Effect of Rotary Nozzles and Cycle and Soak Scheduling on Landscape Irrigation Efficiency

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Introduction:
Efficient water use is mandated by the California state agencies and water districts, and many landscape professionals and home owners desire to use water efficiently to conserve natural resources. In addition, urban irrigation runoff is an environmental issue in the landscape industry.

A recent study by Municipal Water District of Orange County (Anonymous. 2004) showed a 49% reduction results in watershed runoff with the installation of ET controllers on residential sites. The city of Tustin and the Irvine Ranch Water District (Anonymous. 2004) installed a WICK irrigation system on a large street median, which virtually eliminated runoff that had previously occurred at the same site with sprinkler irrigation.

The city of Tustin and the Irvine Ranch Water District (2002-03) installed a WICK irrigation system on a large street median, which virtually eliminated runoff that had previously occurred at the same site with sprinkler irrigation (www.irwd.gov 2004) The research we are proposing would complement current work.

A study (Vis, 2006) reported both surface runoff and runoff due to wind drift on turf plots with 8% slope irrigated by rotary sprinklers on 50 x 50 spacing, and sprinkler precipitation rate near one inch per hour. Approximately twice the required irrigation water requirement was applied because of the runoff data needed for the study. Under these conditions up to 9.5% of the applied water became runoff at the lower end of the plot. Surface runoff, if the irrigation runtime had been correct, was estimated at less than 0.2% of applied water. However, runoff due to wind drift under correct irrigation scheduling and moderate wind conditions (less 5 mph) was a significant volume of water. This study showed that for the given soil, slope, and wind conditions, irrigation scheduling could minimize most surface flow off the site, but that up to 3.3% applied water could become wind overspray and in this case become runoff at the low end of the slope.

The potential for runoff can be reduced by two factors. The first factor is to apply less water, which is possible when distribution uniformity is improved. The second is use a sprinkler with a lower precipitation rate, or use a cycle and soak irrigation schedule to apply water at rates less than soil intake rates.

Rotary nozzles as replacement for spray nozzles are relatively recent on the market and most published data are on distribution uniformity and precipitation rates. Published data suggest rotary nozzles have higher distribution uniformity than traditional spray nozzles which may improve irrigation efficiency. Rotary nozzles have precipitation rates less than half that of spray nozzles which may also reduce runoff from slopes.

Kissinger (2005) reports that 22% less water can be applied by the rotary nozzles than with spray nozzles. In the 2007 report (Vis, 2007) Irrigation scheduling based on the soil moisture DU_{LH} would apply about 17% less water than using the catch can DU_{LQ}.

Distribution uniformity as measured by the low quarter distribution (DU_{LQ}) is a common measurement to determine performance of installed systems. This distribution uniformity is determined by the following:

$$DU_{LQ} = \frac{V_{LQ}}{V_{avg}}$$

where: V_{LQ} = average of the lowest one fourth of catch cans measurements, ml

V_{avg} = average all catch cans, ml.

One approach to the calculation of runtime for an irrigation schedule is to use a runtime multiplier (RTM) to calculate the irrigation water requirement (IWR). Where:

$$RTM = \frac{100}{DU_{LQ}}$$

and:

$$IWR = RTM \; x \; PWR$$

where:

PWR = Plant water requirement

According to Irrigation Association's recommended BMPs "the base run time may need to be divided into multiple cycles with soak time between the cycles". They recommend two ways of determining number of cycle starts 1) Observation method and 2) basic intake rate method. According to Observation method, one observes the time it takes to start runoff at a zone and this becomes the maximum time that zone should be run at a time. The base run time will dictate the number of cycles needed. This is a preferred method when an irrigation zone involves slopes. Soak time is similarly determined by "observation" only.

Basic intake rate method is recommended to be used on relatively flat areas. According to this method divide the Basic Soil intake rate (Table 2-1) by sprinkler precipitation rate and multiply by 60. This gives the maximum run time for a cycle in that zone. This guideline is applicable when the sprinkler precipitation rate is more than Basic Soil intake rate. Soak time in minutes for relatively flat areas is calculated by taking 60 minus the cycle run time.

Table 1. Basic soil intake rates from Irrigation Association publication.

Table 2-1
Basic Soil Intake Rate[a]

Soil Texture Class	Basic Intake Rate[a] (in./hour)
Clay	0.10
Silty Clay	0.15
Clay Loam	0.20
Loam	0.35
Sandy Loam	0.40
Loamy Sand	0.50
Sand	0.60

[a]The basic intake rate is for relatively flat landscapes only.

We propose to study the effectiveness of new rotary nozzles and proper irrigation scheduling to improve irrigation efficiency and reduce potential runoff. Improved irrigation efficiency can be achieved through higher sprinkler distribution uniformity. Each set of tests will be described in the following sections.

Turf Plot Descriptions with Conventional Popup Sprinklers with Spray Nozzles
Methods and Procedures:
There are four turf plots for this project with sprinklers spray heads. Plot dimensions 20 feet by 5 feet. Native soil from the field was used to construct plots on 10% slope. Soil texture is sandy clay loam (58% sand, 18.4% silt, 23.6% silt). The 20 foot dimension of the plots was approximately 45 degrees from North. Runoff was collected from all plots during four irrigations in June 2007.

The sprinkler irrigated plots were designed and installed using traditional 6 inch popup spray heads with 5 foot nozzles (5° trajectory) on 5 foot by 5 foot spacing operated at 30 psi. Manufacturer rated precipitation rate for the sprinkler nozzles in this design was 1.58 inches per hour. The lower row of sprinkler heads was installed approximately 4 inches up the slope from the lower edge of the turf. Sprinklers at each corner of the rectangular plots had 90° arc nozzles, and 3 sprinklers at 5 foot intervals along the 20 foot side had 180° arc nozzles. A-G Elite sod from A-G Sod Farms, Inc was installed.

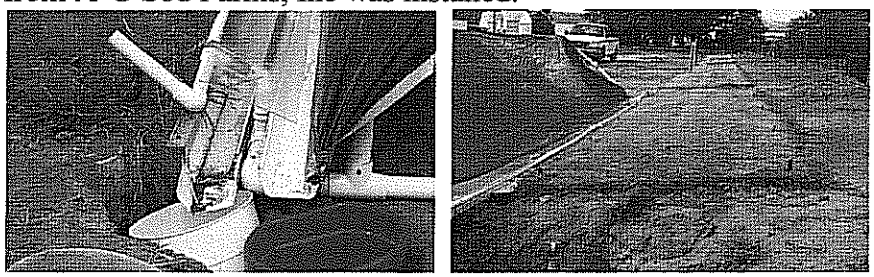

Figure 1. Left is runoff collection system for surface wind drift and right picture shows 5 by 20 foot plots and wind overspray collection barrier.

The volumetric moisture content was measured with a TDR with 4.8 inch probes as means to monitor surface moisture and maintain similar conditions for all plots. The moisture contents were based on 3 reading per plot , one reading 0.5 feet up from the lower end of the slope, the

second was 2.5 feet up the slope, and the last one 4.5 feet (0.5 feet from the top of the slope) up the slope.

Runoff from the sprinkler plots was collected in two components, surface runoff and wind drift runoff. All runoff was collected at the lower end of the plots only (Figure 1)

The plastic barrier directed any wind drift into one collection trough. Surface runoff from each plot was collected in a second trough at the lower edge of the plot. Both troughs drained into containers for runoff volume measurements. Turf was mowed one day before irrigation events.

Results and Discussion

Runoff collected after each irrigation event is shown in Table 2 for both irrigation treatments on four dates. The collected runoff was a combination of surface flow and wind drift for the sprinkler plots. Sprinkler plots had some overspray on the sides and top of the rectangular plots that was not collected in this experiment. .

Runoff as a percentage of applied water is important for using test data and projecting potential runoff from a larger site with irrigation systems operated under similar conditions. Runoff from the sprinkler plots ranged from 3.9 – 4.5% of the applied water (Table 2).

Average hourly wind speed was obtained from a CIMIS weather station (height 2 meters) approximately 0.25 mile from the site. Average hourly wind speeds ranged from 2.9 to 6.5 mph with a mean of 4.6 mph. Instantaneous wind speed measured at the site with an anemometer approximately 1 foot above grade had mean values of 2.2 mph. Wind direction was generally 45 degrees toward the runoff collection device at the lower end of the plots.

The sprinklers for the sprinkler irrigated plots were new, head to head spacing, new nozzles, and no turf interfering with nozzle spray. Therefore, volume of runoff is probably the minimum expected for these general irrigation conditions.

Table 3 reports the sprinkler runoff in two components of surface runoff and overspray. The mean wind speeds of 2.2 mph were moderate, but accounted for 76 – 83% of total runoff for experiment. Surface runoff was 17 – 24% of total collected runoff; this runoff potentially could be reduced or eliminated by cycle and soak irrigation scheduling or extending the irrigation interval. Runoff due to wind may be more difficult to reduce since the time of irrigation with respect to wind is normally not controlled.

Table 2. Runoff as percentage of applied water.

	Sprinkler Spray Nozzles		
Date	Surface Runoff	Overspray Runoff	Total Collected Runoff
6/1/2007	0.9	3.1	4.0
6/5/2007	1.1	3.4	4.5
6/8/2007	0.7	3.2	3.9
6/12/2007	0.7	3.5	4.2

Table 3 Surface runoff and overspray components of runoff from sprinkler plots.

	Sprinkler Spray Nozzles		
Date	Surface Runoff, %	Overspray Runoff,%	Total Collected Runoff,%
6/1/2007	23.6	76.4	100.0
6/5/2007	24.3	75.7	100.0
6/8/2007	18.0	82.0	100.0
6/12/2007	17.4	82.6	100.0

Surface Runoff with Cycle and Soak Schedules for Sprinklers with Spray Nozzles
Methods and Procedures:

There is the question whether surface runoff for sprinklers with spray nozzles can be reduced with cycle and soak programming of the irrigation runtime? The results of one test run of each sprinkler plot in reported in Table 4. Surface runoff with no cycle and soak was more than two times higher than any of cycle and soak irrigations. Therefore further testing seemed warranted since cycle and soak is commonly recommended for irrigation on soils with low infiltration rates.

The second series of tests was conducted with runtimes and soak times as shown in Table 5. The sprinklers were 6 inch popups with 10 foot spray nozzles on head to head spacing for 10 by 20 foot plots. Each cycle and soak schedule was run four times, once on each of the 4 plots.

Table 4. Surface runoff from sprinkler plots

Plot #				4	8	6	2
				Surface Runoff, Liters			
	Total Runtime	Cycle Runtime	Cycle Soak time	24-Jul	30-Jul	30-Jul	30-Jul
Irrigation Cycles	min.	min.	min.	1	2	3	4
1	20	20		3.5	1.2	0.15	0.41
2	20	10	30		0.24	0.61	0.82
3	20	6.7	30			0.11	0.2
4	20	5	30				0.21
Total				**3.5**	**1.44**	**0.87**	**1.64**

Results and Discussion:
The water collected was surface runoff from the 10% slope and any overspray that landed in the 5 inch wide trough at the lower end of the plots. Overspray due to wind drift was not collected during this test. Surface runoff as percentage of applied water ranged from 0.39 to 0.54% (Table 5). One reason there was more runoff for 4 irrigation cycles than for 3 and 2 irrigation cycles may be due to "blow-by" each time the pop-up sprinkler stem is extended or retracted. That water could increase the runoff in areas where sprinklers are closely spaced and near the curb.

Table 5. Surface runoff with cycle and soak schedules for sprinklers with spray nozzles.

Number of Cycles	Cycle Runtime	Soak Time Between Irrigation Cycles	Total Runtime	Runoff	Runoff
	min	min	min	liters	% of Applied Water
1	20	0	20	1.28	0.54
2	10	50	20	0.96	0.40
3	7	53	20	1.13	0.48
4	5	55	20	0.92	0.39

Surface Runoff Comparisons between Spray and Rotary Nozzles
Methods and Procedures:
The same four plots were used in this phase of the study. Six inch popup sprinklers in two plots had spray nozzles and two plots had sprinklers with rotary multi-stream nozzles, all on 30 psi PRS heads. Catch can tests were conducted to determine the distribution uniformity and precipitation rate. Irrigation runtimes were calculated for the soil type, 4 inch root zone, 40% management allowable depletion, and DU_{lh} to determine runtimes of 20 minutes for the spray heads and 27 minutes for rotary nozzles. Runoff was collected in a 5 inch trough at the lower end on the 10% slope. Data was collected for10 irrigations over approximately 2 months.

Results and Discussion
The results for the 10 irrigations showed that runoff was about the same for both spray and rotary nozzles; 0.27% for spray nozzles and 0.29% for rotary nozzles. This result show that the irrigation with proper runtimes caused only minimal surface runoff

Comparison of Cycle and Soak with One, Two, and Three Cycle and Soak Irrigations.
Methods and Procedures:
One modification was made for the rotary sprinkler nozzles replacing the 30 psi PRS with the manufacturer 40 psi PRS. A catch can test was again run and a new irrigation run times of 17 minutes for rotary and 25 minutes for the spray nozzles was determined based on the new DU_{lh} Visual observations to determine the beginning of surface runoff showed no runoff for rotary nozzles and nine minutes for the beginning of runoff for the spray nozzles. The length of cycle runtimes for two and three cycles was based on these initial observations.

Results and Discussion:
The data for 9/8/2008 (Table 6) includes surface water collected and overspray in a 5 inch trough on end of the slope. In this case there was runoff water of 0.12 – 0.42% of applied water for the four plots. These irrigations excluded the airborne water, only surface runoff was collected (Figure 2). Under these conditions only the spray nozzles had surface runoff; the rotary nozzles had no runoff. When the irrigation was scheduled with two and three cycles there was no surface runoff for the spray nozzles.

Table 6. Surface runoff from 4 plots as percent of applied water for one, two and three cycle and soak irrigations

Date		Rotary	Spray	Rotary	Spray	Tests Description
9/8/2008	Runoff, % applied	0.37	0.12	0.42	0.40	Surface runoff and wind drift landing 5 inch past lower edge. One cycle for irrigation runtime
9/10/2008	Runoff, % applied	0	0.13	0	0.17	Surface runoff only. One cycle for irrigation runtime
9/12/2008	Runoff, % applied	n/a	0	n/a	0	Surface runoff only 2 cycles for irrigation runtime
9/15/2008	Runoff, % applied	n/a	0	n/a	0	Surface runoff only 3 cycles for irrigation runtime

Comparison of potential runoff with spray and rotary nozzles after arc and radii adjustment.
Methods and Procedures:
This part of the study was initiated to determine if additional adjustment of the arc and radius of the sprinkler nozzles to minimize overspray would decrease runoff. Rotary nozzles had adjustable arcs and radii while the spray nozzles had fixed arcs and adjustable radii. After adjustments there was some overspray visible but it was best we could do under these field conditions. There were two plots for each type of nozzle. DU_{lh} was used for scheduling purposes. Water was collected by plastic covered panels surrounding the 10 by 20 foot plots. Surface runoff was also collected at the lower end of each sloped plot (Figure 3).

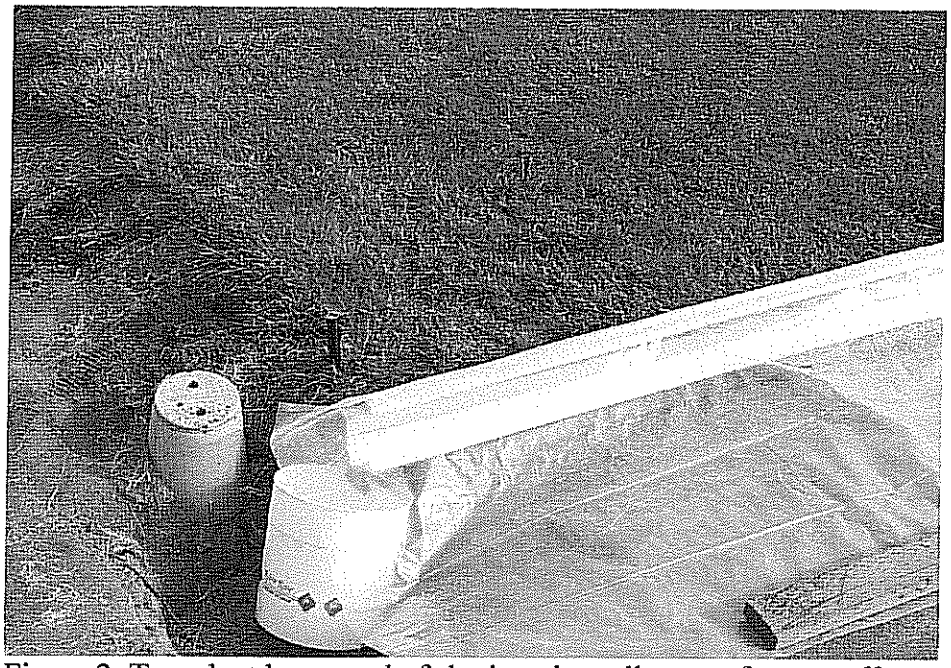

Figure 2. Trough at lower end of sloping plot collects surface runoff.

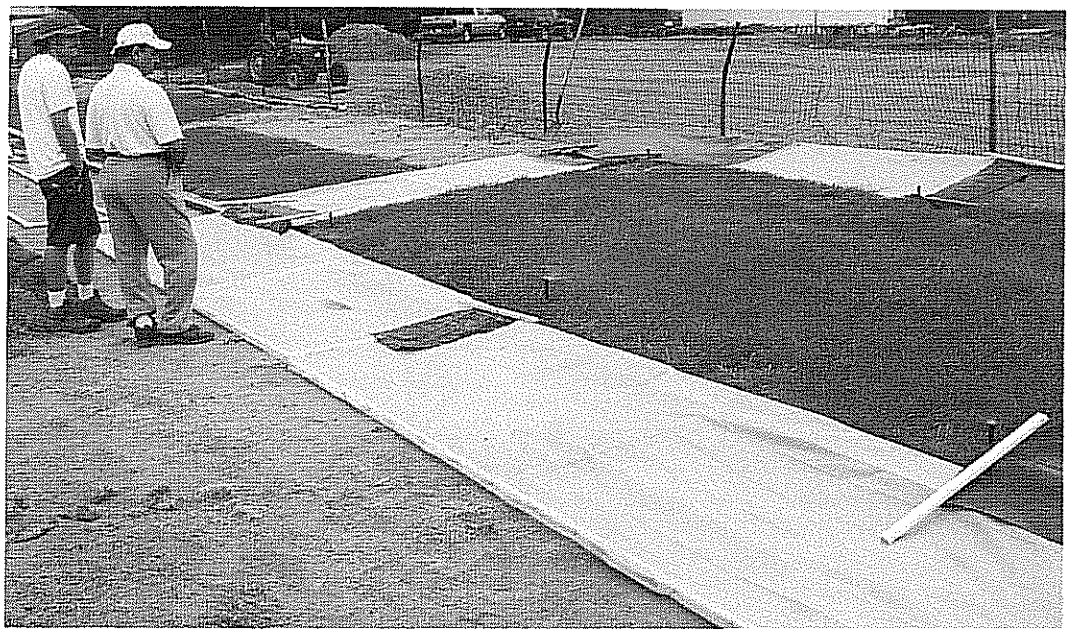

Figure 3. Panels surround plot to collect wind drift.

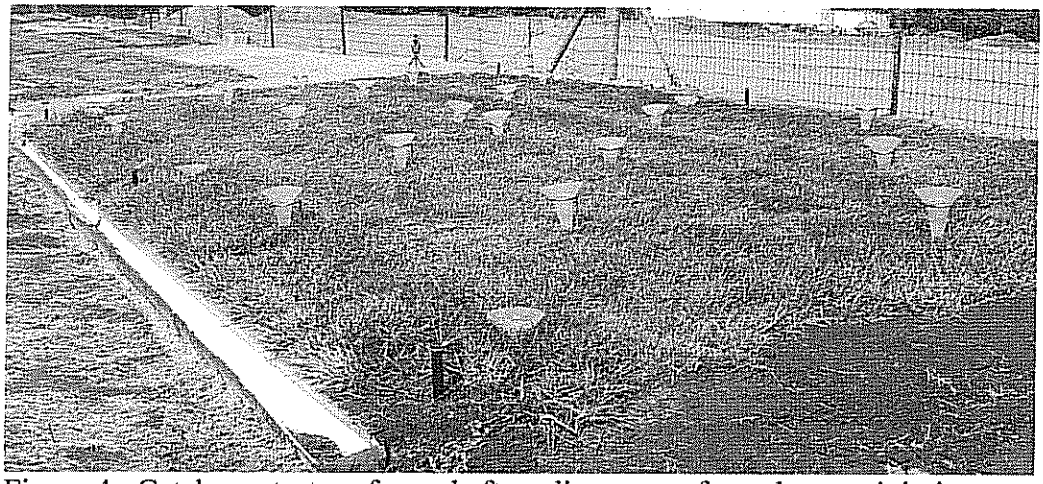

Figure 4. Catch can test performed after adjustment of nozzles to minimize overspray.

Results:

Catch can tests performed on each plot after nozzle adjustment showed DU_{lq} decreased from 38 to 35%for the spray nozzles and 68% to 60% for the rotary nozzles. Total runoff was 6.3% of applied water for plots with spray nozzles and 1.0% for the rotary nozzles (Table 8). Wind drift was the cause of nearly 99% of the runoff in both cases. The irrigation runtime based on DU_{lh} and precipitation rate based on catch can data again resulted in very minimal surface runoff. The total runoff as percent of applied water followed the same pattern as the previous tests where rotary nozzles had less runoff than the spray nozzles.

Table 7. Wind drift, surface runoff and total runoff for sprinklers with spray and rotary nozzles adjusted for minimal overspray in low wind conditions.

Nozzle	Runtime	Wind Drift	Surface Runoff	Total Runoff	Total Runoff % of Applied	Wind Drift % of Runoff	Range of Wind Speeds	Wind Speed Average
Type	min	gal	gal	gal	%	%	mph	mph
Spray	19	3.66	0.02	3.68	6.3	99.4	0 - 4	2
Rotary	30	0.43	0.01	0.44	1.0	98.8	0 - 3	1.5

Turf Quality

The turf quality for the plots was acceptable for the previous tests. For this test the turf was monitored after the nozzles adjustments. Turf quality decreased with noticeable brown spots on the plots with the rotary sprinklers between heads on the upper row of sprinklers (Figures 4 & 5). These sprinklers were spaced about 9.5 feet apart on the 10 by 20 foot plots. The decrease in turf quality suggests that the nozzle adjustments were to severe for the irrigation schedule used.

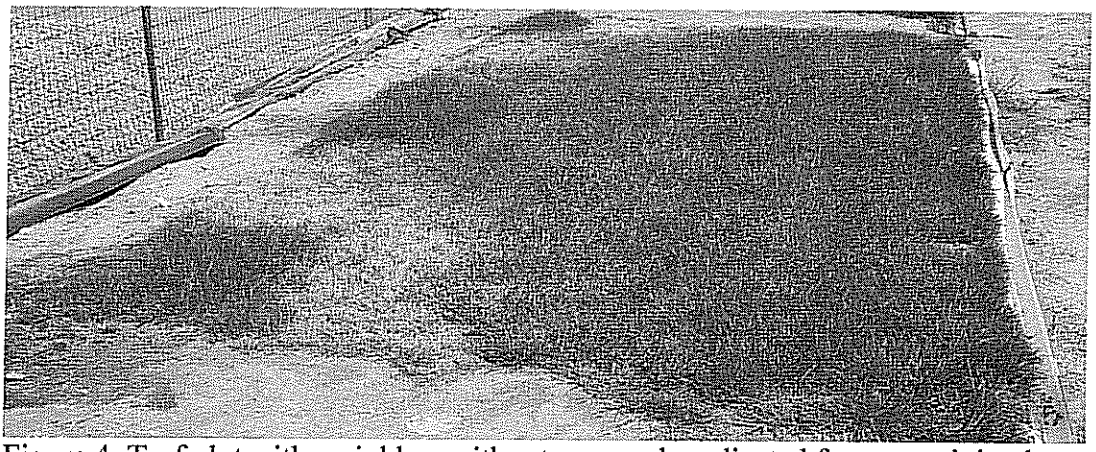

Figure 4. Turf plot with sprinklers with rotary nozzles adjusted for very minimal overspray.

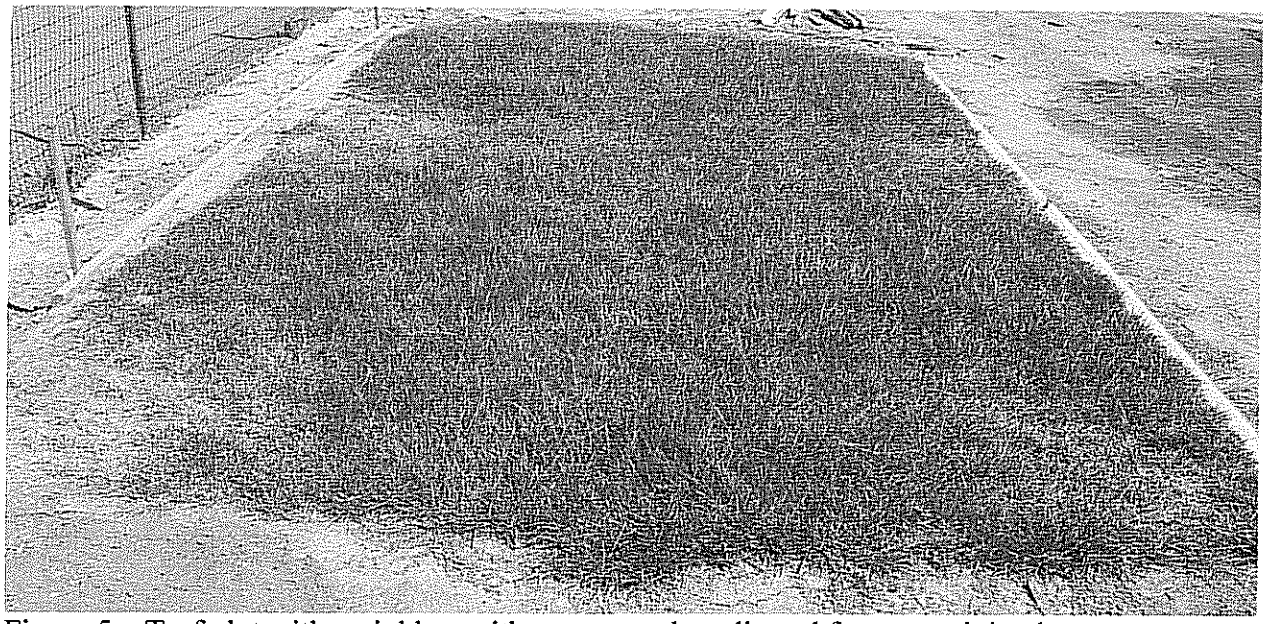

Figure 5. Turf plot with sprinklers with spray nozzles adjusted for very minimal overspray.

Summary

- Sprinklers with spray nozzles had 3.9 to 4.5% of applied water became runoff surface runoff. Seventeen to twenty four percent of the runoff water can be minimized by proper irrigation scheduling.
- Runoff due to wind drift, 76 – 83 % of total runoff, is difficult to reduce with current spray nozzles and controller technologies.
- Total wind drift collected from all sides of plot ranged from 2.4 to 7.9 of applied water for spray nozzles.
- Total wind drift collected from all sides of plot ranged from 0.8 to 2.7 of applied water for rotary multi-stream nozzles.

General Conclusions:

Rotary multi-stream-nozzles may result in less wind drift than spray nozzles on narrow areas. Runoff due to wind drift was in the range of 75-83% of total runoff and total runoff ranged from 3.9 – 4.5% of applied water under the tests conditions. Proper irrigation scheduling can result in minimal surface runoff with a 10% slope. Wind appears to be the major cause of runoff even under moderate wind conditions of 0-5 mph.

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