Measuring Irrigation Uniformity in Bareroot Nurseries: A Case Study

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Abstract

A cup test was conducted to measure irrigation uniformity in a bareroot nursery field on a semipermanent, solid-set irrigation system with lateral irrigation lines 60 ft (18.3 m) apart and 60 ft (18.3 m) between sprinklers in the lines, with sprinklers arranged in a triangular pattern. Irrigation uniformity was good in the middle of the field, with Christian's Coefficient of Uniformity (CU) of 86 percent, and the irrigation precipitation rate was 0.29 in per hr (0.74 cm per hr). Uniformity was considerably lower at the south end of the field (CU = 69 percent), mainly because of a different sprinkler layout designed to compensate for prevailing south and west winds. Precipitation rate at the end of the field was 150 percent more (0.43 in per hr [1.1 cm per hr]) than the interior of the field. Matching precipitation rates on sprinklers at the end of the field may reduce the higher precipitation rate, although the uneven spacing of sprinklers in the area will still reduce uniformity. Other irrigation management factors are discussed in relation to the soil conditions in the field and the results of the irrigation uniformity test.

Introduction

Irrigation uniformity is a key factor in producing high-quality nursery stock. Uniform irrigation allows for better control of seedling growth, more efficient use of fertilizer and other agricultural chemicals, and mitigation of water pollution by reducing runoff and leaching of nutrients and pesticides from nursery fields (Solomon 1990). Measuring irrigation system uniformity is one part of an irrigation audit, which is the process used to determine how effectively the system is applying water at a given point in time (Setson and Mecham 2011). Results of uniformity assessments include Christian's Coefficient of Uniformity (CU) and Lower Quarter Distribution Uniformity (DU_{LQ}) and also the precipitation rate for a particular group of sprinklers operating in the field at a point in time (Zoldoske et al. 1994). These measures are obtained by measuring the amount of water deposited into catch devices placed at specific intervals within the irrigated area. Information gathered during the assessment also helps determine the reasons for the uniformity numbers and can be used to make repair, maintenance, and scheduling decisions.

A number of papers have described methods for measuring and improving irrigation uniformity in forest and conservation nurseries (Shearer 1981, Scholtes 2001, Fernandez 2010). Few examples of results from actual tests conducted in bareroot nurseries, however, are available. This article presents the results of a uniformity test conducted at the Indiana Department of Natural Resources Vallonia State Nursery (Vallonia, IN) in July 2013. The purpose of the test was to characterize the uniformity of irrigation of a production field at the Vallonia Nursery and to examine the difference between the irrigation patterns over the main (interior) part of the field and the pattern at the south end of the field, where the sprinkler pattern was different from the main part of the field.

Methods

Tests were conducted in Vallonia Nursery's Block 3, Section 1, Units 1 and 2 on July 12, 2013. The soil in this field is a sandy loam.

Test Procedure

The four western lateral irrigation lines in the field (figure 1) were operating during the test. Each lateral line contained 11 impact sprinklers on ¾-in (19-mm) diameter risers 18 in (46 cm) in height. Lateral irrigation lines were 60 ft (18.3 m) apart, and sprinklers were 60 ft apart on the laterals (figure 2). Sprinklers were arranged in a triangular pattern, i.e., sprinklers on one lateral were offset 30 ft (9.1 m) from sprinklers on adjacent laterals. Offset sprinklers in adjacent laterals were 67.0 ft (20.4 m) apart. Lateral lines consisted of 3.0-in (7.6-cm) diameter aluminum tubing 30.0-ft (9.1-m) long connected with quick couplers.

Full-circle sprinkler heads were used on the risers in the middle of the field. On the south end of the field, a half-circle sprinkler was located at the end of each irrigation line where

Figure 1. Satellite imagery of test site showing location of irrigation lines (in red) operating during the test. (Source: "Vallonia Nursery" 38°48'06.99"N 86°05'30.91"W, Google Earth, April 4, 2013; accessed May 2014)

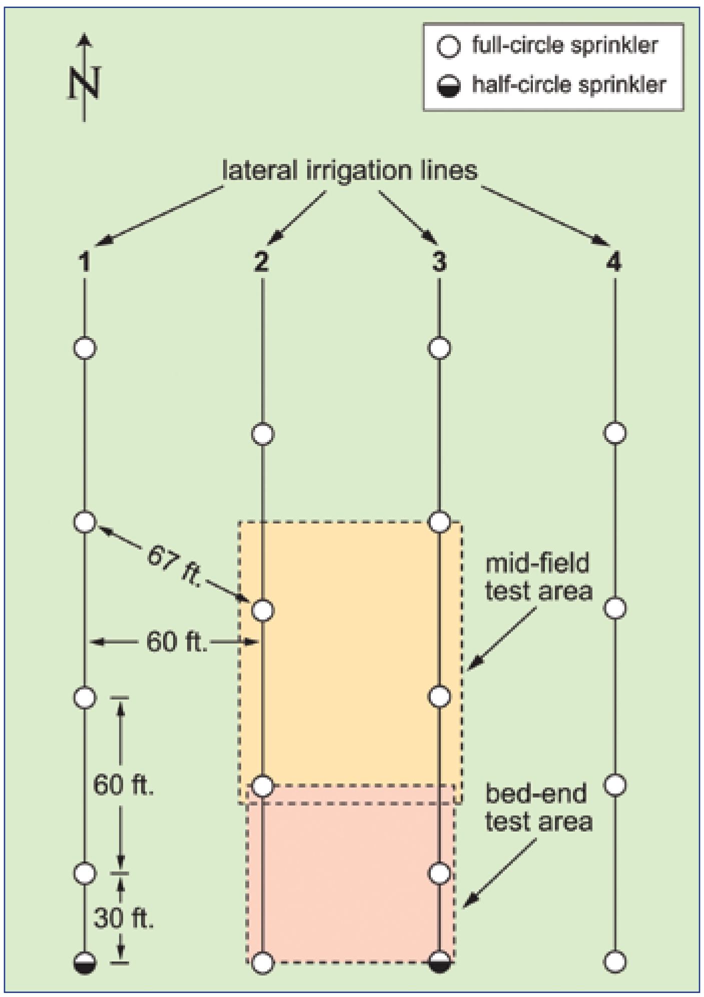

Figure 2. Diagram showing spacing of risers and sprinklers in test areas.

the first full-circle sprinkler was inset 30 ft (9.1 m) from the beginning of the field (figure 2). The purpose of these half-circle sprinklers was to provide more water at the end of the bed to compensate for the lower irrigation rates in these areas resulting from the prevailing south and west summer winds. The full-circle sprinkler heads were Rain Bird® Model 30WH with a 3/16-in (4.8-mm), straight-bore nozzle and a 1/8-in (3.2-mm), 20-degree spreader nozzle. The half-circle sprinklers were Rain Bird® Model 35A-TNT with a 3/16-in (4.8-mm), straight-bore nozzle. Manufacturer's performance data for these sprinklers are shown in tables 1 and 2.

Table 1. Performance data for Rainbird™ 30WH full circle impact sprinkler with a 3/16-in straight bore nozzle and a 1/8-in–20 degree spreader nozzle based on manufacturer's specifications.

Pressure at nozzle (psi)	Sprinkler throw radius (ft)	Flow rate (gpm)
50	50	10.4
55	50	10.9
60	51	11.4
65	51	11.8
70	52	12.3
75	52	12.7

Source: Rainbird (2014a)

Conversions: 100 psi = 6.9 bar; 10 ft = 3.05 m; 10 gpm = 2.27 m^3/hr

Table 2. Performance data for Rainbird™ 35A TNT full or part circle sprinkler.

Pressure at nozzle (psi)	Nozzle size (in)					
	5/32		11/64		3/16	
	Sprinkler radius (ft)	Flow rate (gpm)	Sprinkler radius (ft)	Flow rate (gpm)	Sprinkler radius (ft)	Flow rate (gpm)
50	45	5.0	47	6.0	49	7.2
55	45	5.2	48	6.3	50	7.5
60	46	5.4	48	6.6	51	7.8

Source: Rainbird (2014a)

Conversions: 100 psi = 6.9 bar; 10 ft = 3.05 m; 10 gpm = 2.27 m^3/hr

Collection cups were placed at a 5- by 5-ft (1.5- by 1.5-m) square spacing between the second and third riser lines from the west side of the field (figure 3), starting at the south end of the field and extending north to the fourth riser on the third lateral from the west side of the field (figure 2). A total of 403 cups were used in this test. The cups were 32 oz (0.95 L) round plastic paint-mixing cups with a top opening 4.5 in (11.3 cm) in diameter and 15.6 in^2 (100.6 cm^2) in area.

Figure 3. Cup layout and sprinkler operation during test. (Photo by Ronald Overton 2013)

Water pressure was measured at the first riser in the set by attaching a pressure gauge beneath the sprinkler (figure 4) and by measuring pressure in several sprinklers in each line with a pressure gauge attached to a pitot tube (figure 5). Water pressure at the first riser was 68 psi (4.7 bars) during the test, but fluctuated slightly (1 to 2 psi) (0.07 to 0.14 bars) as a second pump in the system cycled on and off. Pressures measured with the pitot tube gauge at other sprinklers in the set were slightly lower than that of the pressure gauge attached beneath the sprinkler but were within 2 to 3 psi (0.14 to 0.21 bars) of each other. Pressure measured at the end of the nozzle with a pitot tube should not be compared directly with pressure measured with a gauge just beneath the sprinkler, but it is important that pressure differences between sprinklers not vary more than 10 percent of operating pressure or irrigation uniformity will be affected (Irrigation Association 2010).

Figure 4. Measuring water pressure with a pressure gauge installed on a riser. (Photo by Ronald Overton 2014)

The water was turned on at 7:45 a.m. and applied for a total of 69 min. Winds were calm during the test.

Figure 5. Measuring water pressure with a pressure gauge attached to a pitot tube. (Photo by Ronald Overton 2013)

Measurements and Calculations

After the test was complete, the catch (volume of water) in each container was measured using a 250-ml graduated cylinder. Uniformity measures and precipitation rates were calculated for two separate areas of the field: a midfield area farther into the field where only the full-circle sprinklers were depositing water and a bed-end area where the half-circle sprinklers were located (figure 2). Using the cup collection data for the midfield area and bed-end areas (tables 3 and 4, respectively), the following values were calculated from these data using Microsoft Excel software:

1. The average cup catch.
2. The deviations of the individual cup catch from the average cup catch (individual cup catch minus average cup catch). These values for the midfield area are shown in table 5.
3. The absolute deviations of the individual cup catch from the average cup catch, which is calculated by dropping the minus sign from negative deviations in table 5.
4. The average of the absolute deviations of the individual cup catches.
5. The average of the lowest 25 percent of cup catches.

Table 3. Diagram showing position of cups and risers and amount collected (ml) in each cup for midfield area. Lowest 25 percent of cups (65 cups) highlighted in yellow or orange. The upper value (72 ml) of the lowest 25 percent of cups (shown in orange) was shared by 6 cups, 4 of which were included in the 65 cups used to calculate the average catch of the lowest 25 percent of cups. Position of riser = □.

Cup number						Cup line	North □						
	A	B	C	D	E	F	G	H	I	J	K	L	M	
1	97	92	85	82	76	70	64	79	89	96	76	90	93	□
2	98	93	86	86	82	76	68	76	84	92	64	80	96	
3	93	88	88	86	80	79	72	72	80	88	64	56	64	
4	89	88	84	86	82	78	72	70	78	82	74	60	59	
5	82	84	78	73	76	76	72	70	76	83	84	80	77	
6	80	86	70	68	70	76	76	78	78	87	90	90	90	
□7	78	60	58	65	64	66	77	80	80	87	92	104	102	
8	76	54	62	64	60	70	76	83	86	90	98	107	110	
9	50	52	60	59	60	70	76	84	88	92	102	116	113	
10	55	58	58	60	66	71	76	84	84	94	102	112	114	
11	66	56	64	68	68	73	76	86	86	90	100	108	100	
12	80	66	74	76	76	76	78	85	82	90	86	86	92	
13	80	88	84	80	82	82	80	87	84	90	76	87	118	□
14	97	94	86	86	86	83	84	88	82	87	68	84	85	
15	106	104	96	87	84	32	83	93	88	83	68	62	68	
16	108	110	100	88	80	80	80	90	98	84	70	62	66	
17	102	104	100	85	80	76	64	86	90	89	82	74	70	
18	90	80	86	85	72	74	60	78	86	96	94	90	87	
□19	89	70	78	85	64	60	62	76	86	102	108	110	118	
20	72	60	80	81	64	52	58	76	92	110	118	125	130	

Table 4. Diagram showing position of cups and risers and amount collected (ml) in each cup for bed-end area. Lowest 25 percent of cups (39 cups) highlighted in yellow or orange. Upper value (86 ml) of the lowest 25 percent of cups (shown in orange) was shared by 4 cups, only 1 of which was included in the 39 cups used to calculate the average catch of the lowest 25 percent of cups. Position of riser = □.

Cup number						Cup line	North □						
	A	B	C	D	E	F	G	H	I	J	K	L	M	
20	72	60	80	81	64	52	58	76	92	110	118	125	130	
21	66	68	86	80	60	52	54	80	102	122	134	139	140	
22	82	88	86	77	64	57	64	93	110	134	139	141	143	
23	96	94	88	80	64	63	78	114	130	140	136	140	134	
24	109	108	97	86	75	79	98	130	146	151	144	146	130	
25	112	110	96	88	84	96	124	150	158	163	154	148	160	□
26	114	104	98	94	90	103	129	170	180	180	168	176	190	
27	108	102	96	96	89	100	130	168	184	198	180	174	172	
28	106	94	92	86	84	96	128	172	206	213	196	184	180	
29	99	90	84	78	74	90	128	169	204	218	194	190	192	
30	104	94	80	72	74	94	122	162	194	204	182	171	228	
□31	116	74	66	63	76	98	121	142	158	158	158	210	219	□
							South end of block							

Table 5. Deviation of amount collected in individual cups (ml) in midfield test area from average catch of 81.7 ml for all cups in test area. Position of riser = □. Cells highlighted with yellow or orange represent the lowest 25 percent of collected volume.

Cup number	A	B	C	D	E	F	Cup line G	North □ H	I	J	K	L	M	
1	15.3	10.3	3.3	0.3	−5.7	−11.7	−17.7	−2.7	7.3	14.3	−5.7	8.3	11.3	□
2	16.3	11.3	4.3	4.3	0.3	−5.7	−13.7	−5.7	2.3	10.3	−17.7	−1.7	14.3	
3	11.3	6.3	6.3	4.3	−1.7	−2.7	−9.7	−9.7	−1.7	6.3	−17.7	−25.7	−17.7	
4	7.3	6.3	2.3	4.3	0.3	−3.7	−9.7	−11.7	−3.7	0.3	−7.7	−21.7	−22.7	
5	0.3	2.3	−3.7	−8.7	−5.7	−5.7	−9.7	−11.7	−5.7	1.3	2.3	−1.7	−4.7	
6	−1.7	4.3	−11.7	−13.7	−11.7	−5.7	−5.7	−3.7	−3.7	5.3	8.3	8.3	8.3	
□7	−3.7	−21.7	−23.7	−16.7	−17.7	−15.7	−4.7	−1.7	−1.7	5.3	10.3	22.3	20.3	
8	−5.7	−27.7	−19.7	−17.7	−21.7	−11.7	−5.7	1.3	4.3	8.3	16.3	25.3	28.3	
9	−31.7	−29.7	−21.7	−22.7	−21.7	−11.7	−5.7	2.3	6.3	10.3	20.3	34.3	31.3	
10	−26.7	−23.7	−23.7	−21.7	−15.7	−10.7	−5.7	2.3	2.3	12.3	20.3	30.3	32.3	
11	−15.7	−25.7	−17.7	−13.7	−13.7	−8.7	−5.7	4.3	4.3	8.3	18.3	26.3	18.3	
12	−1.7	−15.7	−7.7	−5.7	−5.7	−5.7	−3.7	3.3	0.3	8.3	4.3	4.3	10.3	
13	−1.7	6.3	2.3	−1.7	0.3	0.3	−1.7	5.3	2.3	8.3	−5.7	5.3	36.3	□
14	15.3	12.3	4.3	4.3	4.3	1.3	2.3	6.3	0.3	5.3	−13.7	2.3	3.3	
15	24.3	22.3	14.3	5.3	2.3	−49.7	1.3	11.3	6.3	1.3	−13.7	−19.7	−13.7	
16	26.3	28.3	18.3	6.3	−1.7	−1.7	−1.7	8.3	16.3	2.3	−11.7	−19.7	−15.7	
17	20.3	22.3	18.3	3.3	−1.7	−5.7	−17.7	4.3	8.3	7.3	0.3	−7.7	−11.7	
18	8.3	−1.7	4.3	3.3	−9.7	−7.7	−21.7	−3.7	4.3	14.3	12.3	8.3	5.3	
□19	7.3	−11.7	−3.7	3.3	−17.7	−21.7	−19.7	−5.7	4.3	20.3	26.3	28.3	36.3	
20	−9.7	−21.7	−1.7	−0.7	−17.7	−29.7	−23.7	−5.7	10.3	28.3	36.3	43.3	48.3	

These values were used to calculate precipitation rate DU_{LQ} and CU using the following formulas (Stetson and Mecham 2011).

- Precipitation rate (in per hr) = [3.66 by average cup catch (ml)]/[run time (min) by area of collection cup opening (in^2).
- Where—
  - 3.66 = conversion factor to convert cup catch volume from ml to in^3 and run time from min to hr.
  - Run time = 69 min.
  - Area of collection cup opening = 15.6 in^2 (100 cm^2)
- DU_{LQ} = average of the lowest 25 percent of cup catches/average cup catch.
- CU = 100 by [1-(average of the absolute deviations of cup catches/average cup catch)].

Results and Discussion

Values for average cup catch, average of the absolute deviations of cup catches, average of lowest 25 percent of cup catches, precipitation rate, lower quarter distribution uniformity (DU_{LQ}), and coefficient of uniformity (CU) statistics for both areas are given in table 6.

Table 6. Average cup catch, average absolute deviation from average cup catch, and average of lowest 25 percent of cup volumes, precipitation rates, lower quarter distribution uniformity (DU_{LQ}), and coefficient of uniformity (CU) for midfield and bed-end areas.

	Midfield area	Bed-end area
Average cup catch (ml)	81.7	120.2
Average deviation from average cup catch (ml)	11.2	37.4
Average of lowest 25 percent of cup volumes (ml)	63.3	71.3
Precipitation rate (in per hr)	0.28	0.41
DU_{LQ}	0.78	0.59
CU (percent)	86.3	68.9

Conversions: 100 ml = 3.4 oz; 1 in per hr = 2.5 cm per hr

Midfield Area

The values for DU_{LQ} (0.78) and CU (86 percent) for the midfield area indicate good uniformity for this type of irrigation system under the conditions of this test, i.e., no wind and sprinklers operating at 68 psi. CU considers deviations above and below the average precipitation rate in determining uniformity and is usually used in agricultural situations. Shearer (1981) recommended a minimum CU of 85 percent for nursery crops. CU values between 80 and 90 percent are usually the best that can be obtained, however, for solid-set systems with impact sprinklers (Stetson and Mecham 2011).

DU_{LQ} is more commonly applied to turf or landscape irrigation situations in which the emphasis is on applying enough water to the driest portion of the area for optimum growth, even if it means overwatering much of the rest of the area (Zoldoske et al. 1994). The DU_{LQ} value can be used to calculate a Scheduling Multiplier (SM) to help judge how much additional water should be applied to compensate for not having a perfect DU_{LQ} of 1.0. The SM provides an upper irrigation run time to consider compared with the lower boundary, or ideal run time, if perfect uniformity existed (Stetson and Mecham 2011). The SM can be calculated from the DU_{LQ} using the following equation (Stetson and Mecham 2011):

SM = 1/(0.4 + [0.6 by DU_{LQ}])

The SM calculated using the values for the midfield area in this study would be—

SM = 1/(0.4 + [0.6 by 0.78]) = 1.15

Therefore, if it takes 1 hour to apply an average of 0.28 in (0.71 cm) of water over the midfield area in a system with a DU_{LQ} of 1.0, then a time of 1.15 hours (69 minutes) should be considered an upper run time to actually fulfill this requirement given a DU_{LQ} of 0.78 for this area. The actual run time can be adjusted between the upper and lower run time boundaries based on operator experiences and observations specific to the site (Stetson and Mecham 2011).

The precipitation rate of 0.28 in per hr (0.71 cm per hr) in the midfield area is well matched with the infiltration rates for the sandy loam soil in this field. The basic infiltration rate (the rate which is nearly stable over time) for a sandy loam soil is 0.5 in per hr (1.27 cm per hr), although this rate can vary considerably over time depending on soil cover, organic matter, compaction, and tillage (von Bernuth 2012). Infiltration is higher in drier soil and decreases as water is added. The actual infiltration rate for this field was not determined, but based on the basic infiltration rate for this soil, surface runoff should be minimal at the precipitation rates found in this test.

Bed-End Area

Water distribution uniformity in the bed-end area was poorer than at the midfield area under the conditions of this test, with a DU_{LQ} of 0.59 (versus 0.78 at midfield), and a CU of 69 percent (versus 86 percent at midfield). The precipitation rate at the end of the bed was 0.41 in per hr (1.04 cm per hr), or about 150 percent more than the precipitation rate at midfield. This rate is close to the base infiltration rate for sandy loam of 0.5 in per hr (1.27 cm per hr), noted in the previous section, and, in fact, surface runoff was observed in the bed-end area before the end of the test.

The main reason for the lower uniformity in the bed-end area was the increased precipitation rate in the area covered by the supplemental half-circle nozzle at the end of the lateral located only 30 ft (9.1 m) from a full-circle sprinkler (figure 2). These supplemental sprinkler nozzles were placed at the south end of the field to improve irrigation uniformity at the bed ends during windy periods, because the prevailing wind is from the south and west at this nursery. Because this test was run under calm conditions, it was not possible to determine how well this approach might work.

Increased uniformity of water distribution could be achieved in the bed-end area by better matching the precipitation rates of the full- and half-circle sprinklers. Half-circle sprinklers should have one-half the flow rate of full-circle sprinklers operating in the same zone to provide similar precipitation rates (von Bernuth 2012). The full-circle sprinklers in this system have a flow rate of about 12 gpm (2.73 m^3 per hr) at 68 psi (4.7 bars) (table 1), and the half-circle sprinklers have a flow rate of more than 8 gpm (1.82 m^3 per hr) (estimated, because no data exist for this sprinkler at more than 60 psi [4.14 bars] [table 2]), which is more than 75 percent of the rate of the full-circle sprinklers. The flow rate of the half-circle sprinkler could be reduced to approximately 6 gpm (1.36 m^3 per hr) (estimated based on information in table 2) by using a 5/32-in (4.0-mm) nozzle instead of a 3/16-in (4.8-mm) nozzle. This flow rate would more closely match the precipitation rate for the full-circle sprinklers while still providing coverage of the ends of the fields under windy conditions, although the throw radius of the half-circle sprinkler would be reduced from about 52 ft (15.8 m) to about 46 ft (14.0 m) (table 2).

The uneven spacing of sprinklers will still reduce irrigation uniformity in the bed-end area compared with the midfield area. In addition, the half-circle sprinklers may be operating at more than the manufacturer's recommended water pressure, because no performance data are available for more than 60 psi (4.14 bars). Exceeding recommended water pressure will result in less uniform distribution patterns for these sprinklers (von Bernuth 2012). Beds in this field are about 630-ft (192-m) long, so about 6 percent of the area (the first 40 ft [12.2 m]) is affected by the poorer uniformity.

Irrigation Design Considerations

Watering patterns of irrigation systems are susceptible to distortion by wind speed, wind direction, and changes in wind patterns over time (Solomon 1990). Wind speeds as low as 5 mph can result in considerable changes in water distribution patterns and irrigation uniformity. To improve uniformity during windy conditions, the distance between sprinklers must be reduced, or sprinkler throw diameter increased, as wind speed increases. In the Vallonia Nursery irrigation system, increasing water pressure and using larger nozzles would slightly increase sprinkler throw diameter, but probably not enough to greatly improve uniformity. The main effect of increasing water pressure or nozzle diameter would be to increase precipitation rate.

Solomon (1990) recommends maximum sprinkler spacing of 60 to 65 percent, 50 percent, or 30 to 50 percent of wetted diameter for low (0 to 4 mph [0.0 to 6.4 kph]), medium (4 to 9 mph [6.4 to 14.5 kph]), or high (more than 9 mph) wind conditions, respectively. Full-circle sprinklers in the Vallonia irrigation system have a throw radius of about 52 ft (15.8 m) at 68 psi (4.7 bars) (table 1). Based on Solomon's recommendations, the Vallonia sprinklers should have a maximum spacing of 62 to 67 ft (18.9 to 20.4 m), 52 ft (15.8 m), or 33 to 52 ft (10.1 to 15.8 m) in low, medium, or high wind conditions, respectively. The current spacing of 60.0 ft (18.3 m) between sprinklers on the same lateral and 67.0 ft (20.4 m) between offset sprinklers on adjacent laterals should deliver reasonable uniformity under low wind conditions. Irrigating at higher wind speeds will result in less uniformity. Variable wind patterns during irrigation events may result in more uniform irrigation patterns than steady wind conditions, because the resulting changes in areas of high- and low-precipitation average out (Solomon 1990). Therefore, if irrigation cannot be done under low wind conditions, it may be possible to improve uniformity under variable wind conditions by applying the required amount of water in multiple events. Irrigation under high (> 9.0 mph [14.5 kph]), steady winds should be avoided if possible, because poor uniformity will likely result.

Changing the operating pressure of the sprinklers will affect flow rate and throw, with the larger effect on flow rate (tables 1 and 2) and, hence, precipitation rate. A pressure difference of 10 percent between sprinklers in the same set is considered the maximum allowable for good irrigation uniformity (von Bernuth 2012). Therefore, the total numbers of sprinklers that can be operated and still maintain uniform pressure across a set should be determined for the irrigation system. Open the laterals until pressure differences occur within sets and note the number of sprinkler heads in operation. Irrigation uniformity should be checked under normal operating pressure.

Systematic maintenance of the irrigation system is a key factor in irrigation uniformity (Scholtes 2001, Fernandez 2010). This maintenance includes repairing leaks, keeping risers plumb and sprinkler heads level with the ground, and checking for worn or plugged nozzles and proper sprinkler rotation. Check sprinklers during each watering cycle to make sure they are operating properly.

Irrigation should be scheduled to maintain optimum soil moisture in the rooting zone while reducing surface runoff and percolation beneath the root zone. Although soil moisture availability curves were not determined for this field, sandy loam has an approximate moisture holding capacity of 1.1 in of water per ft (9.2 cm per m) of soil at field capacity (von Bernuth 2012). As a rule of thumb, irrigation is usually scheduled to begin when soil moisture reaches about 50 percent of available water (approximately 1.5 bars of soil matrix potential), because this level is about the point at which growing conditions become less than optimum (von Bernuth 2012). Assuming a rooting depth of about 1 ft (0.3 m), about 1.1 in (2.8 cm) of water is available to plants at field capacity. Irrigation should begin when one-half or 0.55 in (1.4 cm) of water has been removed from the rooting zone by plant evapotranspiration and surface evaporation. The rate of water depletion depends on several factors including temperature, wind speed, and plant size.

The operational irrigation schedule for the Vallonia Nursery is to apply about 2 in (5.1 cm) of water per week. One inch (2.5 cm) of rainfall per week is also considered adequate to meet plant water requirements. Irrigation is increased if temperature or wind is more than normal and rainfall is less than normal. This schedule appears to be sufficient to produce high-quality nursery stock at this site. Some system of more accurately assessing soil moisture levels may improve the irrigation efficiency (i.e., may do a better job of adjusting irrigation rates to apply only enough water to maintain optimum moisture levels in the root zone). Because rainfall is fairly well distributed during the growing season at this nursery, however, increased irrigation efficiency may not affect plant quality here as much as in nurseries where irrigation supplies a larger proportion of plant water needs. Increasing efficiency will reduce operating expenses, such as pumping and fertilizer costs, to the extent that present irrigation practices are overwatering (and leaching fertilizer or other chemicals from the root zone) or poor irrigation system maintenance is affecting irrigation uniformity. Increased efficiency will also reduce runoff and water pollution to the extent the current practice is overwatering.

Lessons Learned

Cup spacing could be reduced when assessing irrigation uniformity. Calculations of CU, DU_{LQ}, and precipitation rate based on cups spaced 10 by 10 ft (3 by 3 m) and 15 by 15 ft (4.6 by 4.6 m) were similar (table 7), although differences were slightly greater in the less-uniform bed-end area. A minimum grid spacing of one-third to one-fourth of the average sprinkler spacing is recommended for impact sprinkler systems in which sprinklers are 40 ft (12.2 m) or more apart (Setson and Mecham 2011). Based on this recommendation, a spacing of 15 by 15 ft is the greatest that should be used in this nursery. A spacing of 10 by 10 ft may provide a more accurate estimate than the 15 by 15 ft spacing if irrigation uniformity is poor.

For the area in this test, 5 by 5 ft, 10 by 10 ft, and 15 by 15 ft spacing required a total of 403, 112, and 55 cups, respectively. A good strategy for future tests would be to use cups at wider spacing distributed in subgroups in several areas of the field. The number of cups in the test, and in the subgroups, should be divisible by four to make it easy to calculate DU_{LQ}.

Table 7. Comparison of coefficient of uniformity (CU), lower quarter distribution uniformity (DU_{LQ}), and precipitation rate calculated from different cup spacings.

Cup spacing (ft)	Midfield			Bed-end area		
	CU (%)	DU	Rate (in per hr)	CU (%)	DU	Rate (in per hr)
5 by 5	86.3	0.78	0.28	68.9	0.59	0.41
10 by 10	86.0	0.78	0.28	70.3	0.58	0.41
15 by 15	85.2	0.76	0.29	71.9	0.59	0.43

Conversions: 5 ft = 1.5 m; 1 in per hr = 2.5 cm per hr

At the end of the cup test, cups near sprinklers should be covered directly before turning off the water to prevent collecting excess water draining from sprinklers.

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ADDITIONAL RESOURCES

The Irrigation Association offers a variety of online and traditional face-to-face classes on various irrigation subjects and a number of technical references on irrigation. More information is available at the Irrigation Association Web site at https://www.irrigation.org.