The plot was kept free of weeds by spraying glyphosate in early February, and hand-weeding thereafter. No water or fertilizer was provided.

Emergence of both blue and valley oak species averaged over 95% for this trial. Only the March-sown blue oak acorns had less than 90% emergence by the middle of May. However, sowing date greatly influenced the timing of seedling emergence. The earlier the acorns were sown, the earlier they came up and started to grow (fig. 2 and 3).

Blue oaks emerged over a wider interval than valley oaks. The average emergence date of blue oaks from the November sowing was more than two weeks earlier than for valley oaks. For the March sowing, valley oaks came up an average of 11 days later. Only 50% of the blue oaks sown in March germinated, compared with 90% of valley oaks.

Blue oak planting trial

In April 1987, one-year-old blue oak seedlings, raised in small plastic containers, were planted on a 5-foot spacing in a weed-free field. Planting holes were dug 3 feet deep with a power auger, and 21-gram fertilizer tablets (20-10-5) were placed below the roots. Seedlings were drip-irrigated from planting time until August, at 2 gallons of water once a week for the first 2 months, and 2 gallons every other week thereafter. Screen cages were placed over the seedlings to protect them from grasshoppers, mice, and deer.

At the time of planting, the 120 seedlings were randomly divided into four groups of 30. Each group received one of the following treatments: shade (an 8- x 12-inch screen block placed on the south side of the seedling); mulch (a 3-foot square of roofing felt around the seedling); shade plus mulch; and a control.

At the end of the first growing season, 95% of the seedlings had survived. Growth varied greatly, ranging from dieback of the initial stem to more than 2 feet. Average height growth of all surviving seedlings was over 10 inches. There were no significant differences in either survival or height growth among the four treatments.

Growth of all seedlings in 1988 was even more rapid and vigorous, even though no irrigation was provided. By late August. seedlings averaged 44 inches tall and had grown, on average, 2.5 feet during their second season. In general, seedlings that remained small and stunted during the first season also grew slowly the second year. There were still no significant differences among treatments.

Conclusions

This research demonstrated that, with proper treatment and planting of acorns and seedlings, California blue and valley oaks can be successfully propagated. If blue oaks are to be seeded directly, acorns should be collected during September or early October while they are still on the trees. After collection, they should be refrigerated immediately (in 1.75-mil zip-lock storage bags) to prevent drying and kept cold until they are planted. Both blue and valley oak acorns can be planted from early fall (after the first soaking rains) until midwinter. Early sowing is favored. In dry years, early initial growth may give seedlings a better chance to become established before soil moisture becomes limiting.

These results have important implications for the production of native oaks in bare-root nurseries. Early-season sowing should allow nursery operators to produce larger seedlings in a shorter time.

Blue oak seedlings can be successfully established by directly planting small container plants. Excellent survival and vigorous growth can be achieved if seedlings are planted in deep augured holes and irrigated and fertilized during the first summer after planting, and if the area around them is kept free of competing vegetation. Damage to seedlings from insects, mice, and deer can be prevented by caging with aluminum window screen. Additional measures to protect seedlings from livestock may be necessary in grazed areas.

Research on the artificial regeneration of oaks is continuing. Investigations include seedling container size, fertilization, effects of acorn size, direct-seeding acorns versus planting seedlings, and irrigation practices.

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Drainage reduction potential of furrow irrigation

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The most practical way to dispose of irrigation drainage water in the San Joaquin Valley is to reduce the volume of the water at its source through better irrigation management. Upgrading furrow irrigation systems and cutting run lengths in problem areas reduced drainage 60% to 80%.

Subsurface drainage results from overirrigation (least-watered areas of the field receive more than the soil moisture depletion) and nonuniform irrigation. Because of nonuniformity, if the least-watered areas receive enough water to replace soil moisture depletion, other areas must receive more, and subsurface drainage occurs. Keys to drainage reduction are thus to improve the uniformity of application and reduce the amount of water applied by improving application efficiency.

A source of nonuniformity in furrow irrigation is the advance time—the time it takes for water to flow from the upper end of the field to the lower. Soil infiltration rate, length of run, furrow inflow rate, surface roughness, slope of the field, and furrow cross-sectional shape all affect advance time, but the infiltration rate has the greatest influence. The advance time plus the time required for water to infiltrate to a desired depth at the end of the furrow is the set time. Advance time is easily measured and is used to assess the effect of system changes on the uniformity of infiltrated water.

A second source of nonuniformity is variability of the soil intake rate in different areas of the field. This includes differences in soil texture, random variability of the infiltration rate within a soil texture, and variability caused by differences between wheel and nonwheel furrows. The extent of this variability is usually unknown. For one soil texture, however, a UC study showed distribution uniformity (DU) to be about 68% (coefficient of uniformity, CU = 80%).

Nonuniformity can also result from different individual furrow inflow rates during a set, variability in the field inflow rate during irrigation, and slope variability within a field. Different day and night set times also contribute to field-wide nonuniform water applications.

Ways to reduce drainage

Subsurface drainage in furrow irrigation systems can be reduced by upgrading existing systems, converting to surge irrigation or level basin irrigation where appropriate, and changing set times.

Furrow irrigation systems can be upgraded by shortening the length of run, increasing the inflow rate, improving the slope uniformity, and reducing the surface roughness and infiltration rate by furrow compaction. These measures cut down the advance time and improve uniformity. Their effects on uniformity due to soil variability are unknown. However, shorter run lengths may improve this uniformity if there are substantial differences in soil texture. One UC study found that compaction of nonwheel furrows may reduce differences between wheel and nonwheel furrows.

The two-year study reported here entailed gathering irrigation data to field-verify computer models of the performance of a furrow irrigation system. Information was collected for three furrow inflow rates—inflow and outflow, advance times, depth of flow and furrow cross-sectional shapes—and field length and slope. This information, coupled with the computer model, was used to assess the potential of upgrading measures to reduce drainage.

TABLE 1. Subsurface drainage, surface runoff, and set times for site ST

Flow rate	Run length	Subsurface drainage	Surface runoff	Set time
gpm	*mile*	*inches*	*inches*	*hours*
37	0.5	2.5	1.1	22
	0.25	1.0	3.4	12
	0.125	0.4	8.4	9
43	0.5	1.6	1.7	19
	0.25	0.7	4.4	11
	0.125	0.3	10.2	8
56	0.5	1.4	2.0	15
	0.25	0.6	4.6	9
	0.125	0.3	11.5	7

TABLE 2. Performance characteristics, site ST

Inflow rate	Run length	Application efficiency*	Distribution uniformity·
gpm	*mile*	%	%
37	0.5	76	78
	0.25	91	87
	0.125	97	92
43	0.5	83	82
	0.25	94	89
	0.125	98	93
56	0.5	86	84
	0.25	95	90
	0.125	98	93

* Assumes recirculation of surface runoff.
· Does not account for soil variability.

TABLE 3. Subsurface drainage, surface runoff, and set times for site BU

Flow rate	Run length	Subsurface drainage	Surface runoff	Set time
gpm	*feet*	*inches*	*inches*	*hours*
18	1,440	3.3	0.2	17
	720	0.8	2.1	8
	480	0.4	4.3	6
25	1,440	4.5	0	14
	720	0.9	1.9	6
	480	0.5	4.1	4
34	1,440	4.3	0.1	10
	720	1.1	1.7	4
	480	0.6	3.5	3

TABLE 4. Performance characteristics, site BU

Inflow rate	Run length	Application efficiency*	Distribution uniformity·
gpm	*feet*	%	%
18	1,440	58	69
	720	89	86
	480	95	90
25	1,440	51	66
	720	88	85
	480	95	92
34	1,440	54	67
	720	85	83
	480	93	89

* Assumes recirculation of surface runoff. · Does not account for soil variability.

Site ST

This field, clay loam with a saline high water table, consisted of a half-mile run length with a 0.16% slope. Furrow inflow rates used for the evaluation were 37 gpm (grower's normal rate), 43 gpm, and 56 gpm. Data were collected for the preirrigation, first seasonal irrigation in June, and the last irrigation in August. Smaller furrow inflow rates were used for the last irrigation.

Soil moisture depletion was about 6 inches, and there was about 2.5 inches of drainage at the normal inflow rate for the half-mile run (table 1). Reducing the run to 1/4 mile lowered the drainage volume by 60% to about an inch. A further reduction to 1/8 mile reduced drainage to about 0.4 inch, or 16% of normal.

Increasing the furrow inflow rate also reduced subsurface drainage. For the half-mile run, the drainage volume for 43 gpm was about 64% of the normal, while that of 56 gpm was about 56%.

A key to drainage reduction when changing run lengths or furrow inflow rates is to reduce the set time, or overirrigation will occur. Normally, it takes about 22 hours for water to infiltrate 6 inches in the lower end of the field (table 1). About 12 hours are needed with a 1/4-mile run. Set times have to be adjusted for increased furrow inflow rates or there will be more subsurface drainage and surface runoff.

A major problem with furrow irrigation is that losses as subsurface drainage and surface runoff are competitive: Reducing one increases the other. Shortening the run increases the surface runoff, particularly for runs of less than 1/4 mile (table 1).

Surface runoff can be returned to the distribution system, recirculated on the field being irrigated, or used on downslope fields. If the runoff is recirculated, it has to be used to irrigate for a set (or partial set) independent of the district supply, or the surface runoff will become subsurface drainage.

Cutback irrigation, in which the inflow rate is reduced after advance to the end of the field, can reduce surface runoff. It can present problems in dealing with surplus water, however, unless the district flow rate into the field can also be reduced.

The effect of these drainage reduction measures on performance characteristics is shown in table 2. Uniformity due to intake time differences and application efficiency increased considerably when the run length was decreased to 1/4 mile. Further decreases improved performance only slightly. (These estimates of application efficiency assume subsurface drainage to be the only loss, and infiltrated water at the end of the field equals soil moisture depletion.)

Analysis of the other irrigations showed that most of the subsurface drainage came from preirrigation. Little drainage occurs after preirrigation because of the seasonal decrease in the soil infiltration rate. The basic infiltration rate of the preirrigation was about 0.15 inch per hour, compared to 0.07 and 0.02 inch per hour for the June and August irrigations.

Site BU

Run length at the BU site, a sandy loam soil with a high water table, was 1,440 feet with a 0.11% slope. Furrow inflow rates of 18 gpm (normal), 25 gpm, and 34 gpm were used during the evaluation. Only the first seasonal irrigation was evaluated.

Soil moisture depletion was assumed to be 4 inches for this analysis. Under normal conditions, subsurface drainage was about 3.3 inches (table 3). Reducing the run length by half reduced subsurface drainage by 76% to about 0.8 inch. Run lengths a third (480 feet) of the original run reduced drainage by 88%. As with site ST, surface runoff increased at an increasing rate as the run length decreased. This site, however, required much shorter run lengths to substantially reduce drainage than site ST did, mainly because of its higher intake rate (basic infiltration rate of about 0.33 inch per hour). At 18 gpm, the set time must be reduced to about 8 hours when reducing the run by half.

Furrow inflow rates had little effect on subsurface drainage and surface runoff. As the inflow rate rose, the intake rate became higher due to an increased wetted area of the furrow. This behavior offset any drainage reduction benefits of a higher uniformity of intake times along the furrow.

Reducing run lengths increased the uniformity of the intake times from 69% to 86%, and the application efficiency from 58% to 89% (table 4).

The effect of the furrow inflow rate on the intake rate at site BU was not found at site ST. There, the same intake relationship with time was found for all inflow rates, because most infiltration apparently occurred through cracks in the soil. Thus, the intake rate appeared to be independent of wetted area. Once the cracks sealed, there was little additional infiltration and any effect of different wetted areas on the intake rate could not be detected.

Other options

Surge irrigation is another way to reduce drainage in furrow irrigation systems. This method, reported in the September-October 1987 issue of *California Agriculture*, requires about one-third less water for advance across the field than does continuous-flow furrow irrigation. UC studies in the San Joaquin Valley revealed a potential reduction of 30% to 40% of current drainage volumes where the infiltration rates were relatively high.

Level basin irrigation has been successfully used to reduce drainage in Arizona's Wellton-Mohawk Valley. A UC demonstration showed the method to have potential for substantial drainage reduction in areas where large district flow rates are available (15 to 20 cfs) and land leveling is economically feasible. Basin lengths should not exceed 1/8 mile.

Considerations

These results show a good potential for subsurface drainage reduction in furrow irrigation systems. The most effective measure is to reduce run lengths. Reductions of 60% to nearly 80% appear possible by cutting the run length in half. The effect of increasing the furrow inflow rate depended on the soil type. Reductions of 30% to 40% appear possible with surge irrigation.

At site ST, preirrigation was the major source of subsurface drainage, and reduction measures only needed to be carried out during that irrigation. At site BU, however, the large amount of subsurface drainage during the first seasonal irrigation suggests that drainage may be generated throughout the irrigation season, requiring seasonal implementation of these measures.

Major problems exist in achieving the potential drainage reduction:

First, there have to be good estimates of both soil moisture depletion and soil infiltration rates. Depletion information is needed to know how much water to apply. It can be estimated from evapotranspiration where high water tables do not exist. With high water tables, depletion must be measured directly by soil sampling, tensiometers, or neutron probe methods, which may be time-consuming and expensive. Estimates based on evapotranspiration between irrigations will be inaccurate because of the upward flow of water from a shallow water table.

The intake rate needs to be estimated to know how long to irrigate. Unfortunately, the intake rates of many Valley soils are almost impossible to estimate by conventional means, such as ring or blocked furrow infiltrometers and inflow/outflow methods. These are too time-consuming and unreliable in cracking soils. However, relatively simple computer models, coupled with some advance time data, offer a potential for rapidly estimating infiltration rates.

Second, the short runs, such as those required in site BU, may cause problems with field-wide operations and may be relatively expensive. Additional conveyance ditches or pipelines and surface runoff recovery systems will be needed, increasing capital costs. Short runs can also interfere with farming practices.

Third, these drainage reduction measures may require set times incompatible with current labor limitations. Normally, set times of 12 or 24 hours are used because of the ease of labor management. Other set times may be difficult to implement.

Fourth, inflexibility in an irrigation district's distribution system in responding to frequent changes in demand may limit opportunities to change set times. However, automation of furrow irrigation, using valves designed for surge irrigation, may overcome the problems of odd set times versus labor management and district inflexibility.

Fifth, leaching requirements under saline high water tables may limit the amount of drainage reduction to less than the potential.

Conclusions

There is a potential for substantial subsurface drainage reduction with properly designed and managed furrow irrigation systems. Existing systems can be upgraded by cutting run lengths and set times, and/or converting to surge irrigation or level basin irrigation, where appropriate.

However, labor management and cultural practices and the management of distribution systems will need to be changed considerably. The limits imposed by these constraints and the reduced run lengths can only be assessed with field-wide demonstrations of drainage reduction measures. Where these practices cannot be changed, other types of irrigation systems, such as drip/trickle irrigation or linear-move machines will need to be considered.

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