IrriGreen Irrigation Audit and Soil VWC Uniformity Test
Experiment and Report Prepared by: Dr. Brian Horgan, Turfgrass Consultant

Introduction:
The irrigation audit was conducted on February 26 and 27, 2014 at Quail Creek Estates in Naples, FL. The site was characterized and irrigation systems were evaluated prior to conducting the audit. Spatial considerations were taken into account and can be used to explain variation in the results. In addition, site selection attempted to account for turfgrass species and antecedent soil moisture.

The site was dried down starting Sunday February 23, 2014. After selecting the replicate sites within each irrigation system, background soil moisture was determined by taking 70 TDR readings within each replication. These background data enabled calculation of relative differences in water delivery after running the respective irrigation systems.

On February 27, the audits were conducted starting with the traditional system followed by the IrriGreen system. For the latter, some minor changes in the audit were required because of pressure and calibration. Within each replicate, 20 catch cans were placed equidistant within the 100 sq. ft. area. Immediately following the irrigation run and collection of catch can data, 70 TDR measurements were taken from each replicate.

Our working hypothesis: (1) traditional irrigation audits will not be sufficient with the IrriGreen system because of the water stream size and (2) IrriGreen will have soil water distribution similar to a traditional spray head system.

Summary of Statistical Methods:

Table 1
-Mean and Standard Deviation of all TDR data (VWC %) was calculated for each plot of each treatment using all measurements within the plot. The statistics were calculated for response variables: Background, Audit, and change in VWC (Δ_{VWC}).

-Coefficient of Uniformity was determined within each plot as $CU_{ij} = 1 - \left(\frac{\sigma_{ij}}{\mu_{ij}}\right)$ where *i* corresponds to the system, *j* corresponds to the replicate plot number within the system, and μ_{ij} and σ_{ij} are the mean and standard deviation of plot *ij*.

Table 2
-Mean and Standard Deviation of all TDR data (VWC %) was calculated for each plot of each treatment using all measurements within the plot. The statistics were calculated for response variables: Background, Audit, and change in VWC (Δ_{VWC}).

-Coefficient of Uniformity was determined within each plot as $CU_{ij} = 1 - \left(\frac{\sigma_{ij}}{\mu_{ij}}\right)$ where i corresponds to the system number (Traditional=1, IrriGreen=2), j corresponds to the replicate plot number within the system, and μ_{ij} and σ_{ij} are the mean and standard deviation of plot *ij*.

-Mean and Standard Deviation of Catch Can (CC) data (mL water) was calculated within each plot for each treatment

Table 3
The following process was used for each response variable (Background, Audit, Δ_{VWC}, and Catch Cans):

-The three CU values from each of the two systems were used as two populations in a two-sample t-test.

-The t-test tests the null hypothesis that the difference between the means of the two populations is not different from zero. The alternative hypothesis is that the difference between the means of the two populations is different from zero.

-Because the variance of the two populations was clearly not equal in most cases, Welch's method was used to correct the degrees of freedom for the test

Table 4
The following process was used for each response variable (Background, Audit, Δ_{VWC}, and Catch Cans):

-The mean value of the response variable was calculated for each replicate plot

-The three mean values from each of the two treatments were used as two populations in a two-sample t-test.

-The t-test tests the null hypothesis that the difference between the means of the two populations is not different from zero. The alternative hypothesis is that the difference between the means of the two populations is different from zero.

-Because the variance of the two populations was clearly not equal in most cases, Welch's method was used to correct the degrees of freedom for the test

-Least squares regression was used to fit a response surface to the data within each plot for each set of data (background, audit, Δ_{VWC}, and CC). AIC was used to select best model order and fit.

Table 5

-Correlation values for the Background and Audit TDR measurements were determined
-Correlation significance tests were carried out using Pearson's method. The significance test has a null hypothesis that the correlation is not different from zero.

Surface Plots

- The surface plots shown were created using a Loess smoother to interpolate a response surface for each response variable in each plot and system
- Loess surface generation fits a regression model to a local subset of the response data within a weighted, sliding window as a function of the X and Y coordinates. The center point of the sliding window is then assigned the predicted value from the resulting regression equation. It effectively acts as a smoother, or low-pass filter, for the data.
- All plots within a response variable were scaled to the same range of values and colors based on the minimum and maximum values for that response variable across all measurements.
- A 2^{nd} order model was used for the loess regressions. That is the generally recommended order when local maxima and minima exist in the data, as they do in this case.
- The tension parameter, α, was set to 0.5 meaning that each localized regression uses half of the points along each axis in the weighted, sliding window.

Results:

- Coefficient of Uniformity (CU) for Catch Can data for the Traditional System (0.91) was higher than IrriGreen (0.68), and the difference was significant (Table 1).

- CU for Background TDR data for the Traditional System (0.82) was lower than IrriGreen (0.847), but the difference was not significant, indicating background soil moisture uniformities are statistically equivalent. (Table 3).

- CU for the TDR Audit data for Traditional (0.846) was lower than IrriGreen (0.854), but the difference was not significant, indicating that final soil moisture uniformities were statistically equivalent. (Table 3)

- The overall mean of the Catch Can volume data was significantly higher for the IrriGreen system (59.1 mL) than the Traditional system (49.68 mL), meaning significantly more total water fell on the IrriGreen plots. (Table 4)

- Coefficient of Uniformity (CU) for Catch Can data for the Traditional System (0.91) was higher than IrriGreen (0.68), and the difference was significant (Table 1).

- The overall mean of the Background TDR data was significantly higher for the IrriGreen system (20.4%) than the Traditional system (15.404%), meaning IrriGreen plots were significantly wetter on average to begin the trial. (Table 4)

- The overall mean of the Audit TDR data was significantly higher for the IrriGreen system (27.533%) than the Traditional system (22.077%), meaning IrriGreen plots were significantly wetter on average at the end of the trial. (Table 4)

- The mean change in VWC ($\overline{\Delta_{VWC}}$) was higher for the IrriGreen system (7.092%) than the Traditional System (6.671%). However, the difference was not statistically significant. Despite the lack of significance, the result demonstrates that more water is reaching the soil from the IrriGreen system than from the Traditional system (Table 4). Alternatively stated, no difference in the mean relative VWC indicates that both systems are equally wetting the soil.

- The CU of the change in VWC ($\overline{\Delta_{VWC}}$) was statistically lower for the IrriGreen system (0.563) than the Traditional system (0.418). Still, the difference of 0.145 ± 0.075 is quite small which demonstrates there is little difference between the two systems in uniformity of the change in soil moisture. (Table 3)

Proving our Hypothesis:

The catch can results differ from the soil moisture audit, possibly a result of the ability of the IrriGreen system to deliver water more directly to the soil surface. The IrriGreen system results in greater soil moisture increases (Δ_{VWC} = 7.092% vs 6.671%), although not statistically different. The Catch Can method is not a suitable assessment of the IrriGreen system's wetting ability and uniformity. The ability of the IrriGreen system to deliver water more efficiently (because of design) and at the same level of precision as a traditional system make this a breakthrough technology that deserves attention by landscape contractors and homeowners.

Table 1. Summary Statistics for Catch Can water volumes. System 1 is the traditional irrigation system and System 2 is IrriGreen.

		Catch Cans		
System	Rep	Mean	SD	CU
1	1	50.65	3.55	0.93
1	2	51.95	4.42	0.91
1	3	46.45	5.19	0.89
2	1	61.8	24.41	0.61
2	2	72.75	15.57	0.79
2	3	42.75	14.52	0.66

Table 2. Summary Statistics for VWC measurements. System 1 is the traditional irrigation system and System 2 is IrriGreen.

		Background			Audit			Δ_{VWC}		
System	Rep	Mean (%)	StDev	CU	Mean (%)	StDev	CU	Mean (%)	StDev	CU
1	1	15.31	2.26	0.852	22.47	2.75	0.877	7.16	3.21	0.55
1	2	15.43	3.47	0.775	21.62	3.83	0.823	6.17	2.86	0.54
1	3	15.46	2.56	0.834	22.14	3.54	0.840	6.67	2.64	0.60
2	1	14.47	2.29	0.842	20.22	3.73	0.815	5.74	3.24	0.435
2	2	22.68	3.76	0.834	31.34	3.97	0.873	8.65	5.02	0.419
2	3	24.16	3.28	0.864	31.03	3.93	0.873	6.88	4.13	0.399

Table 3. Analysis of variance results for VWC and catch can coefficients of uniformity

Data	Mean CU		Difference (Trad. – IrriGreen)	Margin of Error	p-value
	Traditional	IrriGreen			
Background	0.820	0.847	-0.027	0.086	0.382
Audit	0.846	0.854	-0.008	0.071	0.787
Δ_{VWC}	0.563	0.418	0.145	0.075	0.008
Catch Cans	0.911	0.683	0.28	0.216	0.045

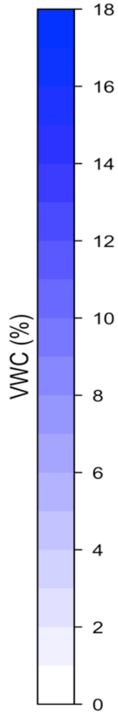
Table 4. Comparison of mean moisture and water collected for both systems

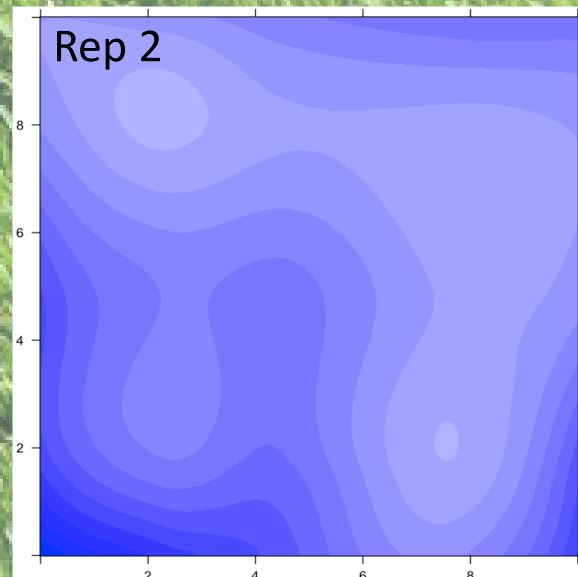
Data	Mean Moisture		Difference (Trad. – IrriGreen)	Margin of Error	p-value
	Traditional	IrriGreen			
Background (%)	15.404	20.440	-5.036	2.517	<0.001
Audit (%)	22.077	27.533	-5.456	0.992	<0.001
Δ_{VWC} (%)	6.671	7.092	-0.421	0.711	0.245
Catch Cans (mL)	49.68	59.10	-9.42	5.873	0.002

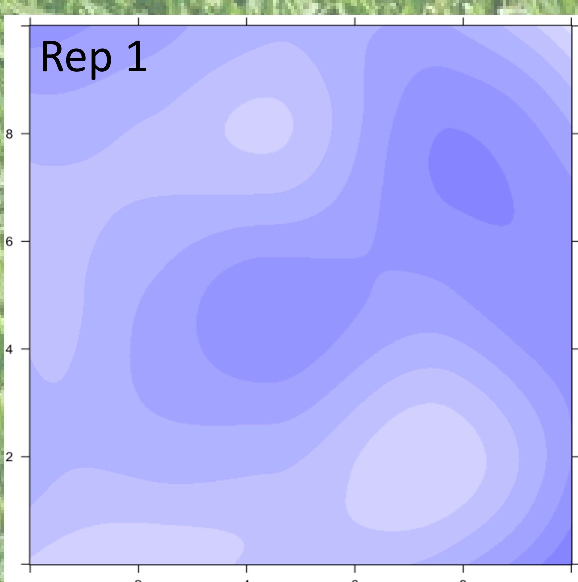
Table 5. Correlation estimates for background and audit measurements. System 1 is the traditional irrigation system and System 2 is IrriGreen.

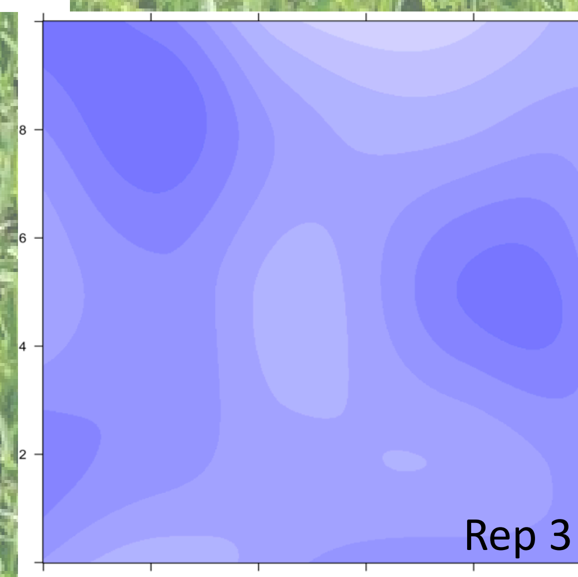
System	Rep	Correlation	p-value
1	1	0.189	0.1154
1	2	0.696	<0.001
1	3	0.667	<0.001
2	1	0.506	<0.001
2	2	0.157	0.193
2	3	0.354	0.002

Approximate layout of three replications of TDR volumetric water content data from the IrriGreen system. Values shown are for the overall change in volumetric water content following the irrigation cycle.

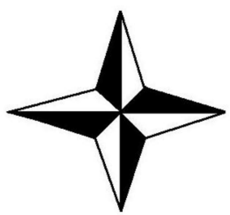


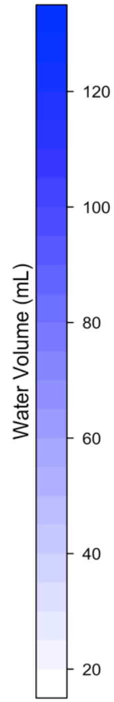


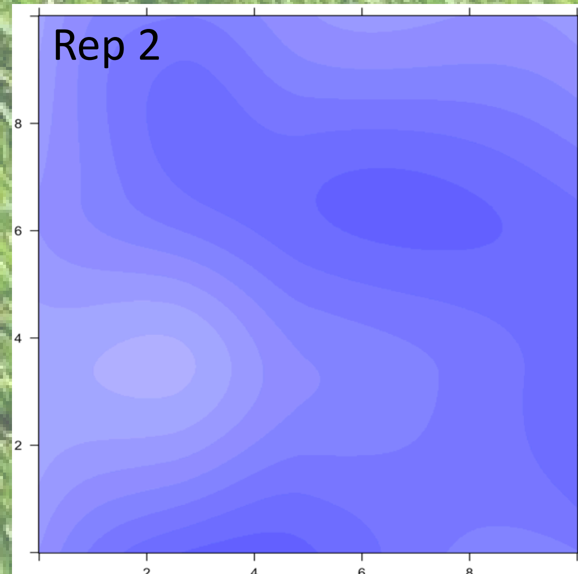


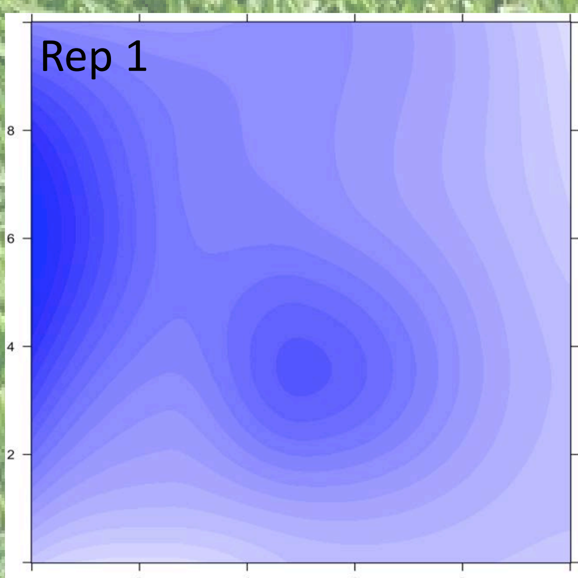


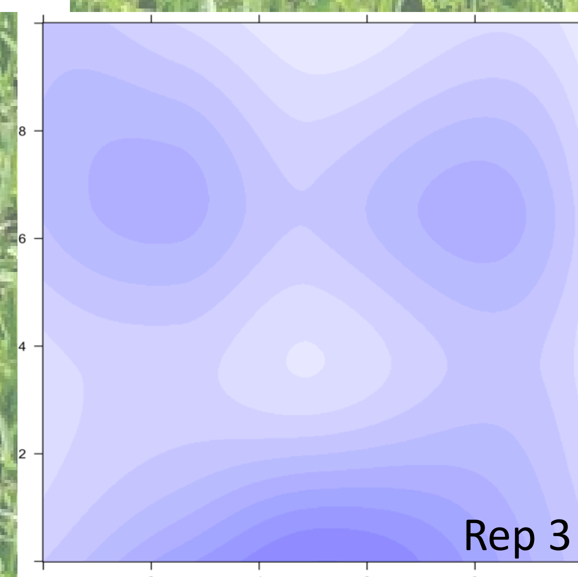
Approximate layout of three replications of Catch Can water volume data from the IrriGreen system. Values shown are for the distribution of water following the irrigation cycle.

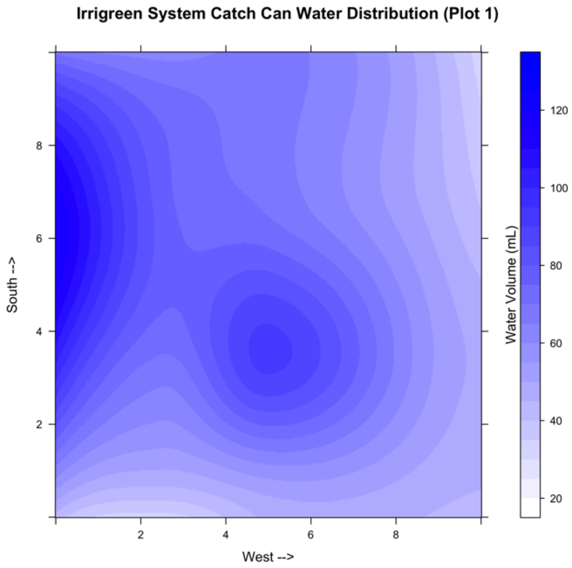


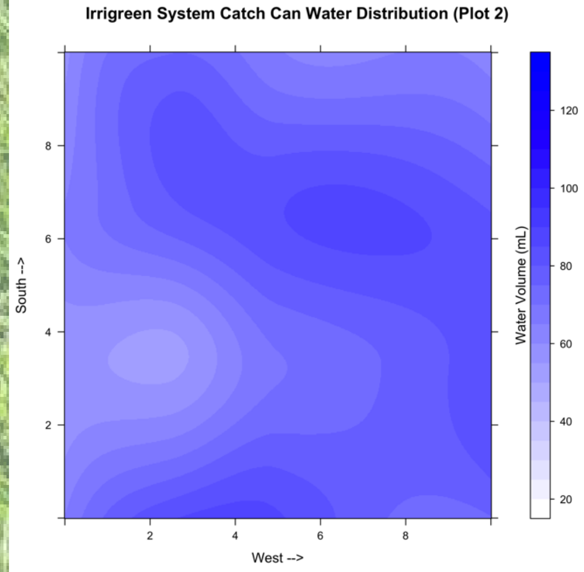


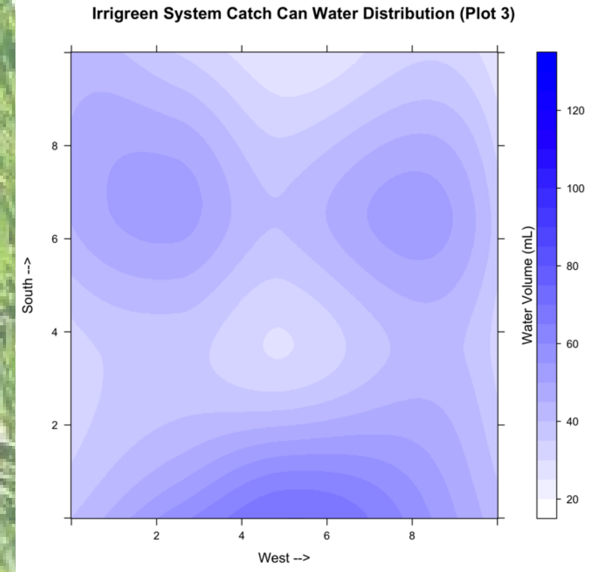


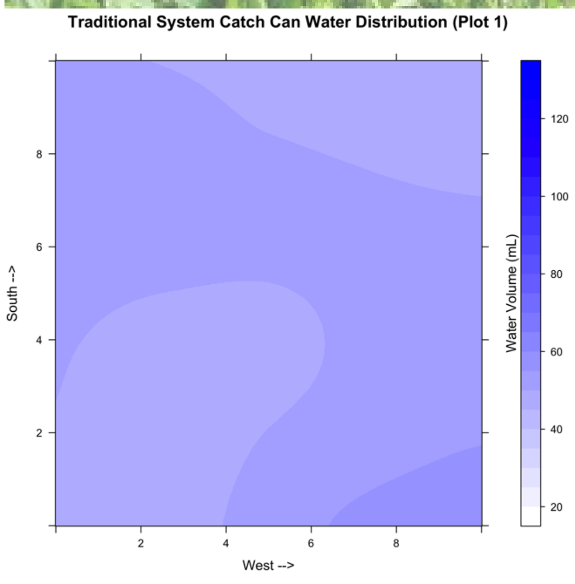


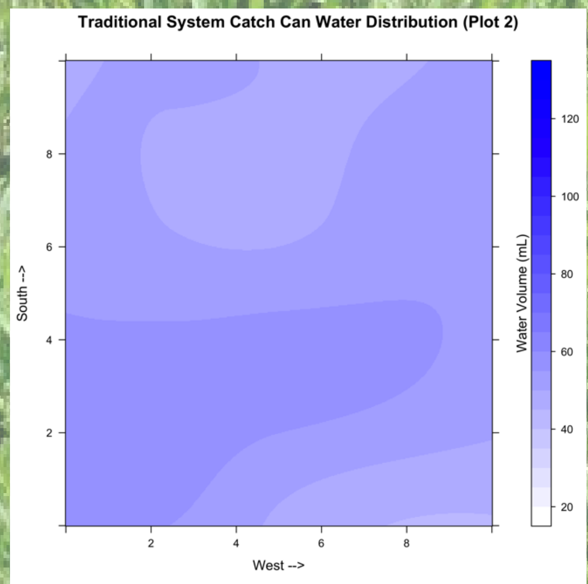


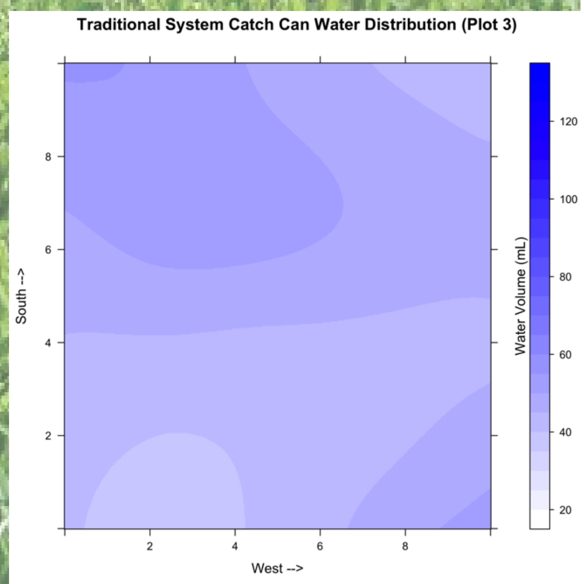

Irrigreen System Catch Can Water Distribution (Plot 1)
South -->
West -->
Water Volume (mL)

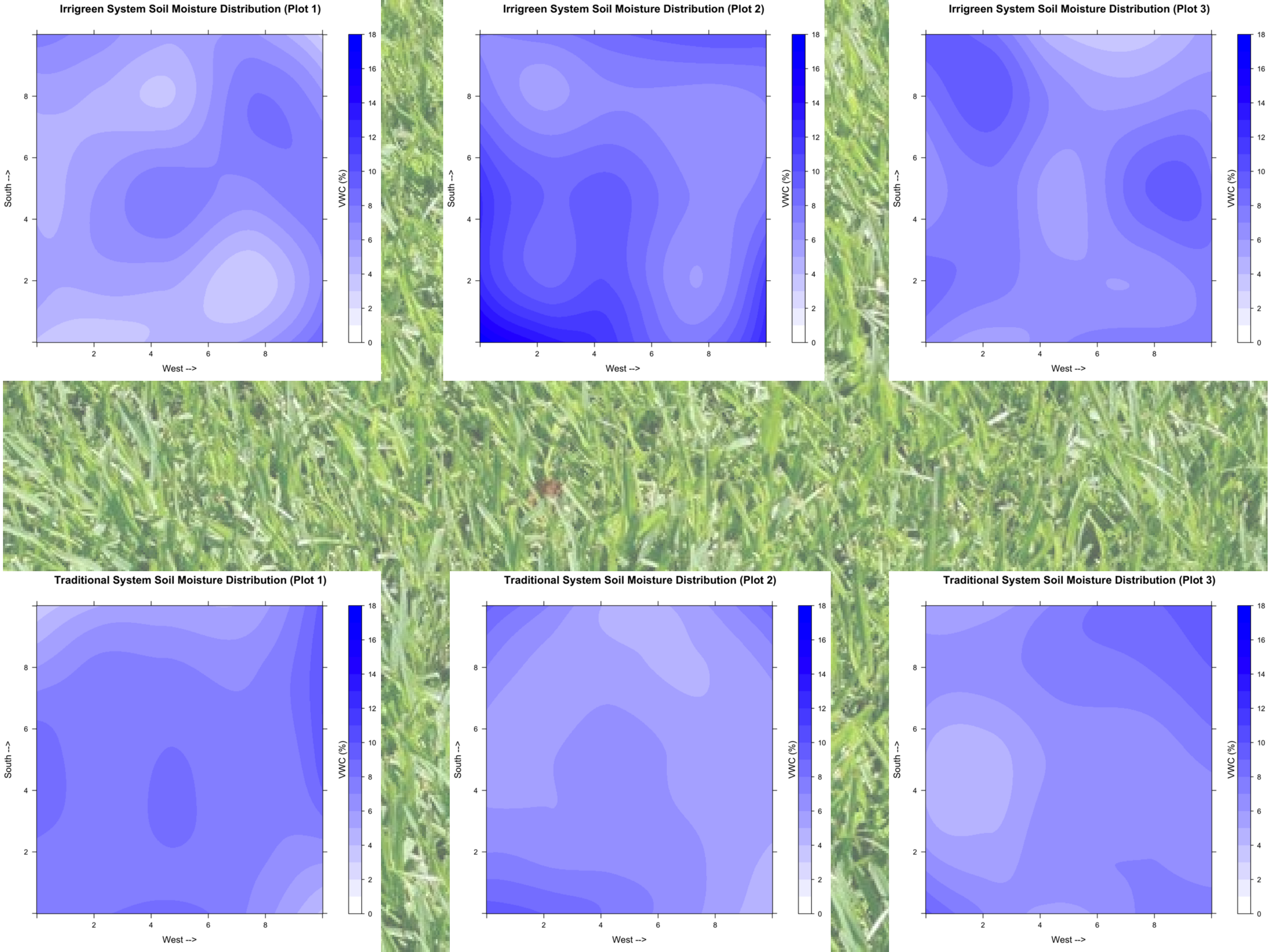

Irrigreen System Catch Can Water Distribution (Plot 2)
South -->
West -->
Water Volume (mL)

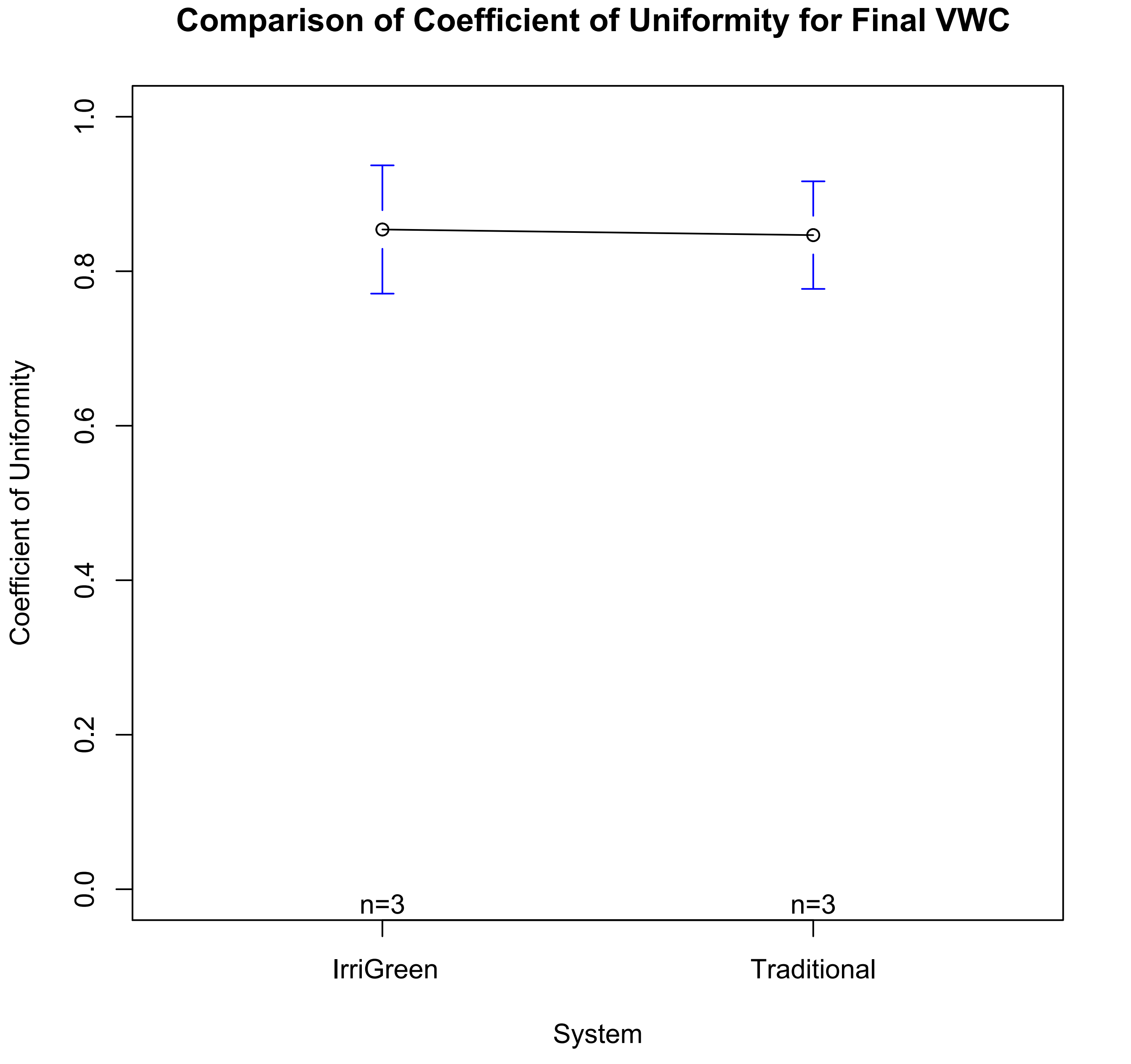

Irrigreen System Catch Can Water Distribution (Plot 3)
South -->
West -->
Water Volume (mL)

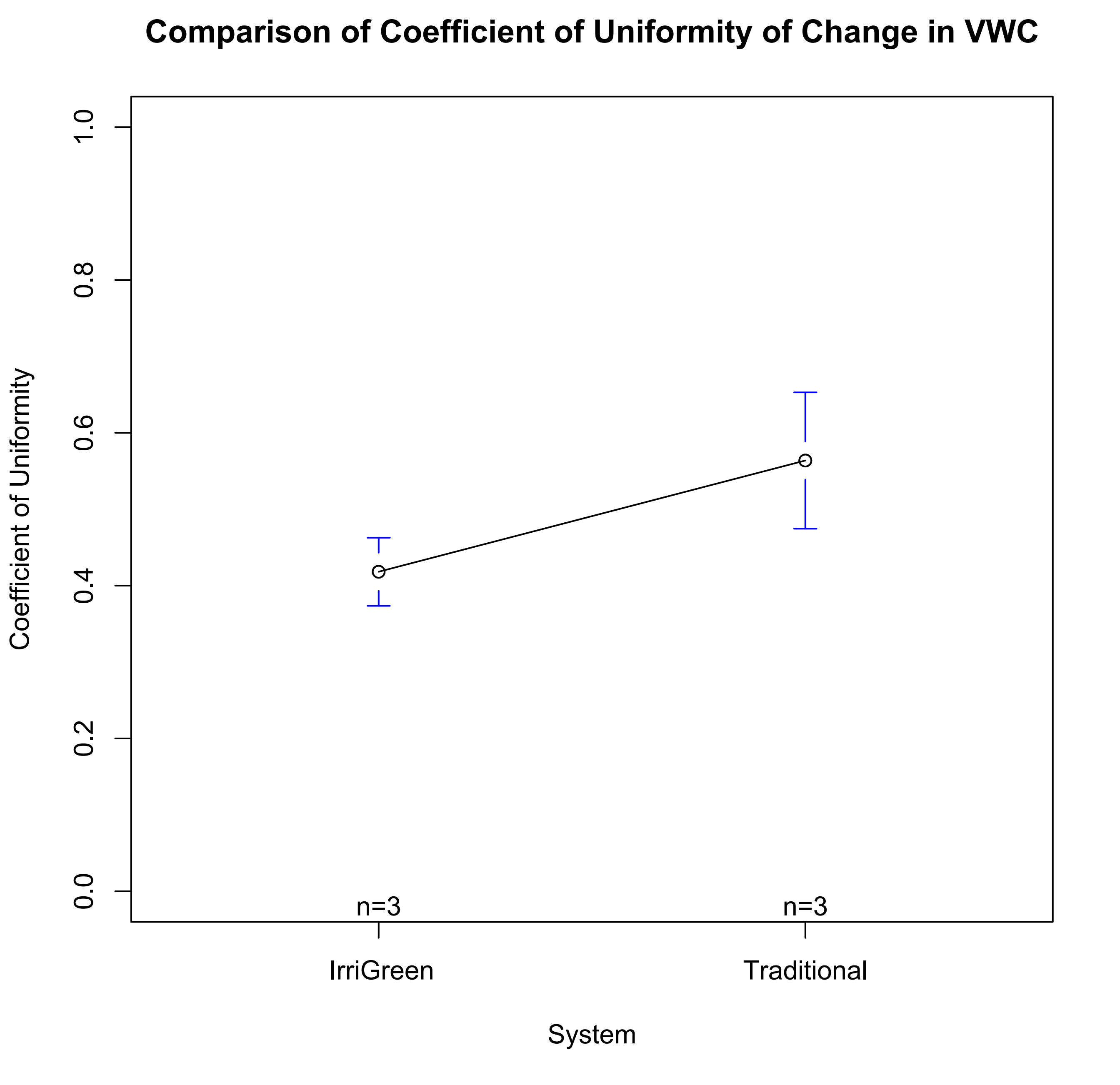

Traditional System Catch Can Water Distribution (Plot 1)
South -->
West -->
Water Volume (mL)


Traditional System Catch Can Water Distribution (Plot 2)
South -->
West -->
Water Volume (mL)

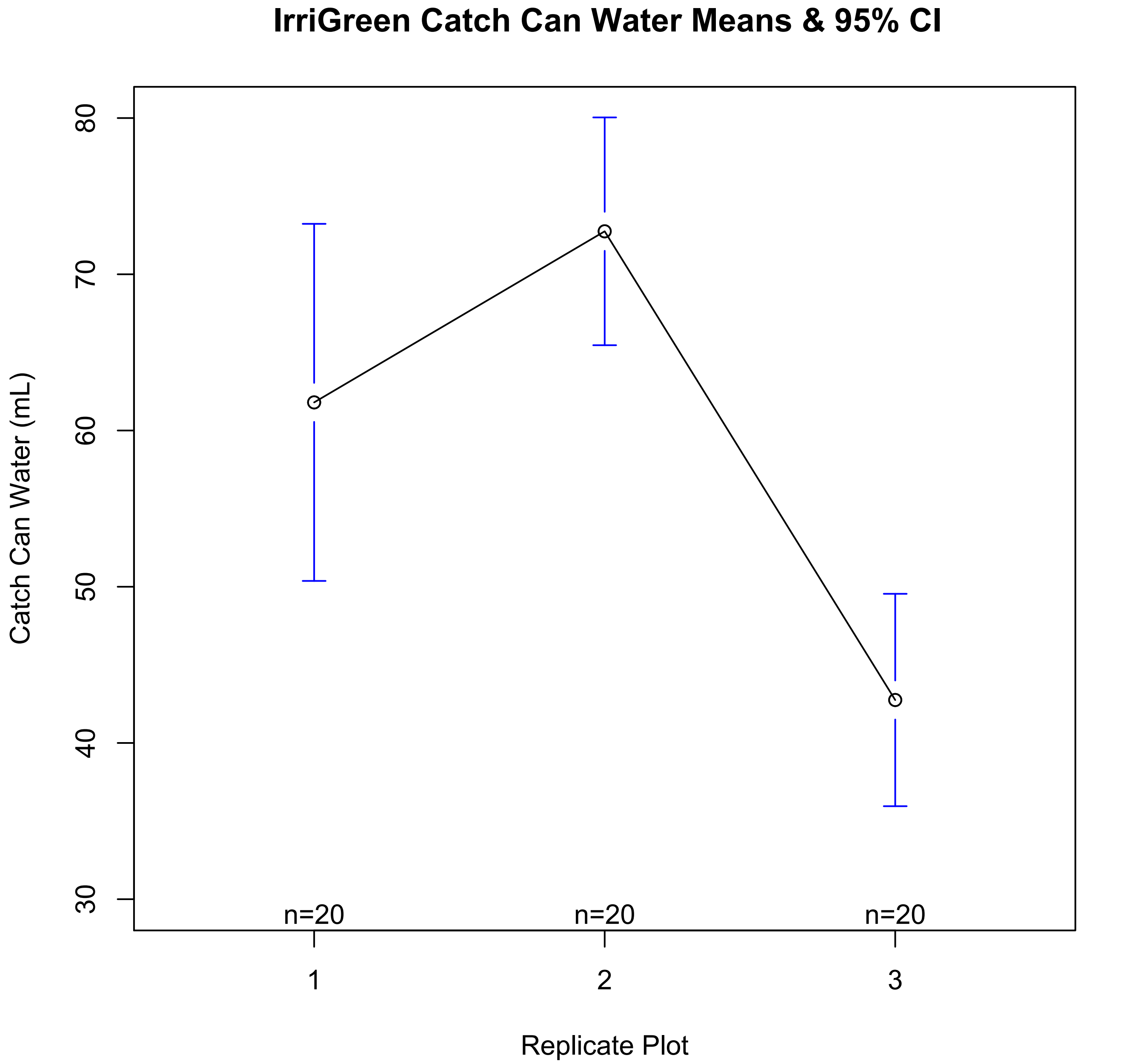

Traditional System Catch Can Water Distribution (Plot 3)
South -->
West -->
Water Volume (mL)


Irrigreen System Soil Moisture Distribution (Plot 1)
Irrigreen System Soil Moisture Distribution (Plot 2)
Irrigreen System Soil Moisture Distribution (Plot 3)
Traditional System Soil Moisture Distribution (Plot 1)
Traditional System Soil Moisture Distribution (Plot 2)
Traditional System Soil Moisture Distribution (Plot 3)
South -->
West -->
VWC (%)
0
2
4
6
8
10
12
14
16
18

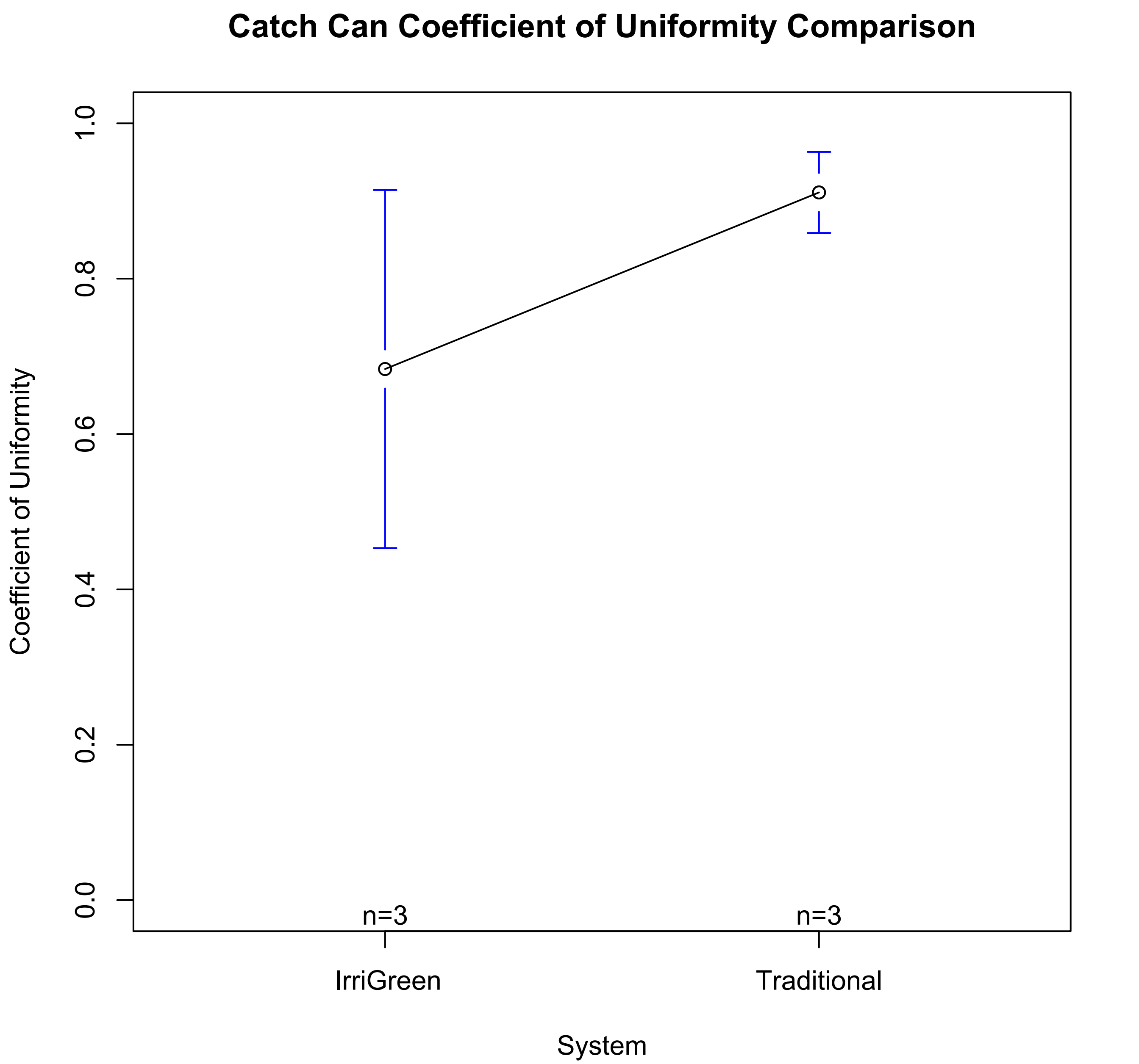

Comparison of Coefficient of Uniformity for Final VWC
Coefficient of Uniformity
0.0
0.2
0.4
0.6
0.8
1.0
n=3
n=3
IrriGreen
Traditional
System



Comparison of Coefficient of Uniformity of Change in VWC
Coefficient of Uniformity
0.0
0.2
0.4
0.6
0.8
1.0
n=3
n=3
IrriGreen
Traditional
System



IrriGreen Catch Can Water Means & 95% CI
Catch Can Water (mL)
30
40
50
60
70
80
n=20
n=20
n=20
1
2
3
Replicate Plot



Catch Can Coefficient of Uniformity Comparison
Coefficient of Uniformity
0.0
0.2
0.4
0.6
0.8
1.0
n=3
n=3
IrriGreen
Traditional
System