Evaluating low-pressure sprinkler systems

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Use caution in modifying a system

In 1970, electrical energy costs for irrigation of agricultural lands were less than two cents per kilowatt-hour in California. Today irrigators may pay up to seven to eight cents per kilowatt-hour. Coping with these increased costs has created more interest in irrigation scheduling, improving pumping plant and irrigation application efficiency, and modifying systems to reduce operating costs.

One such modification is to decrease the pressure of sprinkler irrigation systems by reducing the size of the impellers of pumps and/or changing to sprinkler heads and nozzles designed for distribution of water at low pressures. The nozzles are made with a variety of orifice shapes, such as squares, rectangles, triangles, and circles with notches around the circumference.

In the change to a low-pressure irrigation system, the uniformity of application, and thus the irrigation efficiency, should be considered, along with the effect on the relation between pump and irrigation system performance.

Application uniformity

Field evaluations of 24 sprinkler systems, which included wheel-lines and portable hand-line systems, were conducted to estimate the uniformity of water application at low to medium pressures. The procedure used (described in *Farm Irrigation System Evaluation* by John Merriam and Jack Keller) consisted of installing catch-cans on a grid with a can spacing of 10 feet. After the sprinkler system was operated for several hours, the volume of water in each catch-can was measured. The uniformity was estimated using the Christiansen coefficient of uniformity (CU), the most common method of evaluating uniformity of water distribution by sprinkler systems. A CU of 80 to 85 percent is usually considered acceptable.

The evaluations generally showed satisfactory uniformity for the standard circular nozzles under the conditions experienced during the tests (table 1). Standard nozzles with orifice diameters of 11/64 to 13/64 inch provided acceptable uniformity at pressures between 35 and 45 psi, although the 5/32-inch nozzle in test 11 also provided good uniformity.

The CU of nozzles with rectangular orifices was marginal at both 30 and 25 psi. Good uniformity was obtained with a square nozzle (test 16), but the pressure was about 43 psi. The sprinkler head used for that test would not rotate at lower pressures. Nozzles with rectangular orifices were also tried on the irrigation system used for test 7, but again the sprinkler heads would not rotate.

Nozzles with triangular orifices gave mixed results when winds were low (less than 5 miles per hour). The CU was satisfactory for some of the tests but was unsatisfactory for test 20. At wind speeds greater than 5 miles per hour, the CUs were unsatisfactory.

Nozzles with the notched circular orifices also had a mixed performance. One test showed satisfactory results under moderate wind speeds (5 to 10 miles per hour), but the others were unsatisfactory under the conditions that occurred during the evaluations.

The CU for different spacings along the mainline was calculated using test data to estimate the spacing that provided the best distribution of water. The spacing of sprinkler heads along the lateral was that used by the grower. The CU for nozzles with standard circular orifices was unsatisfactory at spacings greater than 60 feet, but was satisfactory at spacings of 60 feet or less (fig. 1). In fact, since the CU changed only slightly at less than 60 feet, little may be gained by further decreases in mainline spacing. Increasing the spacing beyond 60 feet, however, would be detrimental to the uniformity of application.

At spacings greater than 50 feet, the CU of nozzles with rectangular orifices generally decreased rapidly with increased spacing for the pressures measured during these evaluations (fig. 2). Spacing less than 50 feet did not show any significant increase in CU. The CU-spacing relationship also shows that the CU was less at 25 psi than at 30 psi. These results indicate that irrigators desiring to convert to these nozzles should

TABLE 1. Results of field evaluations of sprinkler systems operating at low to medium pressures

Test no.	Sprinkler system*	Spacing†	Nozzle diameter	Orifice shape‡	Wind speed	Nozzle pressure	Nozzle discharge	CU
		ft	*inches*		*mi/hr*	*psi*	*gpm*	*%*
1	WL	40 × 60	3/16	Circ	≃0	50	7.6	90
2	WL	40 × 60	3/16	Circ	≃5	60	8.4	84
3	WL	40 × 60	11/64 × 1/8	Circ	≃5	45	8.7	79
4	WL	40 × 60	13/64	Circ	4-6	36	6.8	85
5	WL	40 × 60	13/64 × 1/8	Circ	4-6	36	9.3	84
6	WL	40 × 60	11/64 × 3/32	Circ	4	21	-§	75
7	HL	40 × 60	3/16 × 1/8	Circ	3	41	9.9	76
8	HL	40 × 60	7/32 × 1/8	Circ	6	32	9.6	65
9	HL	30 × 40	9/64	Circ	5	56	-§	83
10	WL	40 × 60	11/64	Circ	≃0	40	5.0	79
11	WL	40 × 60	5/32	Circ	3	41	4.5	86
12	WL	30 × 60	3/16	Rect	<5	30	-§	70
13	WL	30 × 60	3/16	Rect	<5	30	-§	75
14	WL	30 × 60	3/16	Rect	<5	25	-§	68
15	WL	30 × 60	3/16	Rect	<5	25	-§	67
16	HL	30 × 40	1/8	Sq	4	43	-§	83
17	HL	35 × 45	9/64**	Tr	10	29-30	3.0	68
18	HL	35 × 45	9/64**	Tr	2	23-30	3.0	83
19	HL	35 × 45	9/64**	Tr	7	33-38	3.3	72
20	HL	30 × 40	7/64**	Tr	5	40	2.0	70
21	WL	40 × 60	3/16**	Tr	≃3	41	6.6	85
22	HL	35 × 45	9/64	3-ntc	7	33-38	3.3	80
23	HL	30 × 40	7/64	3-ntc	4	33-35	2.0	70
24	WL	40 × 60	11/64	4-ntc	≃0	40	-§	75

* WL = wheel-line; HL = hand-line
† Spacing along lateral × spacing along mainline.
‡ Circ = circular; Rect = rectangular; Sq = square, Tr = triangular; 3-ntc = three notches around circumference; 4-ntc = four notches around circumference.
§ Not measured
** Nozzle size is based on circular nozzle size with same discharge as that measured during test or as reported by manufacturer.

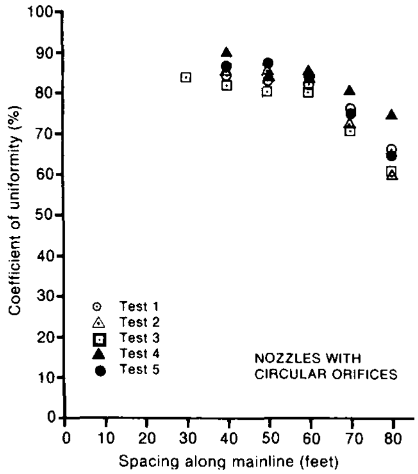

Fig. 1. Uniformity of water distribution (CU) was satisfactory at spacings of 60 feet or less, unsatisfactory at greater spacings.

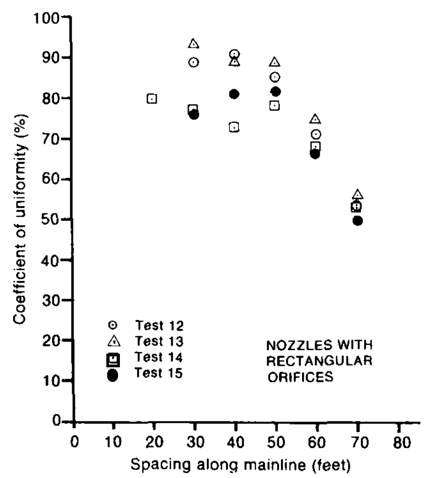

Fig. 2. CU decreased rapidly with increased spacing above 50 feet. At less than 50 feet, CU did not increase significantly.

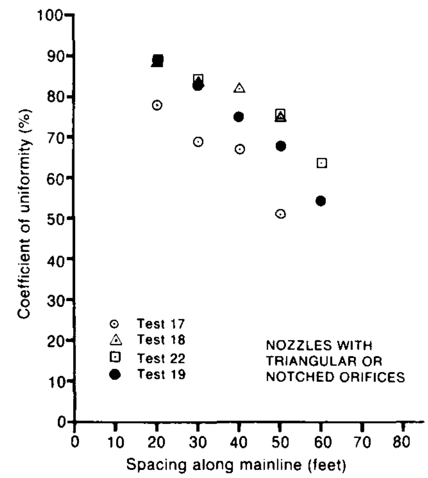

Fig. 3. CU was acceptable at spacings up to 40 feet in light winds (test 18), but only up to 20 feet in winds of 5 to 10 mph.

maintain a pressure of at least 30 psi and use a spacing along the mainline of 50 feet.

The CU mainline spacing relationship for nozzles with triangular orifices shows that, under low wind conditions, uniformity was acceptable at spacings up to 40 feet. However, under moderate wind (5 to 10 mph), acceptable uniformity of application occurred only for spacings up to 20 feet. Thus, growers desiring to use nozzles with triangular orifices should decrease spacings along the mainline to maintain acceptable CU.

The uniformity of application affects energy use: as the CU decreases, the irrigation efficiency (defined as the ratio of volume of water stored in the soil profile to the total volume applied) also decreases (table 2). Suppose a net application of 3 inches is desired. For a CU of 83 percent, the irrigation efficiency would be about 80 percent (excluding spray and evaporation losses), and the gross application would be 3.7 inches (assuming 80 percent of the area irrigated receives at least 3 inches). If the CU decreases to 68 percent, as occurred in test 18, the efficiency would be 62 percent, and a gross application of 4.4 inches would be required. Thus, as the CU decreases, the operating time of the system must increase to apply an adequate irrigation, assuming a constant application rate. The result could be higher energy costs even with decreased operating pressure.

TABLE 2. Relation of the coefficient of uniformity to irrigation efficiency*

CU	Irrigation efficiency†
%	
90	88
80	76
70	64
60	52

* Assumes at least 80 percent of the area is adequately irrigated.
† Ratio of volume of water stored in soil profile to total volume applied.

Changing to low pressure

The effect on energy costs of changing nozzles to reduce pressure depends on the performance characteristics of the pump and the change the nozzles cause in performance characteristics of the sprinkler system. Pump characteristics are described by performance curves developed by the manufacturers. They normally consist of three curves that describe the relationships between total head developed by the pump and capacity (H-Q curve), pump efficiency and capacity (e-Q curve), and brake horsepower and capacity (BHP-Q curve). Normally, as capacity increases, total head decreases. The rate of decrease depends on the characteristics of the pump. As capacity increases, efficiency increases to some maximum and then decreases. In some pumps, BHP increases slightly or remains constant as capacity increases; in others, BHP increases significantly with increasing capacity.

Performance of an irrigation system can be described by a system head curve. If the pump H-Q curve is superimposed over the system head curve, the intersection of the two curves is the operating point of the pump. By developing system head curves for various sprinkler-system operating schemes, one can determine the specific effect of those schemes on pump performance.

To illustrate effects of several possible schemes for reducing nozzle pressures, we designed a hypothetical irrigation system using handlines to irrigate 80 acres. The initial operating pressure at the furthermost nozzle was 50 psi. Nozzle diameter was 1/8 inch (circular orifices). Spacing was 30 feet along the lateral and 40 feet along the mainline. A pump was selected to satisfy the total head-capacity requirements of the irrigation system at maximum pump efficiency. For this pump, BHP increases as capacity increases.

We developed system head curves for the original system and a modified system. Modifications considered were replacing the original 1/8-inch standard nozzle with one of equivalent size designed for low pressures (1/8 LP) and with a low-pressure nozzle one size larger (9/64 LP). The same spacing was used for all configurations.

We also considered the effect of changing pump performance characteristics, trimming the impeller by 5 and 10 percent of the original diameter. Pump H-Q performance curves were developed for each change. By determining the capacity and total head at the points where pump performance and system head curves intersect (fig. 4), one can predict the effect of these changes on energy costs (table 3).

This analysis shows that one should

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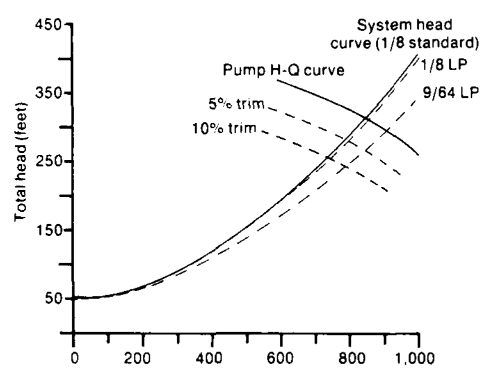

Fig. 4. Intersections of curves for system head and pump head-capacity of hypothetical irrigation system show effects of changes.

Clipping chaparral

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Chaparral is one of the most extensive vegetation types in California, covering 3.5 million hectares (8.6 million acres), or about 8.5 percent of the state. The frequency and intensity of wildfires are normally related to fuel buildup in chaparral, which is usually controlled by prescribed burning of standing or mechanically crushed brush. Because mowing or clipping has been suggested as another technique, we undertook this study to assess clipping as a means of controlling chamise chaparral growth.

Although chaparral is composed of a great variety of plants, its appearance is much the same throughout California. Common characteristics of the evergreen shrubs that dominate the type are extensive root systems in relation to

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Sprinkler systems, continued

use caution in modifying a system. If the original nozzles were replaced with equivalent-size low-pressure nozzles (1/8 LP) and no changes were made to the pumping plant, little change in pressure or in costs would occur. However, with the larger nozzle (9/64 LP), pressure would drop from 50 to 35 psi, which is the desired response of the system. The drop in pressure results from forcing the pump to operate at a higher capacity, which in turn develops less head and consequently less pressure.

At the same time, the application rate of the system would increase slightly, thus reducing the set time required to apply the needed water. For this particular pump, however, the horse-power demand would also increase, because BHP demand increases as capacity increases. This modification would save energy only if the set time were reduced to compensate for the increased application rate. If the set time were not reduced, then energy costs would be higher than those of the original system because of the increased horsepower demand. Thus, it is possible to reduce the pressure of an irrigation system yet increase energy costs.

Table 3 shows that significant energy savings result only from reducing the impeller diameter or rpm. Using a 5 percent impeller trim (or 5 percent reduction in rpm) and the 1/8 low-pressure nozzle would reduce pressure by 14 percent from the initial pressure and energy consumption by about 9 percent. With a 10 percent trim, the pressure would be reduced by 26 percent and energy use by 18 percent.

Our example assumes that no change in uniformity of application occurs as a result of the modification. If a change does occur, spacings should be reduced to maintain a satisfactory uniformity. Otherwise, longer operating times may be required for adequate irrigation.

TABLE 3. Effect of sprinkler system and pump modifications on energy consumption

Modification	Nozzle pressure	Wetted diameter	Nozzle discharge	Application rate	Set time	BHP	Energy consumed per set
	psi	*ft*	*gpm*	*in/hr*	*hr*		*kwh*
Standard nozzle (1/8)	50	80	3.19	0.256	19.9	82	1,353
Low-pressure nozzle (1/8)	49	78	3.22	0.258	19.8	82	1,346
Low-pressure nozzle (9/64)	35	75	3.41	0.273	18.7	84	1,302
5% impeller trim (1/8 low pressure)	42	76	2.99	0.240	21.2	70	1,230
5% impeller trim (9/64 low pressure)	30	74	3.18	0.255	20	71	1,177
10% impeller trim (1/8 low pressure)	37	76	2.80	0.225	22.7	59	1,110
10% impeller trim (9/64 low pressure)	27	74	2.99	0.240	21.2	60	1,054

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