water collected on the plots as indicated by the 16 center catch cans by the total volume of water passing through the meter (AE16) and 2) dividing the total volume of water reaching the entire plot surface (as computed using 16 center catch cans and spatial interpolation of data collected by the 16 perimeter catch cans) by the total volume of water passing through the meter (AE32). All catch cans were installed at ground level.

Irrigation meters were calibrated at the start of the study by connecting a hose to an irrigation riser with no spray head attached. The water was directed to a carboy and weighed to get the volume of water exiting the system. This volume was compared to the change in meter reading during the calibration run to develop meter correction factors if required.

Meteorological data were collected from an automated weather station located just south of the study plots. The weather station collected air temperature, wind speed, relative humidity and wind direction at one-minute intervals. Meteorological sensors were installed at 2 m above ground level.

Results and Discussion

Tables 1, 2 and 3 summarize the results of the comparisons of the non-regulated and pressure-regulated 12Q spray heads at 30, 50 and 70 psi, respectively. The total water applied, as indicated by the meter, increased 0.11” for both regulated and non-regulated heads as pressure was increased from 30 psi to 50 psi, suggesting little impact of the pressure regulator in this range of pressures. However, the impact of pressure regulation was evident as line pressure was increased from 50 to 70 psi. The water applied from non-regulated heads increased by an additional 0.09” at 70 psi while there was little change in the amount of water applied (0.01”) with the regulated heads. It not totally clear why pressure regulation did not impact water applied when the line pressure was at 50 psi. Pressure at the sprinkler head was measured a few times over the course of this study. These values ran lower than the line pressure. It is possible that friction loss or some other factor reduced head pressure below that of line pressure. If these pressure drops were sufficiently large, there may not have been sufficient pressure to activate the regulator.

Application efficiency was higher with pressure regulation, regardless of the incoming lime pressure. Application efficiency computed with the 16 interior catch cans (AE16) was significantly higher at all three line pressures with improvement in AE ranging from 0.02 at 50 psi to 0.05 at 70 psi. A similar significant trend was observed when all 32 catch cans were used to compute application efficiency (AE32) with increases in AE32 with pressure regulation ranging from 0.02 at 50 psi to 0.05 at 70 psi. The improvement in AE16 and AE32 with pressure regulation was 0.03 when line pressure was 30 psi.

The impact of pressure regulation on irrigation uniformity is less clear. On average, both the low quarter distribution uniformity (LQDU) and the low half distribution uniformity (LHDU) were higher with pressure regulation, but the improvements were small and some were not significant from a statistical point of view. Low quarter distribution uniformity (LQDU) increased by 0.03, 0.02 and 0.01 when line pressures were 30, 50 and 70 psi, respectively. However, the increases in LQDU (with regulation) were not statistically significant at the highest two pressures. Likewise, low half distribution uniformity (LHDU) increased by 0.03, 0.02 and 0.01 with pressure regulation when line pressures were 30, 50 and 70 psi, respectively. The increase in LHDU (with regulation) was not significant when line pressure was 70 psi.

The impact of weather conditions on the resulting data sets were evaluated by relating AE16, AE32, LQDU and LHDU to various meteorological variables collected by the on-site weather station. The single meteorological variable that most impacted all system performance measures was wind speed, or wind speed multiplied by vapor pressure deficit (computed from relative humidity). The latter term can be considered a measure of the drying power of the atmosphere as it estimates the amount of dry air passing over the plots during the irrigation event. In general, irrigation system performance factors decreased with both wind speed and wind speed multiplied by the vapor pressure deficit. However, using the latter, more complex meteorological variable did not provide any additional information insight into how meteorological variables impact system performance and was not used to assess weather related impacts. .

Figures 2 through 10 provide plots relating AE16, AE32, LQDU and LHDU to wind speed for the three line pressures evaluated in this study. As indicated in Tables 1 through 3, the system performance parameters for plots using pressure regulation were generally higher that for plots irrigated with non-regulated spray heads. These trends are evident in Figures 2-10 where the data points associated with pressure-regulated spray heads are greater in magnitude than those generated by unregulated spray heads. What is quite interesting in the aforementioned figures is the negative impact of wind speed on system performance. All four performance parameters decline with wind speed regardless of the pressure status of the irrigation system, or whether pressure regulation was used. In all cases the decline in system performance was linearly related to wind speed during system operation. The least squares regression lines plotted on each figure suggest that the decline in system performance is similar between regulated and non-regulated heads regardless of whether pressure regulation was implemented or not. Justification for this statement is based on the fact that the slopes of the least squares regression lines for regulated and non-regulated spray heads were not significantly different for any of the system performance parameters across all three pressure regimes. That said, there are trends in the AE16 and AE32 comparisons with wind speed at 70 psi line pressure that suggest system efficiency declines more rapidly at higher wind speeds when system pressure is not regulated. For example, AE16 and AE32 in plots irrigated with systems operating at 70 psi with no pressure regulation declined at rates of 0.087 and 0.089, respectively for each 1.0 m/s increase in wind speed. With line pressure of 70 psi and pressure regulation, AE16 and AE32 declined 0.068 and 0.075 for each 1.0 m/s increase in wind speed, respectively.

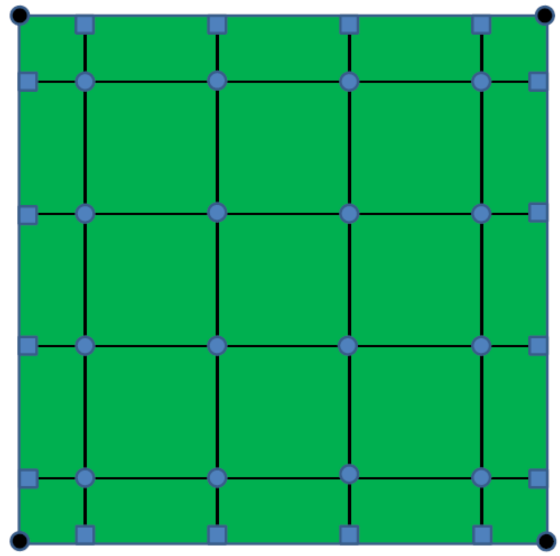

Figure 1. Placement of catch cans on each plot. Blue circles represent interior circular catch cans. Blue squares represent perimeter square catch cans. The separation distance for adjacent circular cans located in the 4x4 matrix was be 3.0’.

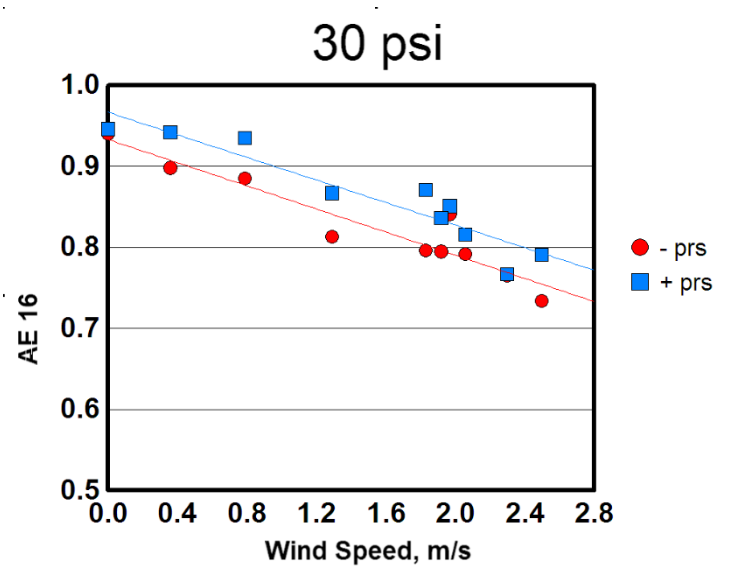

Figure 2. Application efficiency computed using the 16 interior catch cans (AE16) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 30 psi.

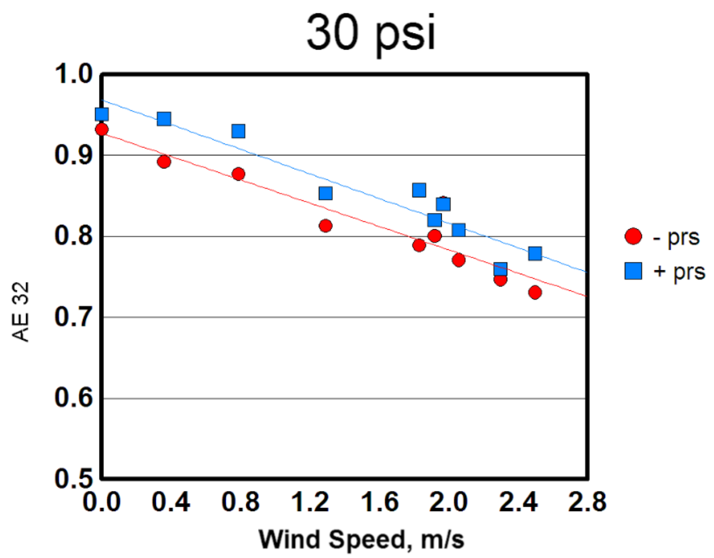

Figure 3. Application efficiency computed using all 32 catch cans (AE32) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 30 psi.

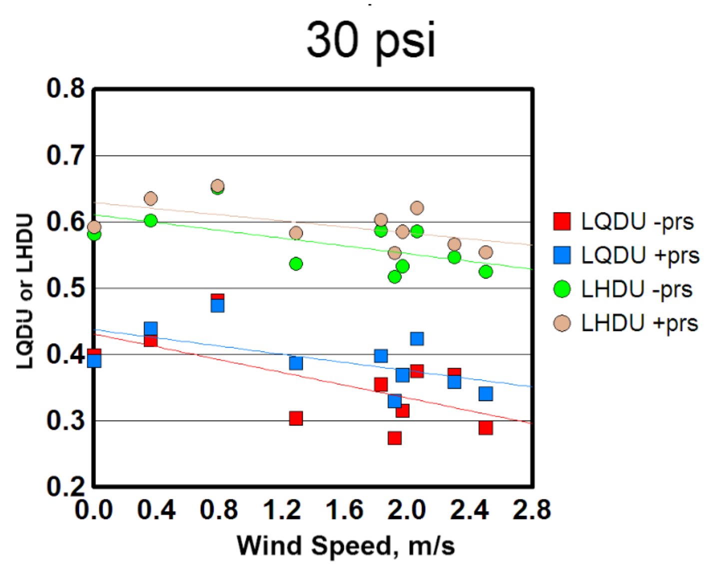

Figure 4. Low quarter distribution uniformity (LQDU) and low half distribution uniformity (LHDU) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 30 psi.

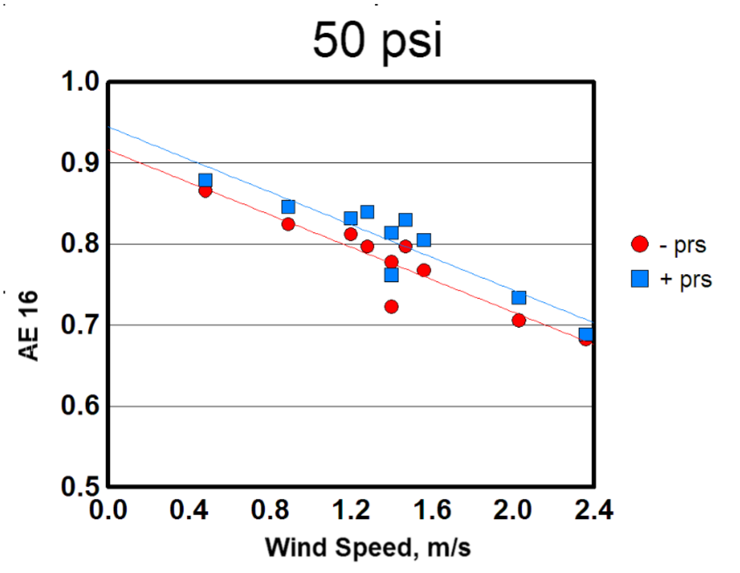

Figure 5. Application efficiency computed using the 16 interior catch cans (AE16) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 50 psi.

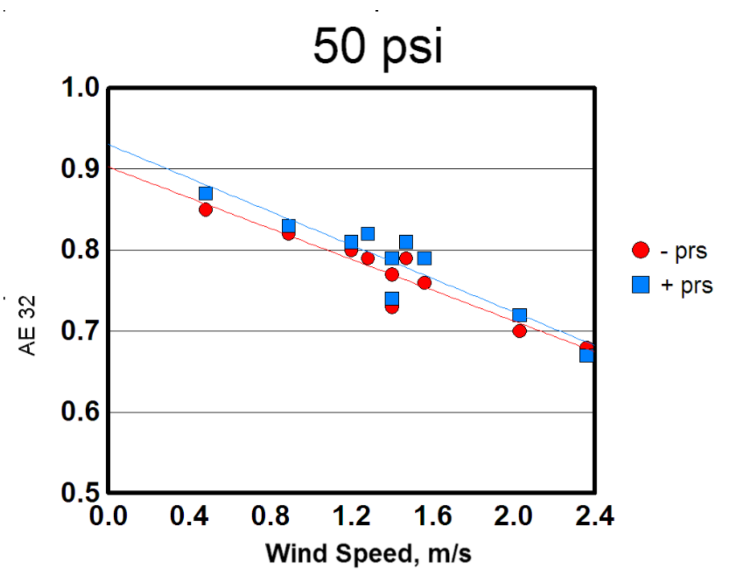

Figure 6. Application efficiency computed using all 32 catch cans (AE32) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 50 psi.

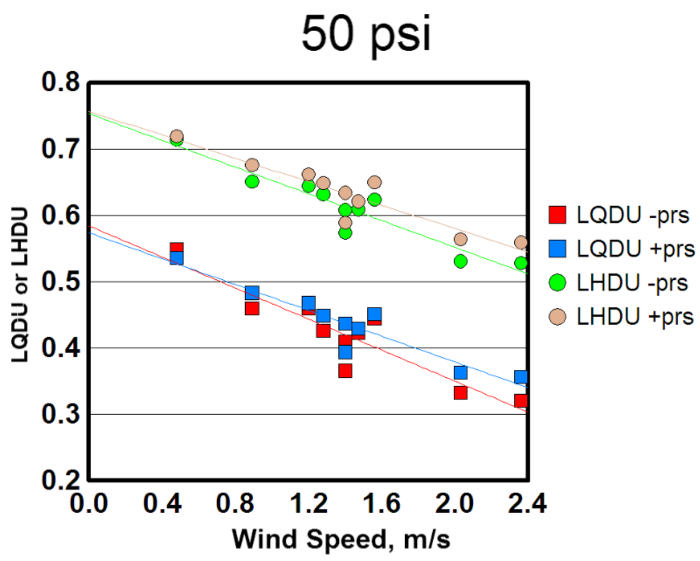

Figure 7. Low quarter distribution uniformity (LQDU) and low half distribution uniformity (LHDU) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 50 psi.

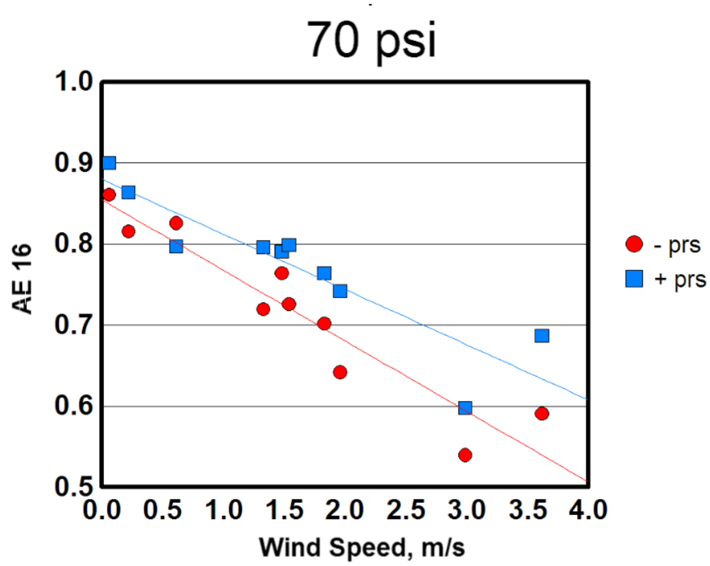

Figure 8. Application efficiency computed using the 16 interior catch cans (AE16) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 70 psi.

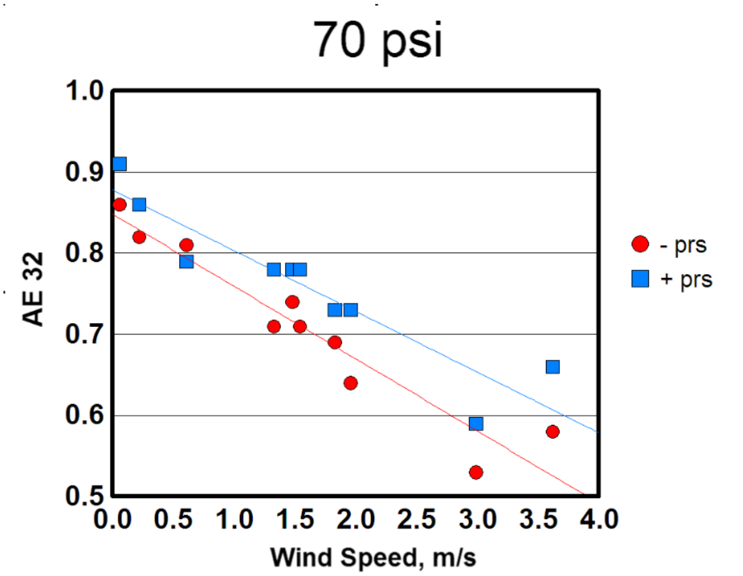

Figure 9. Application efficiency computed using all 32 catch cans (AE 32) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 70 psi.

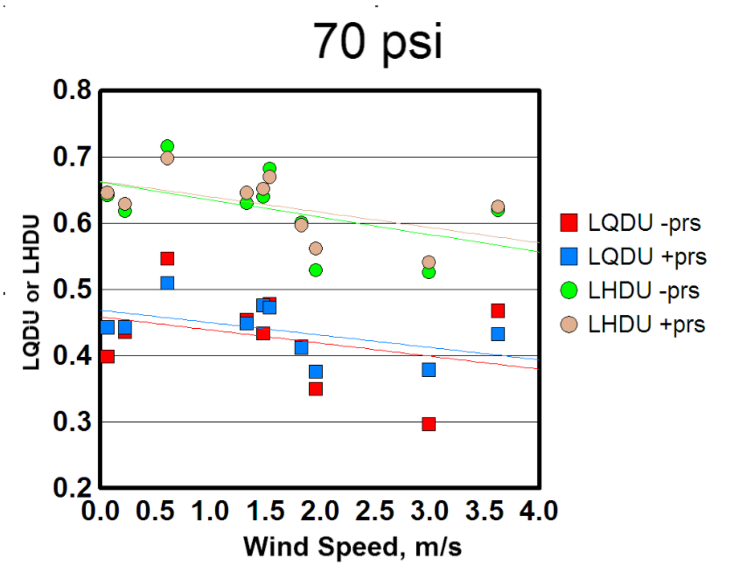

Figure 10. Low quarter distribution uniformity (LQDU) and low half distribution uniformity (LHDU) plotted as a function of wind speed during system operation for plots irrigated with (+prs) and without (-prs) pressure regulation when line pressure was set at 50 psi.

Table 1. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity and application efficiency by date for plots irrigated with (+prs) and without (-prs) pressure regulation with line pressure set at 30 psi. Distribution uniformity determined using only the 16 middle catch cans. Yes in the row labeled Stat Sig indicates overall means are significantly different at p<0.05.

Date	Time		Applied Water		Water Collected						Distribution Uniformity				Application Efficiency			
	On	Off	Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg (Inches)		Edge Cup (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg	
			-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs
11 Jun	715a	730a	0.31	0.31	0.26	0.26	0.26	0.26	0.21	0.20	0.32	0.37	53.3	58.5	0.84	0.85	0.84	0.84
11 Jun	823a	838a	0.30	0.31	0.27	0.29	0.27	0.29	0.19	0.21	0.48	0.47	65.1	65.4	0.88	0.94	0.88	0.93
12 Jun	728a	743a	0.31	0.32	0.29	0.30	0.29	0.30	0.18	0.20	0.40	0.39	58.1	59.2	0.94	0.95	0.93	0.95
12 Jun	828a	843a	0.31	0.32	0.28	0.30	0.27	0.30	0.19	0.22	0.42	0.44	60.2	63.5	0.90	0.94	0.89	0.94
13 Jun	727a	742a	0.30	0.31	0.22	0.25	0.22	0.24	0.18	0.20	0.29	0.34	52.5	55.4	0.73	0.79	0.73	0.78
13 Jun	827a	842a	0.31	0.32	0.24	0.28	0.24	0.27	0.19	0.21	0.36	0.40	58.7	60.3	0.80	0.87	0.79	0.86
16 Jun	723a	738a	0.30	0.31	0.24	0.26	0.24	0.25	0.20	0.20	0.27	0.33	51.7	55.3	0.80	0.84	0.80	0.82
17 Jun	725a	740a	0.30	0.30	0.24	0.26	0.24	0.26	0.19	0.20	0.30	0.39	53.7	58.3	0.81	0.87	0.81	0.85
18 Jun	756a	811a	0.30	0.31	0.24	0.26	0.23	0.25	0.17	0.20	0.38	0.42	58.6	62.1	0.79	0.82	0.77	0.81
18 Jun	903a	918a	0.30	0.31	0.23	0.24	0.22	0.24	0.17	0.20	0.38	0.36	54.7	56.6	0.76	0.77	0.75	0.76
Means			0.30	0.31	0.25	0.27	0.25	0.27	0.19	0.20	0.36	0.39	56.7	59.5	0.83	0.86	0.82	0.85
Stat Sig			Yes		Yes		Yes		Yes		Yes		Yes		Yes		Yes	

Table 2. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity and application efficiency by date for plots irrigated with (+prs) and without (-prs) pressure regulation with line pressure set at 50 psi. Distribution uniformity determined using only the 16 middle catch cans. Yes in the row labeled Stat Sig indicates overall means are significantly different at $p<0.05$.

Date	Time		Applied Water		Water Collected						Distribution Uniformity				Application Efficiency			
	On	Off	Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg (Inches)		Edge Cup (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg	
			-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs
3 Jun	845a	900a	0.41	0.40	0.33	0.34	0.32	0.33	0.25	0.25	0.42	0.43	0.61	0.62	0.80	0.83	0.79	0.81
4 Jun	739a	754a	0.41	0.40	0.33	0.34	0.32	0.33	0.25	0.25	0.43	0.45	0.63	0.65	0.80	0.84	0.79	0.82
4 Jun	842a	857a	0.41	0.43	0.36	0.38	0.35	0.37	0.25	0.28	0.55	0.54	0.71	0.72	0.87	0.88	0.85	0.87
5 Jun	728a	743a	0.41	0.42	0.32	0.34	0.32	0.33	0.25	0.26	0.41	0.44	0.61	0.63	0.78	0.81	0.77	0.79
5 Jun	831a	846a	0.41	0.42	0.31	0.34	0.31	0.33	0.24	0.26	0.44	0.45	0.62	0.65	0.77	0.80	0.76	0.79
6 Jun	708a	723a	0.41	0.43	0.29	0.32	0.29	0.32	0.25	0.26	0.37	0.39	0.57	0.59	0.72	0.76	0.73	0.74
9 Jun	713a	728a	0.40	0.42	0.33	0.36	0.33	0.35	0.25	0.27	0.46	0.48	0.65	0.68	0.82	0.85	0.82	0.83
9 Jun	821a	836a	0.41	0.42	0.33	0.35	0.33	0.34	0.25	0.26	0.46	0.47	0.64	0.66	0.81	0.83	0.80	0.81
10 Jun	719a	734a	0.41	0.42	0.28	0.29	0.28	0.28	0.24	0.24	0.32	0.36	0.53	0.56	0.68	0.69	0.68	0.67
10 Jun	824a	839a	0.41	0.42	0.29	0.31	0.29	0.30	0.25	0.25	0.33	0.36	0.53	0.56	0.71	0.73	0.70	0.72
Means			0.41	0.42	0.32	0.34	0.31	0.33	0.25	0.26	0.42	0.44	0.61	0.63	0.78	0.80	0.77	0.79
Stat Sig			Yes		Yes		Yes		Yes		No		Yes		Yes		Yes	

Table 3. Mean values of applied water (from meter), water collected in catch cups, distribution uniformity and application efficiency by date for plots irrigated with (+prs) and without (-prs) pressure regulation with line pressure set at 70 psi. Distribution uniformity determined using only the 16 middle catch cans. Yes in the row labeled Stat Sig indicates overall means are significantly different at p<0.05.

Date	Time		Applied Water		Water Collected						Distribution Uniformity				Application Efficiency			
	On	Off	Water Applied (Inches)		Middle 16 Cups (Inches)		32-Cup Spatial Avg (Inches)		Edge Cup (Inches)		Low Quarter		Low Half		Middle 16 Cups		32-Cup Spatial Avg	
			-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs	-prs	+prs
20 May	825a	840a	0.46	0.41	0.25	0.24	0.24	0.24	0.22	0.22	0.30	0.38	0.53	0.54	0.54	0.60	0.53	0.59
22 May	820a	835a	0.50	0.47	0.41	0.37	0.41	0.37	0.29	0.27	0.55	0.51	0.72	0.70	0.83	0.80	0.81	0.79
23 May	730a	745a	0.49	0.43	0.40	0.37	0.41	0.37	0.31	0.28	0.44	0.44	0.62	0.63	0.82	0.86	0.82	0.86
27 May	751a	806a	0.45	0.42	0.34	0.33	0.34	0.33	0.25	0.25	0.43	0.48	0.64	0.65	0.76	0.79	0.74	0.78
28 May	751a	806a	0.50	0.44	0.35	0.33	0.34	0.32	0.28	0.24	0.41	0.41	0.60	0.60	0.70	0.76	0.69	0.73
29 May	755a	810a	0.50	0.43	0.30	0.30	0.29	0.28	0.25	0.22	0.47	0.43	0.62	0.62	0.59	0.69	0.58	0.66
30 May	735a	750a	0.50	0.43	0.36	0.34	0.36	0.34	0.29	0.26	0.45	0.45	0.63	0.65	0.72	0.80	0.71	0.78
2 Jun	729a	744a	0.50	0.43	0.32	0.32	0.32	0.31	0.29	0.26	0.35	0.38	0.53	0.56	0.64	0.74	0.64	0.73
2 Jun	837a	852a	0.50	0.43	0.36	0.34	0.35	0.33	0.28	0.27	0.48	0.47	0.68	0.67	0.73	0.80	0.71	0.78
3 Jun	726a	741a	0.50	0.43	0.43	0.38	0.43	0.39	0.31	0.29	0.40	0.44	0.64	0.65	0.86	0.90	0.86	0.91
Means			0.49	0.43	0.35	0.33	0.35	0.33	0.28	0.26	0.43	0.44	0.62	0.63	0.72	0.77	0.71	0.76
Stat Sig			Yes		Yes		Yes		Yes		No		No		Yes		Yes	