A Comparison of Fairway Distribution Uniformity Computed with Catch Can Data and with Soil Moisture Data from Three Sampling Depths

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Paper presented at the 29th Annual Irrigation Show
Anaheim, CA
November 2-4, 2008

Abstract

Distribution uniformity and precipitation rate are important for determining base irrigation schedules. Currently, uniformity is calculated using catch can data. There is interest in using soil moisture data instead because of ease of collecting data and because it measures root-zone moisture. Data were collected at 3 fairways identified as high, medium, and low-traffic areas. Catch cans were placed according to IA recommendations for auditing a fairway. Additional catch cans were placed to give a surplus of data locations. Soil moisture measurements were taken adjacent to each catch can with a portable wave reflectometer before and after irrigation. Sampling depths were 1.5, 3, and 4.8 inches. Distribution uniformities and net precipitation rates were computed for the full data sets and on pre-selected subsets. The reduced data set results were analyzed to determine minimum sampling points necessary to calculate a representative distribution uniformity and precipitation rate.

Introduction

Golf courses are very conspicuous consumers of irrigation water. It is estimated that U.S. golf courses use 2.1 billion gallons of water per day (Ostmeyer, 2008). And, in the southwestern U.S., golf courses average 149 million gallons per year and spend an average of nearly $108,000 per year for water (Ostmeyer, 2008). As water becomes an increasingly scarce and valuable commodity, there is increased pressure on superintendents to manage this resource prudently and efficiently. A golf course, however, consists of 5 main categories of irrigated area; greens, tee boxes, fairways, roughs and landscapes. Although the greens are the most visible and intensely managed features on the course, fairways and rough may offer the best opportunity to realize savings in irrigation water use. The reasons for this are twofold. First, fairways and rough constitute a much greater percentage of the total irrigated turf area on a course. Second, the turf quality threshold for fairway irrigation can be much lower than for the greens. So, there is a greater margin for error when managing these areas.

Evapotranspiration, which represents the amount of amount removed from the soil by the atmosphere and roots, is one way in which the timing of irrigation events can be determined. This data can be accessed from local weather networks or calculated from on-site weather stations. It has been shown that irrigation at 100% ET is not necessary to maintain acceptable turf quality on fairways planted to bentgrass (DaCosta and Huang, 2006), Kentucky bluegrass (Feldhake et al., 1984) and fescue (Feldhake et al., 1984; Fry and Butler, 1989).

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Deficit irrigation has been shown to promote deeper root depths and increased drought tolerance (Jiang and Huang, 2001). Conversely, excess water, whether from heavy rain or over-irrigation can yield anaerobic soil conditions and a moist environment that is conducive to the spread of fungal pathogens. Incidents of over-irrigation are more likely to occur late in the season, assuming irrigation schedules have not been adjusted to reflect shallow root systems resulting from summer heat stress. Lacking the root depth typical of early season, the turf can no longer access the same depth of soil-held water. Consequently, turf water consumption decreases without a corresponding decrease in applied water.

One technique for scheduling and determining if a sprinkler system is performing as expected is to perform an irrigation audit. Currently, this is most commonly done with catch cans placed in a pre-determined pattern depending on the sprinkler configuration and whether the area being audited is a green, tee box or fairway (IA, 2007). The catch cans capture the water applied during a typical irrigation cycle. Net precipitation rate and lower quartile distribution uniformity (DU_{lq}) of the system can then be computed from the volumes collected (Kieffer and O'Connor, 2007). The calculations are as follows:

$$PR_i = \frac{V_{avg} \text{ x } 3.66}{TR \text{ x } CDA}$$

Where:
PR_i = Precipitation rate for an individual catch can, (in./h)
V_{avg} = Average catch can volume (milliliters)
3.66 = Constant that converts milliliters to in.^{3} and minutes to hours
TR = Testing run time (minutes)
CDA = Catch device throat area (square inches)

To calculate net precipitation rate (PR_{net}), the average the catch device water volume must be calculated by dividing the total water volume of all catch devices by the total number of catch devices.

$$DU_{lq} = \frac{\overline{V}_{lq}}{\overline{V}_{total}}$$

Where:
DU_{lq} = Lower quartile distribution uniformity
$\overline{V}_{lq}$ = Average of the lowest 25% of catch can volumes (or soil moisture readings).
$\overline{V}_{total}$ = Average of all catch can volumes (or soil moisture of all readings).

Table 1 - Estimated DU_{lq} for golf systems by sprinkler type and system quality

Sprinkler Type	**Excellent** (achievable)	**Good** (expected)	**Poor** (if lower than this, consider not scheduling or improving irrigation system)
Rotary Sprinklers	80%	70%	55%
Spray Sprinklers	75%	65%	50%

This method is useful for evaluating the performance of the irrigation hardware (Mecham, 2001) as well as determining the precipitation rate. Table 1 lists a standard for using DU_{lq} to rate the quality of the irrigation system (IA, 2003). The catch can audit can be a time consuming process and its accuracy can be affected by wind, number of cups, cup placement and cup spillage. Further, it gives no information on whether the water reaches the soil or how the water distributes itself in the soil. For making irrigation decisions, there is an increased interest in using soil moisture data to calculate the distribution uniformity (Mecham, 2001; Dukes et al, 2006; Miller et al, 2005; Kieffer and O'Connor, 2007; Vis et al, 2007, Li and Rao, 2001). Miller et al (2005) found no correlation between the catch can DU and soil moisture DU. Warrick and Gardener, (1983) found that the uniformity of the irrigation played a major role in soil moisture uniformity, especially for subsurface systems. Li and Rao (2001) found water redistribution to be more important than irrigation uniformity, while Hunsaker and Bucks (1987) determined that soil texture was a more important factor. The volumetric water content (VWC) at field capacity, which is soil texture dependent, is a parameter that has been found to have a similar pattern of spatial variability to other stable landscape parameters (Krum et al, 2007). Therefore, spatial maps of VWC, provide useful information for managing turf grass. Krum et al (2007) used maps of VWC and the normalized difference vegetative index (NDVI) to create site-specific management units for precision agriculture applications.

Portable or in-situ soil moisture data can direct a turf grass irrigator when to irrigate and the amount of water necessary to replenish the root zone. And, while a soil moisture audit gives information on how to adjust the irrigation run-time to account for the uniformity of moisture in the root zone, it gives no information on the irrigation system's precipitation rate. In a 2-year study in Florida, Miller et al (2005) found little change in the precipitation rates measured by catch cans despite using fewer catch cans in the second year of the study. Vinchesi et al. (2007) performed a study with 133 catch cans on a 3600 sq. ft. putting green. They systematically computed precipitation rates on subsets of the full data set. They found that cup configurations consisting of as few as 4 to 9 cups gave precipitation rates similar to that of all 133 cups. Cup placement and the output characteristics of the sprinklers play a role in the minimum number of cups necessary to calculate an accurate precipitation rate.

This paper looks at a comparison of soil moisture and catch can audits on three portions of a golf course fairway in selected high-, medium-, and low-traffic areas. Soil moisture measurements were taken at 3 depths. Subsets of the catch can data set were examined to identify the minimum number of catch cans necessary to calculate an accurate precipitation rate.

Materials and Methods

All data were taken on the 12th hole at the North Shore Country Club in Glenview, IL on July 14 and August 11, 2008. The fairway for hole twelve is composed of Bentgrass and Poa Annua on silty clay loam soil. Three fairway areas, identified by the assistant superintendent as low-, medium-, and high-traffic areas, were evaluated in the study. The fairway has single-row irrigation with a 65 ft. spacing between Toro Model 835 sprinkler heads equipped with 80 PSI pilot valves with nozzle pressures operating between 74 and 80 psi. A rectangular measurement area (figure 1) approximately 65 ft. by 90 ft. was laid out in each treatment.

The longer side is perpendicular to the direction of play. The main sprinklers for each treatment were located near the center of each of the longer sides of the measurement area. Additionally, on the high- and medium- traffic sites, there were 7 additional sprinklers that operated simultaneously

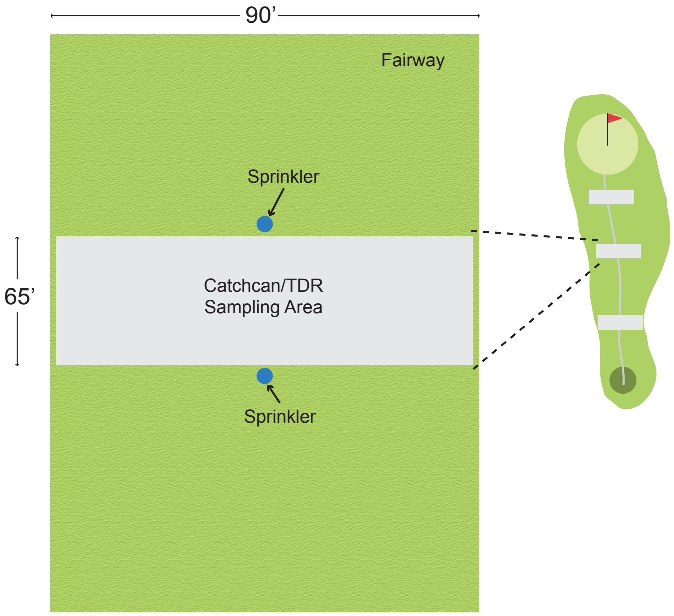

Figure 1. Diagram of sampling area within the fairway for hole 12.

with the fairway sprinklers and could potentially contribute water to the sampling area. Due to narrowing of the fairway near the green, the high-traffic area had only 6 additional sprinklers. Within each sampling area, 81 nails were used to mark out a 9 x 9 grid pattern. Catchments were placed 11 and 8 feet apart in the long and short direction respectively. A small plastic bowl (d = 5.9 inches) was placed at each nail (figure 2). Volumetric water content (VWC) readings were taken with a TDR300 soil moisture probe (Spectrum Technologies, Plainfield, IL) at each grid point (figure 3).

Figure 2. Catch cans laid out in 9 x 9 grid pattern.

Figure 3. Sampling soil moisture with TDR300.

In July, data sets were collected with 1.5, 3, and 4.8 inch rods connected to the meter. In August, only the 4.8 inch rods were used. Soil moisture data was geo-referenced with a Garmin 72 (Garmin International, Olathe, KS) connected to the TDR300. After the soil moisture data was collected for each treatment, the irrigation system was run in that zone for 12 minutes (figure 4).

Figure 4. Irrigating the sample area.

Wind speed was recorded with a hand held anemometer during each irrigation event. The volume of water captured by each bowl was measured after irrigation. The TDR300 measurements were then repeated at each site approximately 1 – 2 hours after the irrigation.

The lower quartile distribution uniformity (DU_{lq}) was calculated for both the soil moisture and catch can data sets. Visual assessment of spatial variability was done using 2-dimensional color plots of soil moisture and catch can data created using the SpecMaps ProTurf mapping utility (Spectrum Technologies, Plainfield, IL). Precipitation rates were calculated using the 81 catchments and pre-selected subsets (Appendix 2). The number of cups in each subset ranged from 4 cups to 41 cups. These subset precipitation rates were then compared to the precipitation rate estimated by the full data set to identify the minimum number of cups necessary to estimate an accurate precipitation rate.

Results and Discussion

Distribution Uniformity

In the weeks preceding data collection, northern Illinois received above-average rainfall. In the Chicago area, 1.85 inches fell from July 6 to July 13 and 2.43 inches from August 3 to August 10 (National Weather Service data for O'Hare International Airport). Additionally, prior to the August sampling date, the irrigation system had been run over the weekend. Therefore, the soil profile was fairly saturated at sampling time. This has likely contributed to somewhat higher soil moisture uniformity data than might otherwise have been recorded in a dry season. However, under normal management practices, the fairway would be receiving regular water applications so the data represent realistic conditions.

Table 2. Summary of lower quartile distribution uniformity (DU_{lq}) calculations.

Date	Traffic Level	CC	Audit Type 5Pre	5Post	3Pre	3Post	1.5Pre	1.5Post	Wind speed (mph)
July 14	High	*62*	92	88	89	86	90	88	5
	Medium	*78*	87	87	88	85	89	86	5
	Low	*65*	83	84	83	83	85	84	2
August 11	High	*76*	89	88	-	-	-	-	4
	Medium	*66*	84	83	-	-	-	-	6
	Low	*70*	81	81	-	-	-	-	2

CC, results from catch-can audit; Pre, data taken prior to irrigation; Post, data taken following irrigation; Numbers in Audit Type columns (5, 3, 1.5) refer to data from TDR300 connected to 4.8", 3", and 1.5" rods respectively.

The results of the lower quartile distribution uniformity (DU_{lq}) calculations are summarized in table 2. Distribution uniformity for the catch cans is always lower than that calculated from the soil moisture data. The wind speeds for the high- and medium- maintenance sites were a bit high but within the maximum threshold of 8 mph recommended by the Irrigation Association. So, wind alone does not account for the differences in uniformity. One or two cups near the sprinklers on the high- and low-maintenance sites tipped and spilled on each sampling date. But, considering the large number of cups involved in this study, this will have a minimal effect on the DU_{lq} computation. Lower half distribution uniformity, DU_{lh}, was also calculated and compared to DU_{lq}. A linear regression of these two parameters yields a relationship between the two as $DU_{lh} = 0.663\ DU_{lq} + 34.5$ which compares well with the equation given by the Irrigation Association, $DU_{lh} = 0.6143\ DU_{lq} + 38.6$.

The soil moisture uniformities are all very high. There is no difference between the uniformity seen before and after the irrigation system is run. This could be due to the fact that the initial soil moisture content was already very high. Consequently, the additional water added by the irrigation did not redistribute as much as it would in a drier soil profile. The expectation would be that the uniformity would increase as moisture is sampled deeper in the profile. This is because the near-surface soil moisture will evaporate at a faster rate and reveal the spatial variability in soil moisture. However, there is no difference or trend seen in the uniformities at the different sampling depths. Again, high soil moisture contents could be masking this effect.

There is a trend for soil moisture DU_{lq} to increase with increasing traffic level. A possible explanation could be that, as traffic increases, the likelihood of the traffic being more evenly spread across the site increases as well. Factors such as compaction and turf wear that impact the infiltration of water will be more evenly spread as well. These differences translate to greater uniformity in soil moisture content.

<u>Map Analysis</u>

Appendix 1 shows 2-dimensional maps of each soil moisture and catch-can data set. The overall pattern of soil moisture variability is very similar across sampling date, sampling depth, and for the pre- and post-irrigation sampling. For each sampling date, a uniform data range is used for all the maps. This allows for easier discernment of differences in location and sampling depth. The patterns can be summarized as follows:

-High Traffic - Wet in the southeast corner, dry in the southwest corner, dry in the north central portion.
-Medium Traffic - Wet in the south and north central portions (near the sprinkler heads). Dry in the east and west central sections.
-Low Traffic - Wet in the southern section. Dry in the northwest and north central portions.

As expected, there is a slight increase in the overall soil moisture content after the irrigation cycle. Therefore, the wetter areas in the post-irrigation maps have a darker blue color than the corresponding pre-irrigation map. There are no visible similarities between the distribution pattern in the soil maps for a given sampling site, and the map of catch can data. For example, comparing the catch can and soil moisture maps for the high traffic area for July shows that the southern part of the maps are opposite one another. The soil moisture maps show it wet in the southeast and wet in the south east. The catch can map is opposite this. This could be related to surface runoff from rain events such that the soil moisture map is evidencing the slope characteristics of this part of the fairway. For the medium- and low-traffic areas, there are noticeable bands of soil moisture that could also indicate variation in slope. These bands are more discernible in the data from the 4.8” rods where the overall range in soil moisture values is smaller.

Precipitation Rate

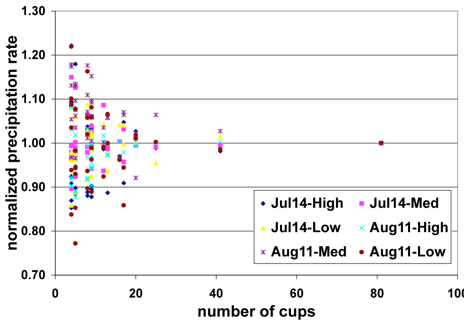

Figure 5. Normalized precip rates as function of number of cups.

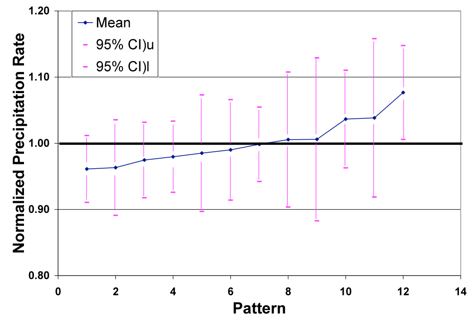

Figure 6. Mean precip rates for 4/5 cup combinations (by pattern).

Although the portable soil moisture measurements can be used to measure and evaluate the uniformity of the fairway, they can not be used for determining the precipitation rate. The precipitation rate and uniformity are both necessary for computing the run-time for the irrigation system. So, catch cans will still need to be part of the audit process. But, the quantity necessary to compute a DU may not be necessary to get a reasonably accurate precipitation rate. In this study, more catch cans were used than would be practical for a typical audit. We calculated the precipitation rate for the full 81-cup data set. Then, following the work of Vinchesi et al. (2007), precipitation rates for a number of pre-selected subsets of the full set were calculated (Appendix 2). There were a total of 6 data sets (3 sampling sites x 2 sampling dates). The precipitation rates were normalized by dividing each subset precipitation rate by the 81-cup precipitation rate. This allowed all 6 data sets to be compared with each other. The data are summarized in Figure 5. It is evident that as the number of catch cans used to calculate precipitation rate is reduced, the greater the variability in the estimated precipitation rate. However, with even as many as 41 catch cans, the calculated value can over- or under-estimate the precipitation rate by 3%. Table 3 shows the normalized precipitation rates for 4 and 5 cup patterns. The means and corresponding 95% confidence intervals are plotted in figure 6. For certain patterns, the estimated precipitation rate is acceptably close to the 81-cup value. For this data set, the “4-square medium” gave the best estimate.

Table 3. Summary of precipitation rates calculated using pre-selected 4- and 5-cup subsets of the full 81-cup data set.

	July			August				
Pattern	Hi	Med	Low	Hi	Med	Low	Mean	StDev
5 Diamond Large	0.93	1.08	0.89	0.97	0.97	0.94	**0.96**	**0.06**
5 X-cross Small	0.88	0.98	0.96	0.89	1.13	0.93	**0.96**	**0.09**
5 X-cross Medium	0.95	0.99	0.98	1.02	1.06	0.85	**0.97**	**0.07**
5 X-cross Large	0.90	0.92	0.96	0.98	1.04	1.08	**0.98**	**0.07**
4-Square Small	0.85	0.96	0.96	0.92	1.17	1.04	**0.99**	**0.11**
4-Diamond Large	0.91	1.09	0.86	1.03	0.97	1.09	**0.99**	**0.09**
4-Square Medium	0.92	0.98	0.98	1.08	1.09	0.94	**1.00**	**0.07**
4-Square Large	0.87	0.90	0.96	1.03	1.05	1.22	**1.01**	**0.13**
5 Diamond Small	1.18	1.00	1.06	0.89	1.13	0.77	**1.01**	**0.15**
5 Diamond Medium	1.08	1.13	1.06	0.88	1.10	0.98	**1.04**	**0.09**
4-Diamond Small	1.22	0.99	1.08	0.92	1.18	0.84	**1.04**	**0.15**
4-Diamond Medium	1.09	1.15	1.08	0.90	1.13	1.10	**1.08**	**0.09**

Hi, Med, and Lo refer to data from the High-, Medium- and Low-Traffic areas respectively. Patterns are described in Appendix 2.

Conclusions

Our data, again, demonstrates that distribution uniformity calculated using soil moisture data is greater than for those calculated with catch can data. These results however may have been skewed by pre-existing soil moisture due to rainfall occurring between catch can evaluations. Additional evaluation in an arid location may provide more consistent data. Additionally creation of a DU_{lq} table (similar to Table 1) that correlates specifically to soil moisture data may need to be developed in order to rank acceptable distribution when measured by soil moisture data. The spatial pattern of soil moisture variability was not greatly influenced by the depth of sampling. However, the effect of depth may not have been evident because of the high pre-irrigation soil moisture levels. The pattern of spatial variability of SM did not vary significantly from one sampling time to the next and was not greatly affected by overall soil moisture content. This suggests that SM variability (and thus SMDU) is mainly a feature of permanent soil features such as texture, structure, and slope than application pattern. Precipitation rate can be estimated from as few as 4 or 5 cups on a site to expedite the audit data collection process. Placement of 9 or 10 cups, however, will be less vulnerable to the possibility of being placed in an unusually low or high application area.

Acknowledgements

The authors would like to thank Dan Dinelli and Matt Leinen from the North Shore Country club for their advice and assistance. We would also like to thank Cynthia Turski and Tom Ebeling for their help with data collection.

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Appendix 1: Spatial Variability Maps

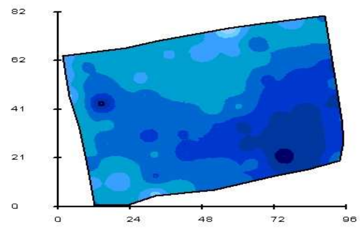
July 14 Data

VWC (%)		
30	to	34
34	to	38
38	to	42
42	to	46
46	to	50
50	to	54
54	to	58
58	to	62

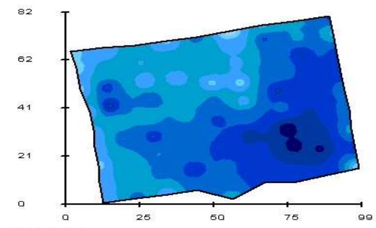
Legend for TDR data

Catch Can Volumes (inches)		
8	to	18
18	to	28
28	to	38
38	to	48
48	to	58
58	to	68
68	to	78
78	to	88

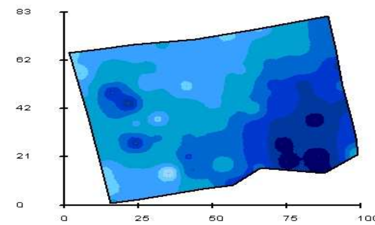
Legend for catch can data



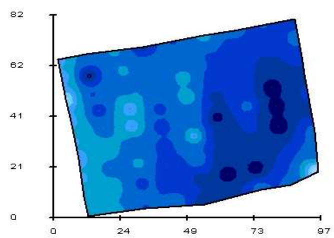
High Traffic area
1.5” rod length
Pre-Irrigation
DU= 90



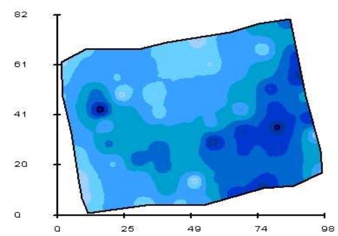
High Traffic area
1.5” rod length
Post-Irrigation
DU= 88



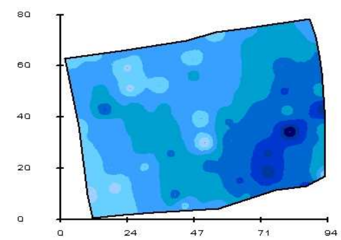
High Traffic area
3.0” rod length
Pre-Irrigation
DU= 89



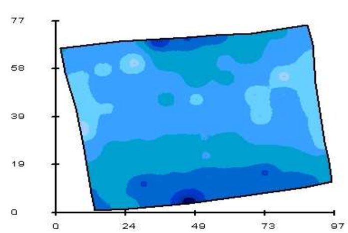
High Traffic area
3.0” rod length
Post-Irrigation
DU= 86



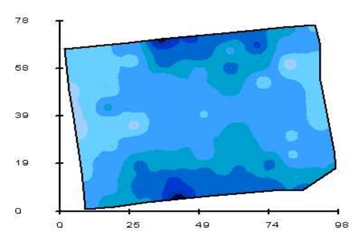
High Traffic area
5.0” rod length
Pre-Irrigation
DU= 92



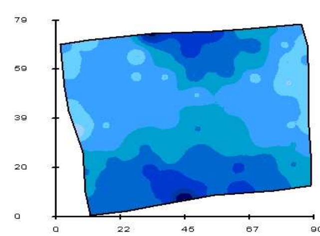
High Traffic area
5.0” rod length
Post-Irrigation
DU= 88



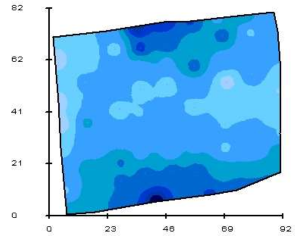
Medium Traffic area
1.5” rod length
Pre-Irrigation
DU= 89



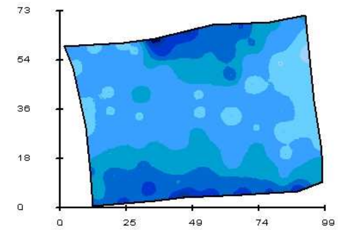
Medium Traffic area
1.5” rod length
Post-Irrigation
DU= 86



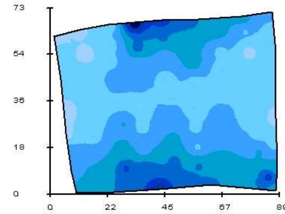
Medium Traffic area
3.0” rod length
Pre-Irrigation
DU= 88



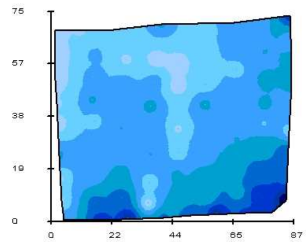
Medium Traffic area
3.0” rod length
Post-Irrigation
DU= 85



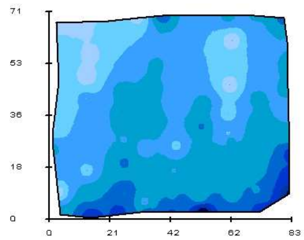
Medium Traffic area
5.0” rod length
Pre-Irrigation
DU= 87



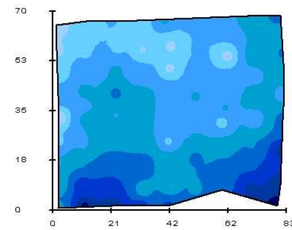
Medium Traffic area
5.0” rod length
Post-Irrigation
DU= 87



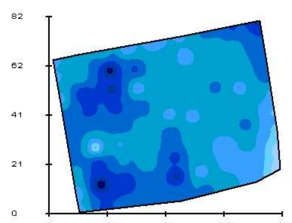
Low Traffic area
1.5” rod length
Pre-Irrigation
DU= 85



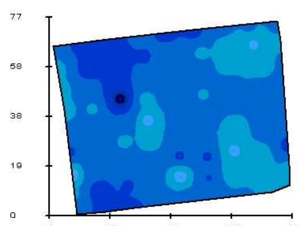
Low Traffic area
1.5” rod length
Post-Irrigation
DU= 84



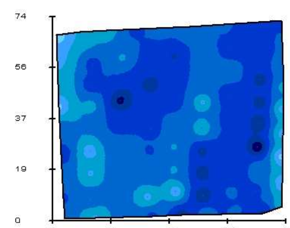
Low Traffic area
3.0” rod length
Pre-Irrigation
DU= 83



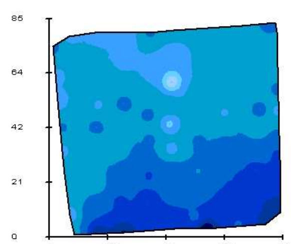
High Traffic area
Catch Can
DU= 62



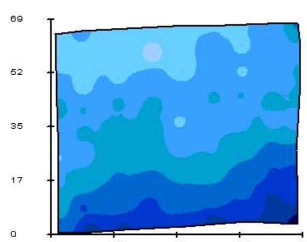
Medium Traffic area
Catch Can
DU= 78



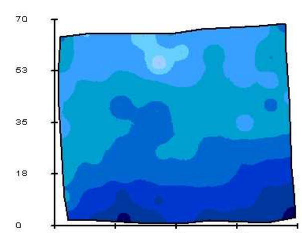
Low Traffic area
Catch Can
DU= 65



Low Traffic area
3.0” rod length
Post-Irrigation
DU= 83



Low Traffic area
5.0” rod length
Pre-Irrigation
DU= 83



Low Traffic area
5.0” rod length
Post-Irrigation
DU= 84

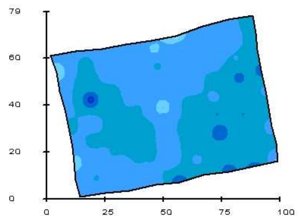
August 11 Data

VWC (%)			
	25	to	29
	29	to	33
	33	to	37
	37	to	41
	41	to	45
	45	to	49
	49	to	53
	53	to	57

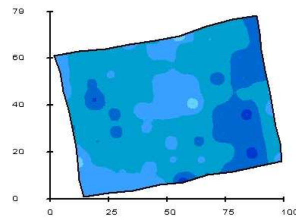
Legend for TDR data

Catch Can Volumes (inches)			
	27	to	35
	35	to	43
	43	to	51
	51	to	59
	59	to	67
	67	to	75
	75	to	83
	83	to	91

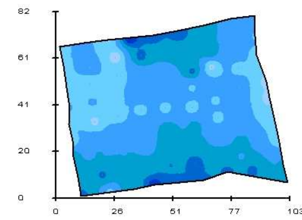
Legend for catch can data



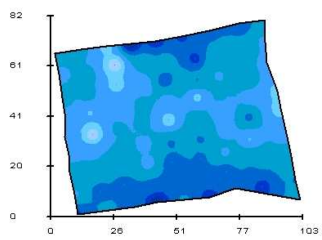
High Traffic area
5.0” rod length
Pre-Irrigation
DU= 89



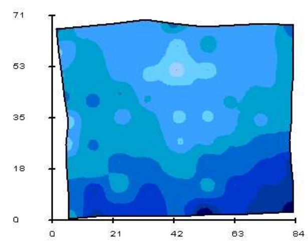
High Traffic area
5.0” rod length
Post-Irrigation
DU= 88



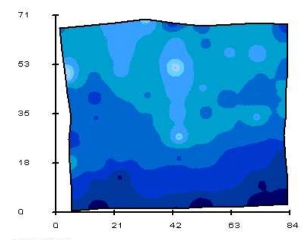
Medium Traffic area
5.0” rod length
Pre-Irrigation
DU= 84



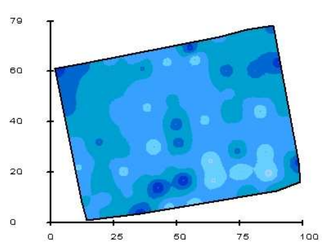
Medium Traffic area
5.0” rod length
Post-Irrigation
DU= 83



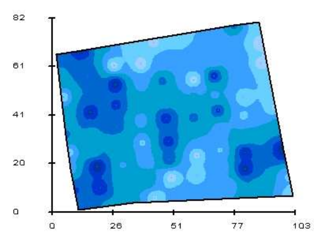
Low Traffic area
5.0” rod length
Pre-Irrigation
DU= 81



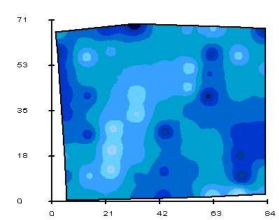
Low Traffic area
5.0” rod length
Post-Irrigation
DU= 81



High Traffic area
Catch Can
DU= 76

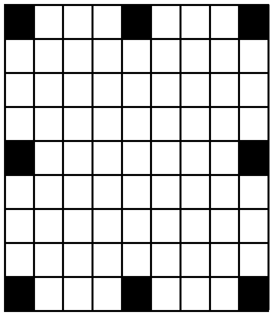


Medium Traffic area
Catch Can
DU= 66

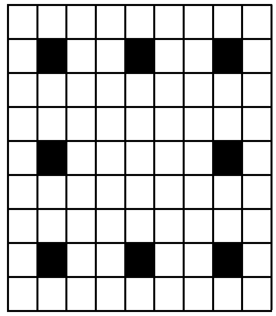


Low Traffic area
Catch Can
DU= 70

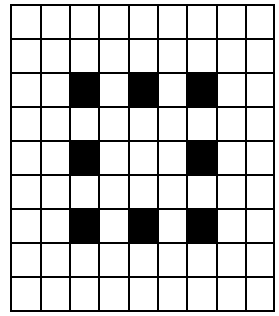
Appendix 2: Pre-selected cup configurations used in precipitation rate study



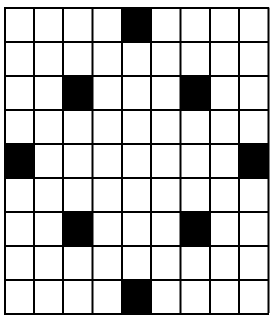
8 Square Large



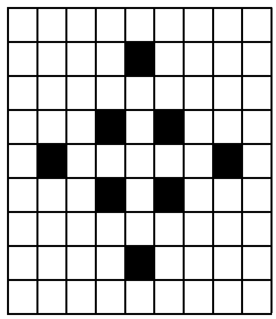
8 Square Medium



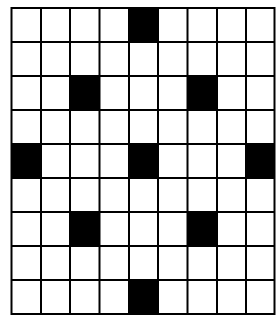
8 Square Small



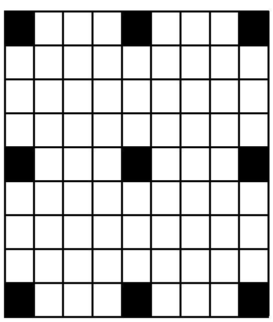
8 Diamond Large



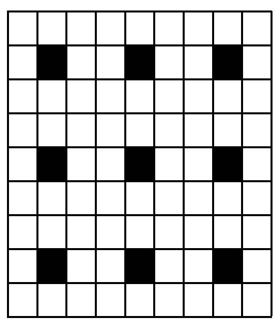
8 Diamond Medium



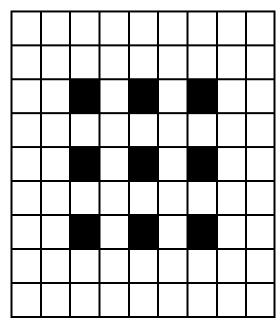
9 Diamond



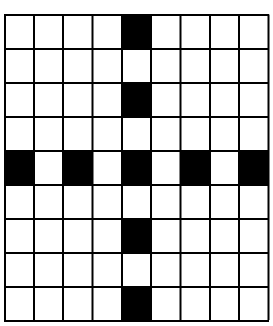
9 Square Large



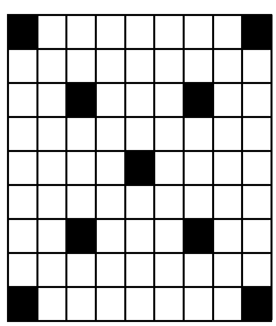
9 Square Medium



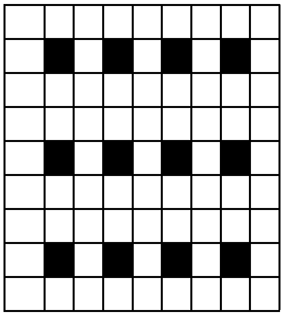
9 Square Small

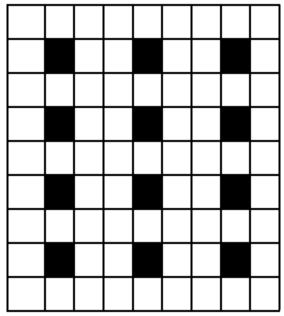


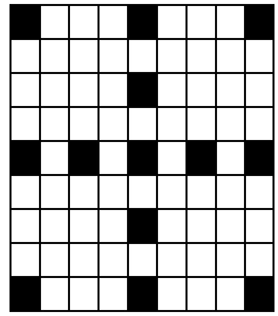
9 Diamond +-Cross

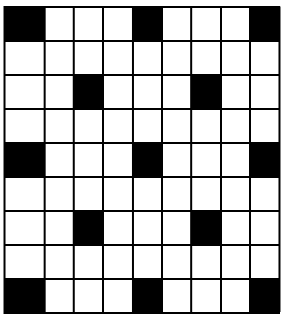


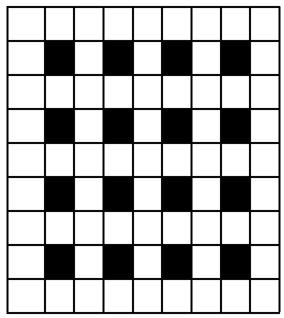
9 X-Cross

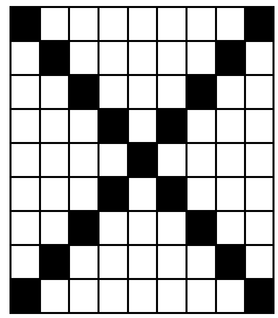

12 Square Horizontal

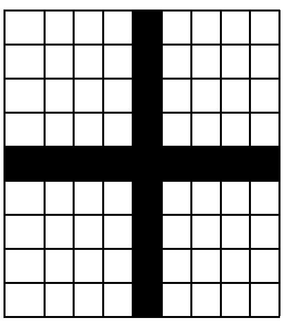

12 Square Vertical

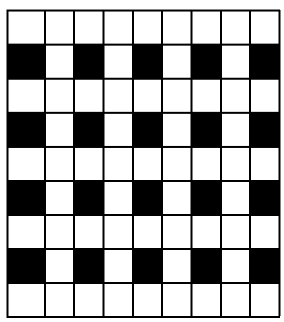

13 +-Cross/Corner

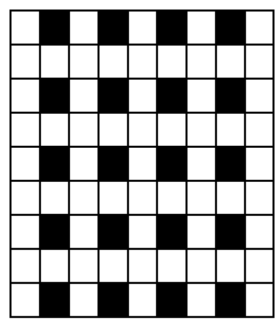

13 X-cross/middles

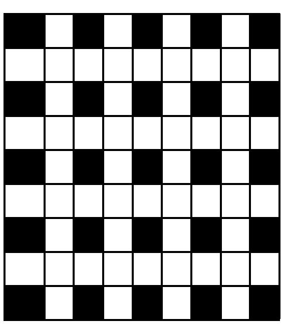

16 Square


17 X-cross


17 +-cross


20 horizontal


20 vertical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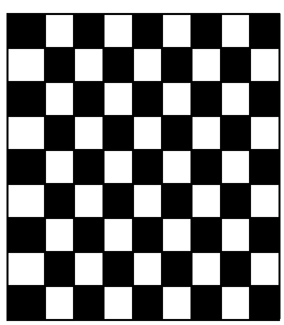
41