most effective, and the two lower EZ:EE ratios captured relatively few moths (table 1).

Analysis of the septa after this test showed that, after 19 days, EZ:EE ratios in all septa had decreased to below the average figure of 89.2:10.8 found in the females. The ratios found in the lures indicate that, during the test, those with initial values of 98.5:1.5 and 90:10 EZ:EE were changing, mainly throughout the range found in the females, while the 80:20 lures would have been, at best, marginal at the beginning of the test and considerably below the values found in females during much of the test. Thus males in this area greatly preferred the percentages found in females native to this area.

In San Diego, the 50:50 EZ:EE lures caught very few moths, while catches of the other treatments increased with increasing EZ:EE ratio (table 1).

All seven single pair matings between low-ratio moths produced either all progeny in the 37 percent EZ range or progeny in both the 58 percent and 37 percent ranges (table 2). These results suggest that the females in the low-ratio areas consist of two races.

Conclusions

Results of pheromone gland analyses and trapping studies in Santa Barbara and San Diego County avocado groves suggest that males in the dominant populations of *Amorbia cuneana* respond to high-ratio EZ:EE (greater than 8:2) female sex pheromone. These findings contrast with the response to low-ratio EZ:EE (equal to or less than approximately 1:1) previously found in males from Riverside, Orange, Ventura, and Tulare counties. The current evidence suggests that high- and low-ratio populations may not cross-respond. If so, the possibility exists that such populations represent different species. In the case of the low-ratio population collected in Ventura, limited "forced" mating trials suggest that the existing differences could possibly involve two races.

Growers and pest management professionals can benefit from this research in at least two ways: (1) it is possible to learn which pheromone ratio is most effective in their particular area, and (2) the pheromones have potential use in timing control procedures in an integrated pest management (IPM) strategy.

J. Blair Bailey is Extension Entomologist, Department of Entomology, University of California, Riverside, currently stationed at the UC South Coast Field Station, Irvine; Kirk N. Olsen is Field Assistant, South Coast Field Station; Leslie M. McDonough is Pheromone Chemist, USDA-ARS Laboratory, Yakima, Washington; and Michael P. Hoffmann is Staff Research Associate, Department of Entomology, UC Davis.

Uniformity of low-energy precise-application (LEPA) irrigation machines

Blaine R. Hanson ❑ Lawrence J. Schwankl ❑ Allan Fulton

Machine movement and soil characteristics are important

Since a major source of saline subsurface drainage water in the San Joaquin Valley is nonuniform irrigation, increasing the uniformity of applied water should help solve the problem. The higher the uniformity, the greater the potential for drainage reduction with little effect on yield.

Low-energy precise application (LEPA), developed in Texas to reduce irrigation energy costs, has been reported to have a high potential uniformity. This system uses a center-pivot or a linear-move machine with drop tubes that discharge water directly into a furrow. A nozzle or emitter at the end of the drop tube controls the flow.

Uniformities between 94 and 97 percent have been reported for an experimental system in Texas with the only losses stemming from a drop in hydraulic pressure along the 480-foot lateral and possible manufacturing variability among the outlets. Because of these reported high uniformities, LEPA has been advocated as a way to reduce drainage in the San Joaquin Valley. At the reported uniformities, subsurface drainage could be reduced to 5 to 6 percent of the applied water with little adverse effect on yield.

There are possible problems, however. Because the discharge rate from drop tubes of LEPA systems is much higher than the soil's intake rate, ponding in the furrow may occur. This creates a potential for surface runoff and lower application uniformities. In west Texas, runoff is prevented by furrow dikes or checks.

A source of nonuniformity not considered in the Texas study is variation in the discharge time (defined here as the discharge opportunity time [DOT]) between checks, which depends on both the spacing of the furrow checks and the movement characteristics of the machine. Although classified as continuous-move, LEPA machines actually move in a start/stop pattern, which may result in significant nonuniformity of the applied water. Computer modeling by Arizona researchers showed uniformities ranging from 60 percent for a 3-foot check spacing to about 80 percent for a 30-foot spacing. Ponding of applied water may also contribute to nonuniformity because of variability of the soil infiltration rate between checks.

For these reasons, a LEPA system may have considerably lower uniformity than that determined by measuring only hydraulic losses. This study was designed to evaluate the effect of these sources of nonuniformity on the performance of LEPA.

Procedures

We measured the discharge opportunity times of a linear-move machine designed for either drop tubes or spray nozzles every 40 inches. Span length was 150 feet, with eight spans on either side of the engine/pump tower. No furrow checks were used.

Movement characteristics of towers 1 (adjacent to engine tower), 3, 5, 7, and 8 (outermost and control tower) were determined by monitoring tower movement along a 195-foot sample area divided into 3-foot intervals. Since the grower was using spray nozzles at the time of the test, we simulated drop tubes discharging into a furrow by establishing a reference point on the towers. Times required for the reference point to move each 3 feet were recorded, along with on/off times and distances per move. The movement times were considered as the discharge opportunity time for each interval. Different check spacings were simulated by grouping the smaller intervals into progressively larger sets. Uniformity (Christiansen's coefficient of uniformity) for the discharge opportunity times was calculated for each simulated spacing.

The effect of the variability of the soil intake rate was analyzed using data obtained during an experiment on furrow irrigation by W. W. Wallender. For this experiment, furrow intake rates were measured in consecutive 3.2-foot intervals. Intake rates between checks were simulated for different spacings by grouping the 3.2-foot intervals into sets of 6.5-, 9.8-, 13.1-, 26.2-, and 52.5-foot intervals.

Experimental low-energy precise-application (LEPA) machine equipped with both spray nozzles (background) and drop tubes (foreground). "Bubblers" at the ends of the tubes discharge water directly into furrows (right). The system is credited in some areas with uniformities as high as 97 percent, but tests in California that considered machine movement patterns and soil intake rates showed lower uniformities.

Results

Discharge opportunity times for tower 8 were fairly constant along the sample line except for a large spike at about 125 feet (fig. 1). A marked repeating pattern occurred every 6.5 to 9.8 feet. Movement characteristics (on/off times; distances per move) were constant (table 1). The average distance per move of 4.6 feet and the consistency of these characteristics caused the strong repeating pattern in the opportunity times.

Tower 5 had much more variable movement times, with several large spikes and a small time at about 85 feet (fig. 1). There was no apparent regular pattern. Movement characteristics were also much more variable; average distance per move was 1.3 feet (table 1). As a result, correlations between discharge opportunity times and movement characteristics were not evident. This behavior was typical of the other towers.

TABLE 1. Statistics of movement characteristics of towers 5 and 8

Characteristic	Average	Standard deviation	Coefficient of variation
			%
Tower 5:			
Distance/move (feet)	1.3	0.7	59
On times (seconds)	9	6	72
Off times (seconds)	8	8	100
Tower 8:			
Distance/move (feet)	4.6	1.0	25
On times (seconds)	34	8	24
Off times (seconds)	21	10	48

Uniformity of discharge opportunity times for the five towers tested was 69 to 80 percent at a 3-foot spacing, with an average of 74 percent. Tower 8, with the most consistent movement, had the highest uniformity. Uniformity rapidly increased with spacing up to about 13 feet, where it was 91 to 95 percent (average, 93 percent). Thereafter, uniformity slowly increased with spacing. At the 52.5-foot spacing, uniformities ranged between 95 and 98 percent, with an average of 96 percent.

As the check spacing increases, uniformity of the volume of water discharged between checks increases, but uniformity of the infiltrated water may decrease. Ponding of water means that variability of the soil intake rate between checks can cause nonuniform water infiltration. Such variability may be minimal for small spacings but, for large spacings, may control the uniformity.

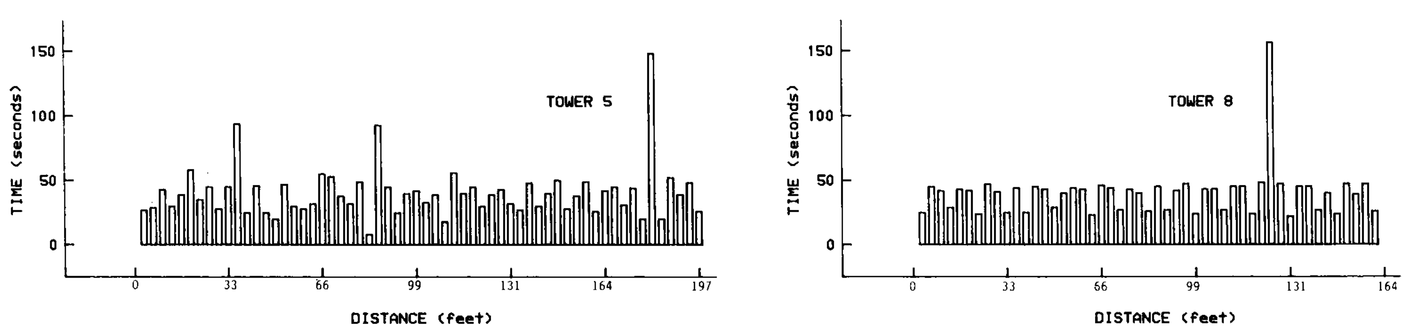

Fig. 1. Discharge opportunity times at 3-foot intervals along travel paths of two typical irrigation machine towers. Tower 8 (right) had fairly constant times, except for a large spike at about 125 feet. Tower 5 had much more variable movement times.

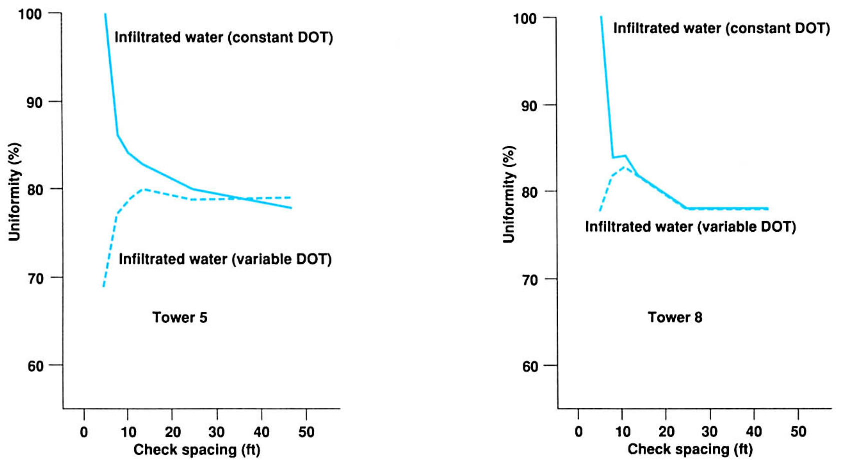

Fig. 2. Uniformity of infiltrated water for constant and variable discharge opportunity times (DOT). Uniformity decreased to about 83 percent with an increase in check spacing to 6 feet, then continued to decrease slightly.

The uniformity of infiltrated water as affected by variability of the intake rate is shown in figure 2 for both constant and variable discharge opportunity times. For constant discharge opportunity times, the same volume of water is applied between each check, and the only source of uniformity of infiltrated water is variability in the intake rate. For a 3-foot spacing, uniformity is assumed to be 100 percent, since intake rates were measured over 3-foot intervals. As the check spacing increased to 6.5 feet, however, uniformity of infiltrated water decreased to about 83 percent. Further increases in check spacing only slightly decreased the uniformity of infiltrated water. The uniformity for a 52.5-foot spacing, about 79 percent, probably reflects the uniformity of the soil intake rate.

The decrease in uniformity from 3- to 6.5-foot spacings would be expected, but the reason for the decrease at larger spacings is less obvious. Between two checks, transfers of ponded water from sections of relatively low intake rates to sections of higher rates will occur. As check spacing increases and larger volumes of water are ponded between checks, slightly more water infiltrates into the sections with the higher intake rates. This causes uniformity to decrease slightly as the check spacing increases.

For the variable discharge opportunity times, both nonuniformity of the DOTs and the intake rates affect the uniformity of infiltrated water. The minimum uniformity occurred for the 3-foot spacing. As check spacing increased, however, the uniformity of infiltrated water increased to a maximum, about 80 to 82 percent, for check spacings of 9.8 to 13.1 feet (fig. 2). Further increases in the check spacing slightly reduced the uniformity. For spacings of less than about 10 feet, uniformity of infiltrated water was controlled by variability in the discharge opportunity times, with the uniformity of the infiltrated water for the 3-foot spacing equal to that of the 3-foot discharge opportunity times. For larger spacings, the uniformity was controlled by the variability in the soil intake rate.

This analysis assumes level fields. For many areas of the San Joaquin Valley, this assumption would be appropriate if furrows were perpendicular to existing field slopes, frequently between 0.1 and 0.2 percent. For sloping furrows, however, a nonuniform depth of ponded water between checks can contribute to nonuniform infiltration. This source of nonuniformity, affected by slope, spacing, and volume of applied water, causes an upper limit to the maximum check spacing for complete coverage of water between checks, as suggested in the Arizona study.

The uniformity of infiltrated water might be improved by frequent applications so that the soil intake rate remains at or near the steady-state intake rate. This strategy also may be desirable in cracking soils to maintain the condition of furrow checks. However, frequent irrigations can decrease the percentage of time the machine is available for applying water, thus resulting in less than effective use of the system.

The trade-offs between check spacing, machine movement, and variability of soil intake rates suggest that a substantial increase in uniformity might result from improvement in the uniformity of the discharge opportunity times for the 3-foot spacing. The use of such spacings would greatly reduce the nonuniformity due to variability of the soil intake rate. A comparison between uniformities of 3-foot check spacings and of movement showed that high uniformity will occur if the average distance per move equals 3 feet with little variability in the movement characteristics. While those characteristics may be attainable for the control tower, current technology does not provide such precise movement along the lateral.

TABLE 2. Coefficient of uniformity of cumulative volume of infiltrated water for multiple irrigations, tower 5

	Uniformity at check spacing of (feet):					
Irrigation	3	6.5	9.8	13.1	26.2	52.5
			%			
1	69.4	77.4	78.1	79.5	79.0	78.9
2	78.3	81.1	81.0	81.5	79.0	79.0
3	79.4	82.3	79.9	82.8	79.0	79.0
4	81.6	82.6	81.0	82.4	78.8	78.9
5	82.9	83.4	80.6	82.6	78.8	78.9
6	82.9	83.7	81.6	82.1	79.0	79.0

This analysis is based on a single irrigation. As multiple irrigations occur, the uniformity of the cumulative infiltrated water will increase. We assessed this behavior for six irrigations by randomly selecting starting points along the sample lines of 3-foot movement times for each irrigation and then developing a new sequence of times. Volumes of infiltrated water calculated with the new data were compared with previous irrigations. The results for six irrigations (table 2) show that for a 3-foot check spacing, the uniformity increased from about 69 percent for the single event to nearly 83 percent for the fifth and sixth irrigations (we used tower 5 data for this analysis since it was typical of most of the other towers). Uniformity of the 6-foot spacing increased from 77 to 84 percent. Little change occurred for larger spacings, indicating that soil variability controls the uniformity.

Conclusions

We feel that, while uniformity as affected by hydraulic losses alone may be high with a LEPA system, uniformity of infiltrated water also depends on movement characteristics of the machine and on variability of the soil intake rate. For the data used in this analysis, a realistic potential uniformity might be 80 to 85 percent for check spacings of 10 to 13 feet for level furrows. For smaller spacings, uniformity of discharge opportunity times (determined by the machine movement) is the controlling factor. The soil intake rate controlled the uniformity of infiltrated water for larger spacings.

This analysis is based on one type of machine, one speed setting, and one soil type. For other conditions, results might be different. These results show, however, that uniformity of infiltrated water under LEPA irrigation systems can be affected by the sources of nonuniformity we have considered here. Evaluations of these irrigation systems under other conditions must take these sources into account if a realistic assessment of uniformity is to be obtained.

Blaine R. Hanson is Irrigation and Drainage Specialist, and Lawrence J. Schwankl is Irrigation Specialist, Department of Land, Air, and Water Resources, University of California, Davis; Allan Fulton is Farm Advisor, Kings County.