Sprinkler Spacing Does Not Affect Carrot Yield and Quality

J.P. Mitchell,[1]
S.E. Allaire-Leung,[2]
B.L. Sanden,[3] and L. Wu[4]

ADDITIONAL INDEX WORDS. *Daucus carota*, irrigation uniformity

SUMMARY. Optimal water management is essential in irrigated agricultural regions to sustain productivity, conserve water resources and protect groundwater quality. The southern San Joaquin Valley (SJV) of California is a major irrigated production region in which solid set sprinkler systems are commonly used to grow such crops as carrots (*Daucus carota* L.), potatoes (*Solanum tuberosum* L.), garlic (*Allium sativum* L.) and onions (*Allium cepa* L.) in predominantly sandy soils. Water and fertilizer use efficiencies are important concerns in this region. In 1996 and 1997, we evaluated the effects of three sprinkler spacings [32.2, 38.6 and 45 ft (9.8, 11.8 and 13.7 m)] and irrigation uniformity within these spacings on carrot yield, quality and nitrogen content. Applied water and soil nitrate and ammonium contents were monitored at four locations within each sprinkler lateral spacing throughout both seasons. Neither sprinkler spacing nor location within a given sprinkler spacing affected carrot production or quality. Distributions of soil nitrate and ammonium resulting from the different sprinkler spacings were also not correlated with carrot yields. These results suggest that any of the three spacings can be used for high carrot quality and productivity.

This research was funded in part by the California Department of Food and Agriculture Fertilizer Research and Education Program. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Assistant vegetable crops cooperative extension specialist, Department of Vegetable Crops, University of California, Davis, CA 95616.

[2]Postdoctoral fellow, United States Department of Agriculture Salinity Laboratory, 450 West Big Springs Road, Riverside, CA 92507.

[3]Cooperative extension farm advisor, University of California Cooperative Extension, Kern County, 1031 South Mt. Vernon Avenue, Bakersfield, CA 93307.

[4]Assistant professor and water management cooperative extension specialist, Department of Environmental Sciences, University of California, Riverside, CA 92521.

In the semiarid southern San Joaquin Valley (SJV) in California, irrigation is a costly though essential input for economically viable vegetable crop production. Solid-set sprinkler systems are commonly maintained in fields throughout entire production seasons for crops such as carrots and potatoes, which account for about 65% of the total production acreage and value in this area. Most sprinkler irrigation and fertigation systems that are used in the southern SJV are based on 41.2 × 34.8 ft (12.6 × 10.6 m) spacings that have an average precipitation distribution uniformity (DU) of 66%. For sprinklers, DU is defined as the average of the lowest 25% of measured amounts of precipitation in a field divided by the overall field average depth of applied water, assuming runoff is negligible (Heerman et al., 1990). The practical impact of a low DU is that significant portions of a field will be overirrigated while 17% or more of the field may be underirrigated, based on a DU of 66%. While wind is generally thought to be the primary cause of these low uniformities (Hanson and Bowers, 1993), sprinkler system design may also be a contributing factor. Nonuniformity of sprinkler water application can be a major constraint to uniform crop growth and yield optimization (Seginer, 1987). Wilchelns and Oster (1991) demonstrated that cotton (*Gossypium hirsutum* L.) yield in the SJV is positively correlated to irrigation uniformity. Ayars et al. (1991) found that cotton canopy growth is significantly influenced by water application patterns and depths. Or and Hanks (1992) showed that soil water, crop height and corn (*Zea mays* L.) yield variability all exhibit spatial structures similar to those of applied irrigation uniformity.

To overcome constraints that result from nonuniform water applications, growers often water and fertilize an entire field at above-optimal rates to compensate for areas that have lower water or nitrogen availability. Uniformity evaluations (Pratt et al., 1979; Wallach, 1990) indicate that decreasing the lateral spacing in sprinkler irrigation systems may increase DU, reduce irrigation set times and lessen the potential for nitrate (NO_3^-) leaching losses. Closer lateral spacings would typically increase the capital costs of sprinkler systems. However, in the long run, given current and anticipated water costs in this region, closer spacings might save in applied water, possibly increase yields, and offset these costs to growers.

Several studies have shown that in certain crop and water management contexts, reduced irrigation water applications can maintain yields while decreasing NO_3^--leaching losses. Hergert (1986), for example, quantifying NO_3^--leaching losses for sprinkler irrigated corn in Nebraska, found that soil water percolation and NO_3^--leaching losses were about five times higher when irrigation rates were increased from 85% to 130% of potential evapotranspiration (ET). Jackson et al. (1994), using a computer simulation model of nitrate leaching in a lettuce (*Lactuca sativa* L.) crop grown in the Salinas Valley of California, predicted that applying 12 inches (30 cm) of irrigation water and 75 lb/acre (84 $kg \cdot ha^{-1}$) of nitrogen would reduce leaching by 75% while maintaining yield and profitability. This work was conducted in a silt loam soil typically requiring 24 inches (61 cm) of water and 150 lb/acre (168 $kg \cdot ha^{-1}$) of nitrogen. No work, however, has considered the extent to which alternative sprinkler system configurations might increase production and resource use efficiencies in commercial carrot production fields. The objective of these field studies was to evaluate the impact of typical [45 ft (13.7 m)] and alternative [32.2 and 38.6 ft (9.8 and 11.8 m)] lateral spacings in solid set sprinkler irrigation systems on carrot yields and quality.

Materials and methods

SITE DESCRIPTION. Two field experiments were conducted in a 28.9-acre (11.7-ha) commercial field in western Kern County in California in Spring 1996 and in Fall 1997. The soil type was a Cajon loamy sand (mixed thermic typic Torripsamments) with low salinity (<2 $dS \cdot m^{-1}$) overlying a deep water table [>80 ft (24.4 m)]. Annual precipitation in the region ranges from 4.9 to 6.4 inches (125 to 163 mm). In Spring 1996, 32.5-, 39.2-, and 45.7-ft (9.9-, 11.9-, and 13.9-m)

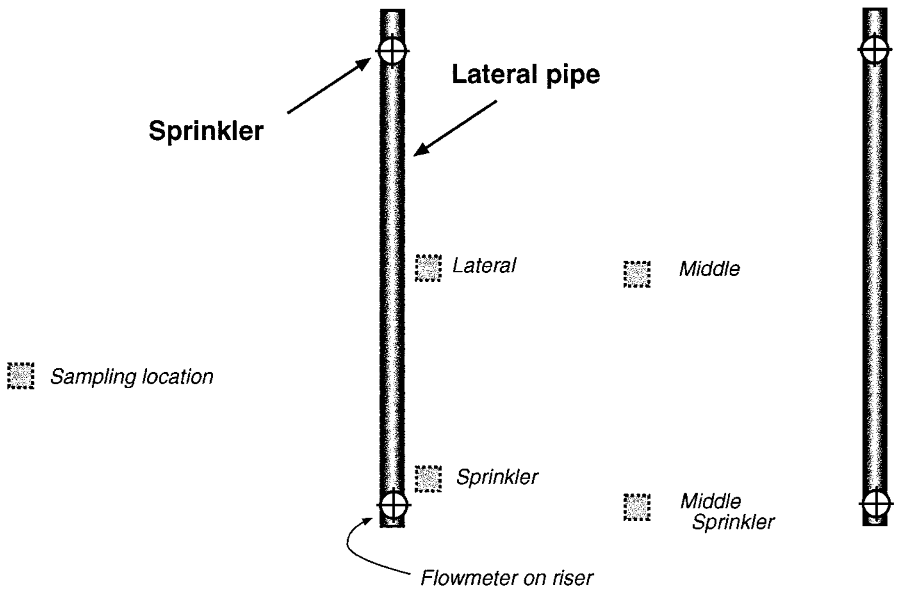

Fig. 1. Schematic representation of the four sampling locations relative to sprinklers.

laterals were tested and in Fall 1997 35.4-, 41.2-, and 44.1-ft (10.8-, 11.8-, and 13.4-m) spacings were used. For simplicity, these spacings will be referred to as 32.2-, 38.6-, and 45-ft (9.8-, 11.8-, and 13.7-m) laterals. Each lateral consisted of 75 joints of standard hand-move aluminum sprinkler pipe (3 inch diameter × 29.3 ft long; 7.6 cm diameter × 8.9 m long) with 1.97 ft (0.6 m) risers and WeatherTec 10 / 20 sprinklers with 7/64 inch (2.8 mm) diameter nozzles (WeatherTec, Fresno, Calif.). A 12-inch (30-cm) diameter mainline was laid across the middle of the field with 40 joints form each lateral connected to the downslope side and 35 joints to the upslope side. Sprinklers were generally operated at 52 to 56 lb / inch^2 (0.36 to 0.39 MPa) which delivered water at a rate of about 2.6 to 2.9 gal / min (9.8 to 11 L·min^{-1}). Irrigation set times were adjusted to apply the same amount of water to each spacing treatment [2.3 inches (5.8 cm) over 8.5 to 12 h per irrigation]. Irrigation scheduling was done by the farm's foreman, or roughly every 7 d. Thirteen irrigations were applied in 1996 and eight in 1997. Rainfall was negligible during 1996, but was 5.1 inches (129 mm) in 1997. In 1996, the field was planted at a high density [998,227 plants / acre (404,082 plants / ha)] to produce shortcut carrots) on 29 Jan. and harvested on 4 June. In 1997, a lower density planting [376,592 plants / acre (152,400 plants / ha)] to produce longer, cello pack carrots) was made on 1 Sept. and harvested on 2 Feb. 1998. Fertilizer was applied with the irrigation water at N, P and K rates of 250, 11.6 and 360 lb / acre (280, 13, and 403 kg·hg^{-1}) in 1996 and at 230, 3.6 and 347 lb / acre (258, 4, and 389 kg·ha^{-1}) in 1997. Fertigations were applied about every 1 to 3 weeks depending on crop appearance and growth rate. Each lateral sprinkler spacing was replicated three times in a completely randomized block design.

Water, soil, and crop monitoring. Water application was measured using small flowmeters mounted along sprinkler lines and nonevaporating rain gauges that were placed at four locations within a grid of four sprinklers (Fig. 1). These sites were selected to determine the relative differences in applied water for quadrants or grids between sprinklers for each lateral spacing. Soil NO_3^- and ammonium (NH_4^+) contents were determined from potassium chloride extracts using the method of Carlson et al. (1990). Samples were collected in 0 to 1, 1 to 2, 2 to 3 and 3 to 4 ft (0 to 30, 30 to 60, 60 to 90 and 90 to 120 cm) increments at each of the four locations within a sprinkler grid in all lateral spacings and in all replications at the beginning and end of each production season. Crop growth was determined by harvesting, drying, and weighing plants along 3.2 ft (1 m) of bed eight times in 1996 and seven times in 1997. Total and marketable yields and unmarketable or cull carrots were determined by digging, sorting and weighing carrots within a 25 ft^2 (2.3 m^2) section at each within-grid location site as indicated in Fig. 1 for all spacings when the field was ready for commercial harvest. Culls were those carrots which were misshapen, undersized or diseased. Statistical analyses were done using SAS / STAT software release 6.12 for Windows 95 (SAS Inst., Cary, N.C.). Applied water, yield and carrot quality at locations within a sprinkler grid were determined by averaging values for each of these variables across the three sprinkler lateral spacing treatments.

Results and discussion

Sprinkler spacing did not significantly impact either total or marketable yield of carrots in the two years of this study (Table 1). There were also no significant differences in marketable carrot yields that were related to location within a grid of four sprinklers in either year (Table 2). However, total yields were lower at the lateral sprinkler location in 1997, though not in 1996. The lower carrot yield at the lateral sprinkler location was related to less applied water at the lateral site (Table 3). These results demonstrate no clear advantage for any of the three sprinkler lateral spacings tested in terms of carrot growth or productivity for either of the carrot planting densities evaluated. They further suggest that the water application uniformities of these three spacings resulted in sufficient applied water for comparable whole-field and location-specific productivity with respect to sprinklers.

Previous work by White (1992) showed that carrots produce acceptable yields of marketable roots when grown over a wide range of irrigation regimes, but that carrot growth is reduced at high soil water levels. White and Strandberg (1979) showed that carrots subjected to saturated soil conditions during early root growth were smaller than roots in unsaturated conditions. Despite differences in the amount of cumulative irrigation water measured at the locations within a sprinkler grid (Table 4), these differences in water application uniformity resulted in lower total yield at the lateral sprinkler location in 1997, but did not impact marketable yield in either year.

Carrot quality was also unaffected by sprinkler spacing (Table 1). While the relative proportions of cello-pack, shortcut carrots, and cull carrots var-

Table 1. Effect of sprinkler spacing on carrot yield, quality, and nitrogen content for Spring 1996 and Fall 1997 (1.0 ft = 0.3 m, 1.0 ton/acre = 2.24 t·ha^{-1}).

Spacing (ft)	Total yield (ton/acre)	Marketable yield[z] (ton/acre)	Cello pack[y] (ton/acre)	Shortcut[x] (ton/acre)	Cull[w] (ton/acre)	Whole-plant N (%)
			Spring 1996 (high density planting)			
32.5	38.1 a[v]	36.8 a	13.8 a	22.9 a	1.4 a	2.11 a
39.3	36.6 a	35.8 a	13.6 a	21.6 a	1.0 a	2.17 a
45.7	36.0 a	34.7 a	12.9 a	21.9 a	1.4 a	2.16 a
			Fall 1997 (low density planting)			
35.4	32.5 a	29.5 a	24.5 a	5.0 a	0.6 a	2.04 ab
41.2	30.7 a	26.8 a	22.6 a	4.3 a	1.4 a	2.13 a
44.1	30.6 a	27.8 a	22.4 a	5.5 a	0.5 a	1.95 b

[z]Combined yield of cello pack and short-cut carrots.
[y]Yield of standard, full-size carrots with approximate 0.5-inch (1.3-cm) diameter.
[x]Yield of carrots used for cut snack-size products with approximate 0.25- to 0.5-inch (0.6- to 1.3-cm) diameter.
[w]Misshapen, forked or otherwise unmarketable carrots.
[v]Means followed by different letters are significantly different at 0.05 confidence level by Duncan's multiple range test.

Table 2. Effect of location within the gird of four sprinklers on carrot yield and quality (1.0 ton/acre = 2.24 t·ha^{-1}).

Location	Total yield (ton/acre)	Marketable yield (ton/acre)	Shortcut[z] (ton/acre)	Cull[y] (ton/acre)
		Spring 1996		
Middle sprinkler	37.5 a[x]	36.7 a	23.6 a	0.9 a
Middle	36.4 a	34.8 a	20.2 b	1.6 a
Lateral	36.9 a	35.6 a	22.0 ab	1.4 a
		Fall 1997		
Middle sprinkler	33.6 a	30.1 a	6.0 a	0.5 a
Middle	31.0 ab	27.2 a	4.2 a	0.7 a
Lateral	28.9 b	27.0 a	4.4 a	0.5 a
Sprinkler	31.6 ab	28.0 a	5.1 a	1.0 a

[z]Yield of carrots used for cut snack-size products with approximate 0.25- to 0.5-inch (0.6- to 1.3-cm) diameter.
[y]Misshapen, forked or otherwise unmarketable carrots.
[x]Means separated by different letters are significantly different at 0.05 confidence level by Duncan's multiple range test.

Table 3. Effect of lateral spacing on cumulative depths of water application (1.0 ft = 0.3 m, 1.0 inch = 2.54 cm).

Spacing (ft)	Depth of water applied (inches)
1996	
32.5	21.6 a[z]
39.3	21.8 a
45.7	21.8 a
1997	
35.4	17.8 a
41.2	16.6 ab
44.1	15.5 b

[z]Means separated by different letters are significantly different at 0.05 confidence level by Duncan's multiple range test.

Table 4. Effect of location within a sprinkler grid on cumulative depths of water application (1.0 inch = 2.54 cm).

Spacing (ft)	Depth of water applied (inches)
1996	
Middle sprinkler	22.8 a[z]
Middle	23.2 a
Lateral	19.2 b
1997	
Middle sprinkler	15.3 b
Middle	16.3 b
Lateral	13.6 c
Sprinkler	21.5 a

[z]Means separated by different letters are significantly different at 0.05 confidence level by Duncan's multiple range test.

ied between the 2 years due to planting densities, distance between sprinkler laterals did not significantly impact these quality parameters in either year (Table 1). Location within a sprinkler grid affected neither the amounts of marketable nor culled carrots in both years, however production of shortcut carrots was lower in the middle of a sprinkler grid in the 1996 study (Table 2). The distribution uniformities of cello-pack, shortcut and cull carrots was also not related to soil NO_3^- or NH_4^+ distribution patterns that resulted from the sprinkler lateral spacings or as a result of field position within a sprinkler grid (data not shown). Whole plant tissue N content was not affected by sprinkler lateral spacing in 1996 (Table 1). However, tissue N content was lower in 1997 at the widest sprinkler spacing. There were no relationships between whole plant N and soil NO_3^- (P = 0.39) or whole plant N and soil NH_4^+ (P = 0.50) for both years.

This study found that the sprinkler lateral spacings of 32.8 to 45.9 ft (10 to 14 m) were all effective in producing high yields of quality carrots when irrigated with long duration sets. However, no difference in yield and quality with respect to the locations within the grid of four sprinklers indicates that the current irrigation practices might have overirrigated the field, since the lateral locations in both 1996 and 1997 received substantially less irrigation water. Further work is needed to identify the upper limit for sprinkler lateral spacings that will maximize both economic and environmental objectives, and will determine the extent to which this finding applies for other crops and fertilization practices.

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