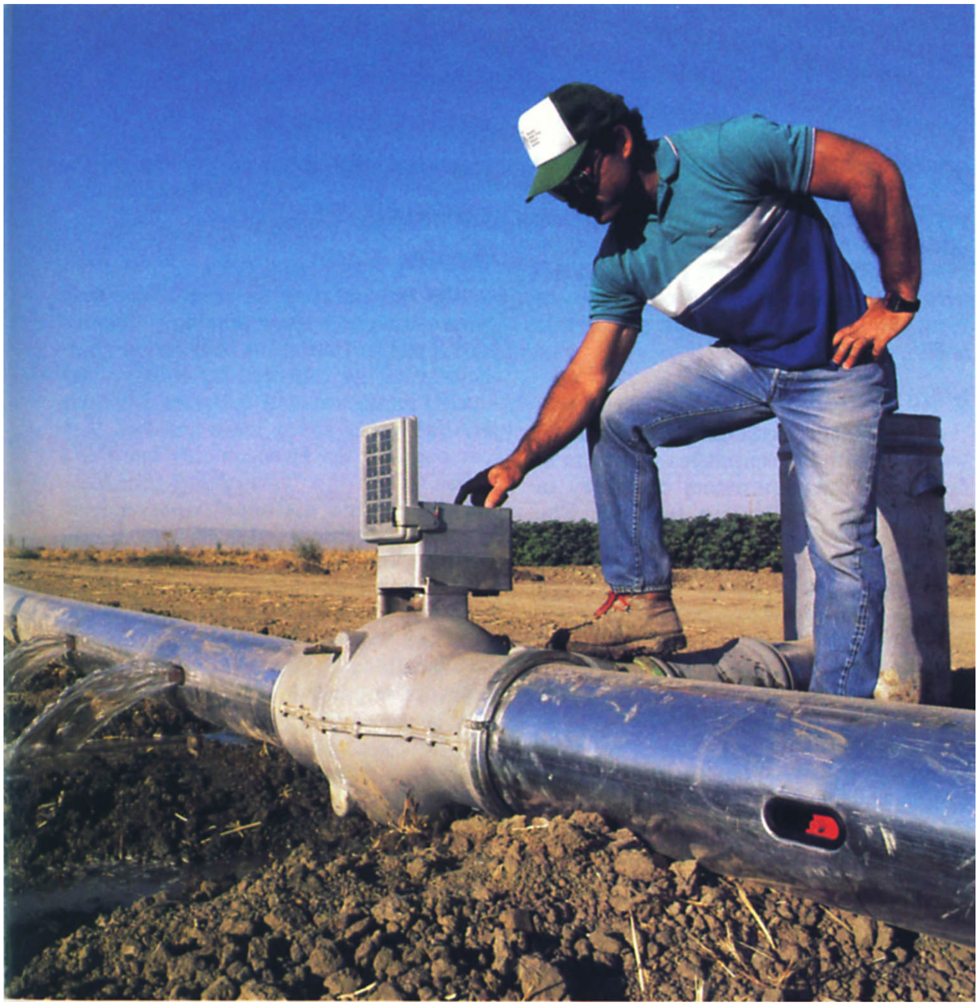

Irrigation specialist Dave Goldhamer sets the solar-powered flow control valve of a surge irrigation system, in which water is applied in a series of pulses.

Jack Kelly Clark

Surge vs. continuous-flow irrigation

David A. Goldhamer ☐ Mohammad H. Alemi ☐ Rebecca C. Phene

A primary goal of good irrigation management is to minimize deep percolation of water (infiltration exceeding the irrigation requirement) while replenishing soil water in the plant root zone along the entire length of the field. Deep percolation losses depend directly on irrigation system performance, which, in turn, depends mainly on how evenly water infiltrates across the field. Furrow and border irrigation, the primary methods used in the drainage problem area of the San Joaquin Valley's West Side, usually have relatively low uniformities because of (1) unequal infiltration opportunity times for water across the field, and (2) spatial variability in soil water transport properties. Properly designed and managed sprinkler and drip irrigation systems, on the other hand, commonly achieve a better uniformity, since the amounts infiltrated depend primarily on application rates and system design rather than on soil infiltration properties.

Changing from surface to sprinkler or drip irrigation systems to improve the uniformity of infiltrated water and decrease drainage volumes may not be economically feasible for many growers. Even though the best-managed surface systems may not equal the application efficiencies possible with sprinkler or drip systems, enhancing the performance of existing surface systems by improved management or innovative irrigation strategies may be an alternative until long-term solutions to the drainage water disposal problem are found.

Surge irrigation, the application of water as a series of pulses rather than conventional continuous inflow, has been proposed as a means of improving the uniformity of surface methods. The principles of this technique are not new to California; "bumping," or noncontinuous application, has been used when attaining water advance to the end of the field has been a problem. Research conducted primarily in Utah, Colorado, and California has shown that the surge method can increase the rate of stream advance, thereby decreasing differences in infiltration opportunity times across the field. The improvement in advance has been attributed to a reduction in the infiltration rate due to wetting and drying cycles created by the pulse application. Suggested mechanisms responsible for this behavior include surface sealing due to soil particle rearrangement, surface layer consolidation, a more diffuse wetting front, and air entrapment in the soil.

While accelerated advance rates with surge are clearly documented, other studies have found it to provide little or no improvement. Lack of positive results with surge appears to occur most often on fine-textured, cracking soils, which are the type most often found in the drainage problem areas of California. Since field evaluation of surge irrigation on these and other soils in California has been limited, we undertook a study to compare the performance of surge and continuous-flow irrigation on different California soil types.

Field studies

This work was conducted with grower cooperators in Kern and Fresno counties. We studied numerous fields, but report here on results from two sites, one with a Wasco sandy loam and the other a Panoche clay loam. Each field was 1,200 feet long and had graded furrows. Evaluations were made during preplant irrigation or the first postplant irrigation, when infiltration rates are relatively high. Randomized plots, usually replicated four times, were established for both irrigation methods.

Each plot contained at least one of the four furrow "types" found in each tractor/implement pass through the field: (1) traffic (hard), (2) nontraffic (soft), (3) nontraffic — guess (last furrow in each pass), and (4) nontraffic — belly (furrow between traffic furrows). Each furrow type be-

TABLE 1. Operational data for each case evaluated

Item	Wasco sandy loam	Panoche clay loam
Basic intake rate (inch/hr)	0.91	0.53
Field length (ft)	1,200	1,200
Irrigation requirement (inches)	8	8
Inflow rate (gal/min)		
Surge	40	35
Continuous	40	31
Total application time (min)		
Surge	270	942
Continuous	475	1,190
Surge on-times (min)		
Advance 1	24	27
2	32	36
3	40	45
4	48	54
5	56	63
6	70	75
7	—	72
8	—	120
Post advance	42	45

haves differently with respect to advance, and we have limited our presentation here to data only for the nontraffic (soft) furrows.

Two parallel gated pipelines were positioned at the top of the field, one equipped with a Tee-type (butterfly) surge valve and the other set to operate continuously. The surge valve had a controller and internal program that allowed for variable surge "on-times" during the irrigation. A cycle ratio of 0.5 was used, resulting in equal on- and off-times.

High, non-erosive inflow rates were selected. Equal instantaneous inflow rates for each method were compared, although slight differences sometimes existed. Flow rates were monitored with flumes or orifice plates at the inlet and the end of field throughout the irrigation. Steady state (basic) intake rates were determined by taking the difference in inflow and runoff just before the end of the irrigation. Advance and recession were monitored by recording the arrival and disappearance of water at increments of 50 or 100 feet across the field. Intake opportunity times were calculated as the difference between the advance and recession values. Hydraulic cross-sectional area was measured at various distances from the inlet during stream advance in each monitored furrow.

Infiltration distribution

A "two-point" volume balance model was used with the continuous-flow data to determine the parameters necessary to describe the infiltration function. The two-point technique has proved to be quite accurate in previous continuous-flow furrow evaluations based on predicted and measured runoff. We used the infiltration data, along with the measured intake opportunity times, to calculate the distributions of infiltrated water under both irrigation methods.

Predicting the distribution of infiltrated water under surge is more complex than under continuous flow, in that multiple infiltration functions must be used to account for the intermittent wetting. Several researchers have presented models that include descriptions of infiltration under surge. These mathematical descriptions allow for adjusting the normal infiltration function based on the immediate wetting history of the soil. The following three zones (parts of the furrow) are identified for computing infiltration:

(1) dry zone — soil wetted only by the current surge.

(2) transition zone — soil wetted by one or two previous surges.

(3) wet zone — soil wetted by two or three previous surges.

Researchers have chosen different wetting regimes associated with the transition and wet zones. Our choice of the appropriate transition and wet zone descriptions used in each comparative evaluation reported here was based on the predicted cumulative infiltration and the measured cumulative inflow during the advance phase differing by no more than 5 percent.

Results

Operational data for each of the field sites evaluated appear in table 1. The two soil types had different infiltration characteristics, as reflected by steady state (basic) intake rates of 0.91 inch per hour for the Wasco sandy loam and 0.53 inch per hour for the Panoche clay loam. We chose to use the "variable on-time/constant advance distance" approach to surge management in our studies. By increasing the on-time for each successive surge, the advance of water over dry soil is nearly constant. This approach is opposed to "constant on-time/variable advance distance," in which dry advance is progressively less for each surge.

The surge advance and recession data for the Wasco sandy loam show that water traveled rapidly over the soil wetted by previous surges but then slowed dramatically once dry soil was encountered (fig. 1). This behavior results in the trajectories having a "knife" shape, except at the head end of the field, where the recession was relatively fast. More time was required for the surge irrigation to reach a given distance across the field than with continuous flow. With surge, however, water was applied to the test furrows for only one half of the elapsed irrigation time. Thus, if the continuous advance trajectory just touched the tips of each of the surge "knives," equivalent advance would have been achieved with 50 percent less water than required with continuous flow.

The conditions at the Wasco site under which the comparison of infiltration distributions was made — a high infiltration rate and a small irrigation requirement (2.75 inches) — made it difficult to achieve good irrigation performance (fig. 2). Much less infiltration occurred with surge; the maximum amount infiltrated

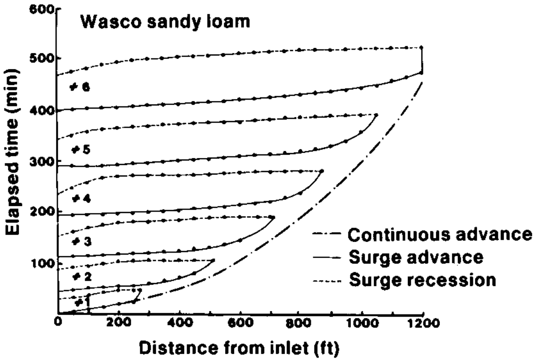

Fig. 1. Measured advance and recession trajectories for the six surges required for full advance at site with Wasco soil. Continuous flow advance is also shown.

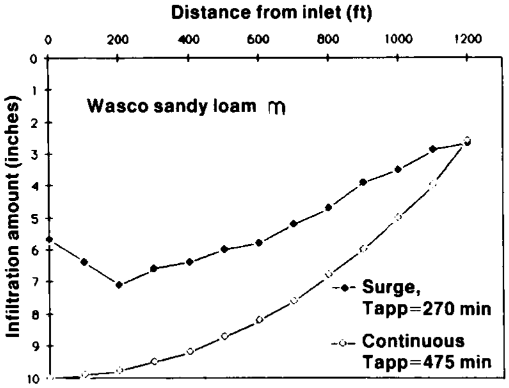

Fig. 2. Calculated distributions of infiltrated water at water application times (Tapp) when the irrigation requirement (2.75 inches) at the end of the field was satisfied.

TABLE 2. Irrigation performance parameters

Case	Full advance Appl. time	Full advance Volume ratio*	Amount stored	Deep percolation	Runoff	Appl. effic.	Distri. unfrmty
		min	inches			%	
Wasco sandy loam							
Surge	270	0.61	2.75	2.54	0.03	60.4	55.6
Continuous	440	0.61	2.75	4.87	0.10	35.5	57.2
Panoche clay loam							
Surge	492	0.57	7.87	2.41	1.44	67.1	81.4
Continuous	868	0.57	7.87	5.69	0.65	55.4	70.8

* $\text{Volume}_{\text{surge}}/\text{Volume}_{\text{continuous}}$

was 7.1 inches compared with 10 inches for the continuous flow. However, the calculated distribution uniformities, based on infiltration near the end of the field relative to the average amount infiltrated, were 55.6 for surge and 57.2 for continuous flow (table 2). Deep percolation was much greater with continuous flow, which was largely responsible for an application efficiency (the percentage of applied water stored in the root zone) of 35.5 percent compared with 60.4 percent for surge irrigation. Even though the calculated uniformity was lower, the surge technique improved irrigation performance.

One measure of the relative performance of surge and continuous flow is the ratio of the volumes of water required to attain a given advance distance (fig. 3). Advance times used to generate this information were always less than or equal to the on-time for each surge (that is, advance that occurred after inflow for a particular surge had ceased was not considered). Values of the volume ratio less than one indicate that less water was required for surge than for continuous advance. Both cases show that the volume ratio was always less than one. Volume ratios decreased with distance from the inlet at the Wasco site but generally increased with distance at the Panoche site. While the reason for this behavior is not clear, it apparently involves the number of advance surges used — six and eight for the Wasco and Panoche sites, respectively — and associated on-times. The volume ratios at the end of the field were similar, averaging 0.59. Field-measured full advance volume ratio data collected at other sites had similar values.

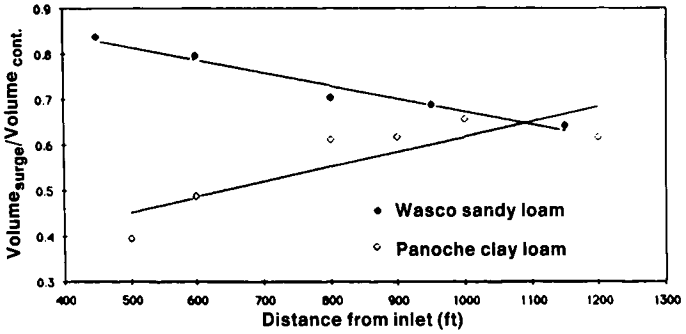

Fig. 3. Advance volume ratios with distance across the field.

The calculated distributions of infiltrated water at the Panoche site shown in figure 4 are, again, for when the irrigation requirement at the end of the field (7.9 inches) had just been satisfied. This case represents a typical preplant irrigation situation on the West Side of the San Joaquin Valley. Under surge, 942 minutes of water application were needed to meet the irrigation requirement, compared with 1,190 minutes for continuous flow. The resulting distribution uniformities were 81.4 and 70.8 percent for surge and continuous, respectively. More than twice as much deep percolation occurred under continuous flow, although cumulative runoff was less.

It should be noted that total surge runoff was greater at the Panoche site because of the longer elapsed irrigation time required by the intermittent water applications. Cumulative runoff hydrographs for the Panoche soil show that the time-averaged runoff rate over the period during which runoff occurred for each irrigation method was lower with surge (fig. 5). This result suggests that there was no large reduction in the basic soil intake rate with surge, a situation that could present a water management problem in attempting to refill the soil moisture reservoir in a timely manner. In other words, the surge influence appears to occur during the early stages of infiltration when the intake rate is relatively high.

Using linear slopes of the hydrographs over the period that runoff took place, the surge runoff rate was approximately 75 percent that of continuous. Recent research has shown that using a shorter post advance (cutback) surge cycle or using continuous flow during post advance (setting the surge valve in the "neutral" position, thus applying water through open gates on both sides of the Tee but at half the advance inflow rate) can further decrease the runoff rate, minimizing tail-

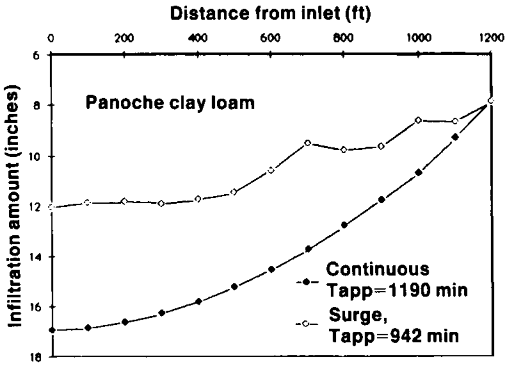

Fig. 4. Calculated distributions of infiltrated water for the Panoche soil site when the irrigation requirement at the end of the field was satisfied.

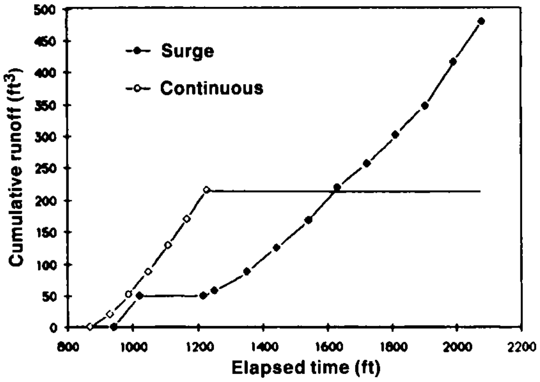

Fig. 5. Cumulative runoff hydrographs showed that the runoff rate was lower with surge irrigation.

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water. One of the problems in the past in using relatively high inflow rates with continuous flow to achieve good distribution uniformity has been excessive runoff. Surge irrigation appears to offer a partial solution by using rapid post advance cycling or continuous inflow at a relatively low rate.

Conclusions

Surge irrigation accelerated water advance rates in the two field situations reported in this study. Other evaluations (data not shown) yielded similar results. The results were presumably due to the influence of the wetting and drying cycles on soil infiltration characteristics. The full (end of field) advance volume ratio of surge to continuous flow averaged 0.59. This resulted in generally improved distributions of infiltrated water and consequently lower drainage volumes. Time-averaged runoff rates were lower under surge, although cumulative runoff was greater because of longer irrigation set times required to apply a given amount of water.

Based on this study, surge irrigation appears to be a promising short-term alternative for decreasing drainage volumes in California while using existing surface irrigation systems, especially for early-season irrigations where high infiltration rates can result in low application efficiencies with continuous flow. Improving poor efficiencies associated with surface-irrigated, shallow-rooted crops also appears to be possible using surge irrigation. More information is needed to establish best management practices, including the optimum combination of inflow rates, cycle times, and number of surges.

David A. Goldhamer is Irrigation and Soil Specialist, Cooperative Extension, University of California Kearney Agricultural Center, Parlier; Mohammad H. Alemi is Visiting Soil and Water Scientist, Department of Land, Air and Water Resources, UC Davis; and Rebecca C. Phene is Staff Research Associate, Cooperative Extension, Kearney Agricultural Center, Parlier. *The authors thank the following for help in this study: Kater Hake, Kern County Farm Advisor; Christine Peterson, Kern County Research Assistant; and Zeferino Cervantes, Research Assistant. They also appreciate the cooperation of growers Gary Wilson, John Diener, and Air-Way Farms, Inc.*

Jack Kelly Clark

Surge irrigation, in which water is released into furrows intermittently instead of as a continuous flow, may reduce irrigation water needs by a third, substantially reducing drainage requirements. UC researcher Dave Goldhamer (top) and visiting Japanese scientist Tomoo Inaba check the flow of water from the main feeder line through RBC flumes that measure in-furrow flow rates.