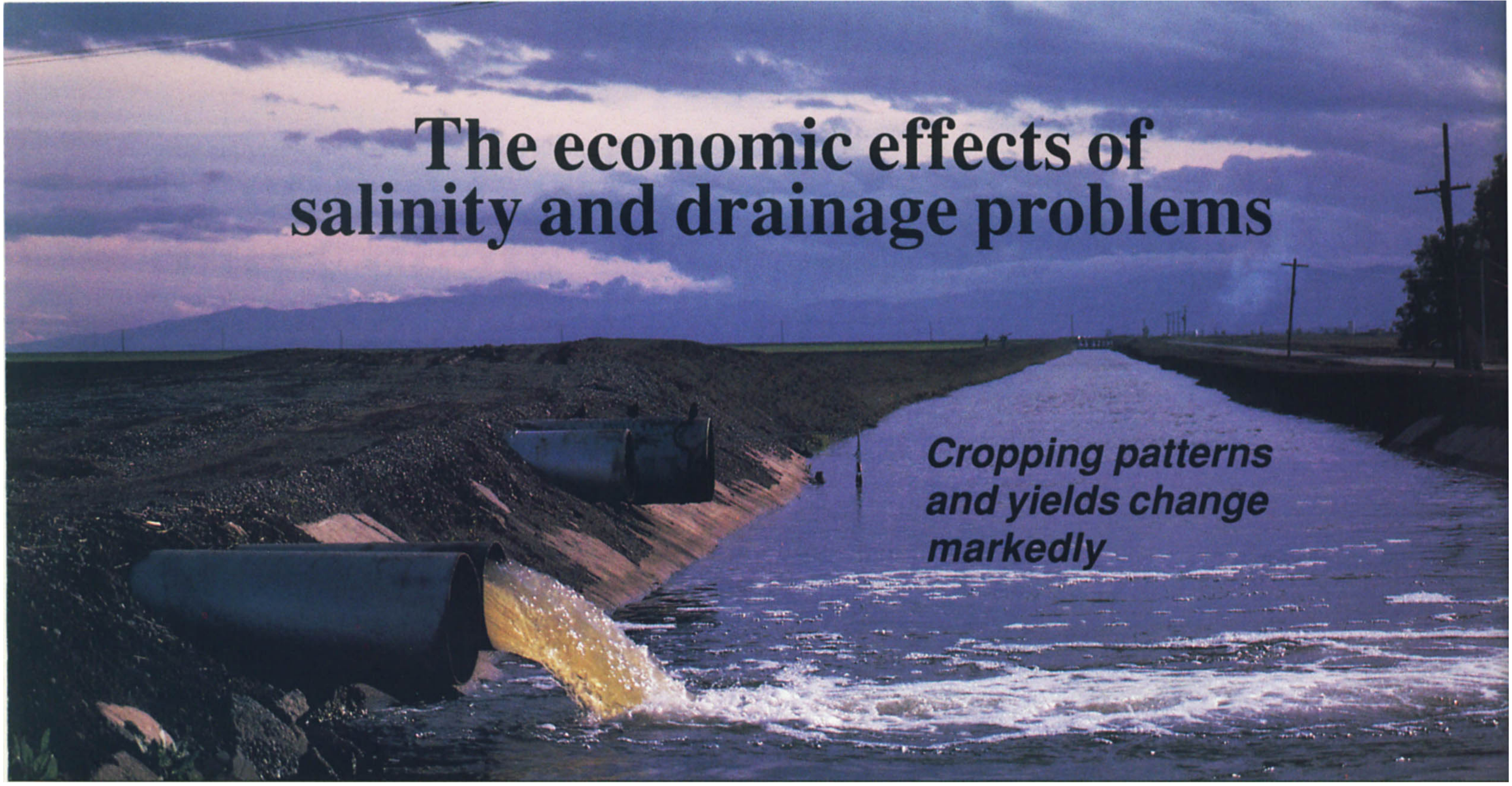
The economic effects of salinity and drainage problems



Cropping patterns and yields change markedly

Until 1983, the Broadview Water District in Fresno County had no drainage outlet for irrigation water and had to recycle surface tailwater and subsurface drain water (below) by mingling it with new water deliveries from the Sacramento River Delta (above). Installation of a drainage outlet significantly improved yields.

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Farmers affected by salinity and high water tables can alter cropping patterns and water use to maintain productivity in the short term. They can apply water to leach salts from the root zone, and install subsurface drainage systems to manage the soil water level in fields with perched water tables. These practices are effective when the salt content of irrigation water is not excessive and when drainage and disposal systems are adequate. In recent years, the environmental and technical costs of developing drainage outlets and treatment facilities have received increased attention. Some of these costs have resulted in restrictions on drainage outflows in some locations.

Yields of salt-sensitive crops will decline if salinity cannot be managed effectively. In this situation, farmers will shift to growing salt-tolerant crops when it is no longer profitable to produce the sensitive ones. The ultimate economic effects of salinity can therefore be described by examining changes in yields and cropping patterns over time. Observed changes in these, however, may also be caused by market factors such as changes in relative prices. Salinity effects need to be separated from market effects.

We have estimated some of the costs associated with crop yield losses due to salinity and high water tables. We collected farm-level, time-series data on yields and cropping patterns in a small water district on the west side of California's San Joaquin Valley. The district is in an area known for its problems with salinity and high water tables. In our study, we examined changes in crop yields and the average value of land productivity, over time, for the major crops grown and compared these changes with trends throughout a larger production area. The purpose was to identify yield effects that may have been due to salts and high water tables in the smaller district.

Background

The 10,000-acre Broadview Water District is in the northwest corner of Fresno County. Surface water, the major source for irrigation in Broadview, has generally been available in adequate amounts since 1957. The fresh water supply is delivered from the Sacramento River Delta via the federal Delta-Mendota Canal. The average salinity level ranges from 200 to 400 parts per million (ppm) of total dissolved solids, which is typical of good-quality canal water in the San Joaquin Valley.

A drainage outlet was not available until 1983, however, and through 1982 Broadview had to recycle all of its mingled surface (tailwater) and subsurface drainage water collected in the main district drain. This recycling resulted in the application of high-salt irrigation water and the accumulation of salts in district soils. The ratio of drainage to fresh water in quantities actually delivered to growers increased, over time, from near zero in the 1960s to about 50 percent in the early 1980s. Since 1983 it has decreased to an estimated 20 percent.

District personnel began collecting soil and water salinity information in 1980. The average level of salinity in the Broadview drain ranged from 2,700 to 2,960 ppm total dissolved solids from 1980 through 1982. Several readings indicate salinity levels greater than 5,000 ppm. Fresh canal water salinity averaged from 300 to 350 ppm during this period. The blended drainage and fresh water delivered to growers occasionally exceeded 5,000 ppm, but averaged from 1,800 to 2,150 ppm. These measurements imply that salts had accumulated in district soils and contributed to significant increases in the salinity level of water applied to crops.

Yields and acreages

We collected data on crop acreages and yields on Broadview farms from annual reports submitted to the district. Throughout the data collection process, district growers suggested that cropping patterns had shifted significantly during the 1970s. The consensus was that high-value crops such as tomatoes, melons, and alfalfa seed had been replaced with lower value, salt-tolerant cotton and sugarbeets as soil salinity problems increased.

Annual crop production and yield data for Fresno County came from the agricultural commissioner's reports. The data provided information on the total acreage and average yields of crops grown in the county.

Unlike Broadview, most other areas of the county are not adversely affected by salinity or high water tables. Since growers throughout the county face similar technological and market conditions, significant differences between the county and the district in yields and cropping patterns may be attributable to deteriorating soil and water conditions in Broadview.

Cotton acreage increased over time in both Broadview and Fresno County as a whole (fig. 1). Differing trends are apparent for tomatoes and alfalfa seed. Acreages of those crops countywide either remained constant (tomatoes) or increased (alfalfa seed) after the early 1970s, but they declined in Broadview. Tomato acreage in Broadview was greatest in 1973, declining to zero in 1982. Alfalfa seed acreage fell from nearly 4,000 in 1970 to 560 in 1982. Acres in sugarbeets have remained constant in Fresno County but have increased in the water district.

These differing trends for tomatoes and alfalfa seed led us to examine crop yields in the two areas to determine if these were also diverging over time. Cotton yields per acre have generally been higher in Broadview than in Fresno County. Yields of tomatoes in Broadview were consistently higher than the county average through 1973. District tomato yields were highest in the middle to late 1960s and declined in the 1970s. County yields were at or above the Broadview level from 1974 through 1982.

Yields of alfalfa seed increased in the early 1960s in Broadview, before falling at the end of the decade. Despite this decline, yields were at or above those in Fresno County for the 11 years 1971 through 1981.

One important reason for the reduced alfalfa seed yields and acreage in Broadview in 1969 and the early 1970s was the decline of alkali bee populations. Broadview growers report that these bees are much preferred to normal honey bees for pollination, because (1) alkali bees are less distracted by blossoms of other crops in neighboring fields, and (2) they are better adapted to and more persistent in the difficult task of distributing alfalfa seed pollen. According to growers, bees are a key input in growing alfalfa seed, and difficulties in obtaining good pollination can significantly affect yields.

Barley and wheat yields have generally been higher in Broadview than in Fresno County, with exceptions in some years. Sugarbeet yields were higher in Broadview through 1974, while county averages were greater in 1976, 1979, and 1980.

Examination of crop yields from a time-trend perspective suggests important differences that evolved between 1962 and 1982. Cotton and barley yields remained relatively constant in both locations throughout those years. Tomato yields rose in Fresno County while declining in Broadview. Alfalfa seed yields remained constant in the county while declining in the water district. Wheat yields increased over time in each region. Sugarbeet yields increased in Fresno County, but remained steady in Broadview.

Yields and revenues

The review of yields and cropping patterns in Broadview and Fresno County suggests important differences for some crops. The crops examined represent varying degrees of salt sensitivity. Barley, wheat, cotton, and sugarbeets are generally regarded as salt-tolerant, while tomatoes and alfalfa seed are relatively sensitive. Site-specific soil and water table conditions, irrigation water quality, and management practices can influence the effect that salts have on yields and the longevity of crop production.

Broadview cropping patterns indicate increasing acreages of cotton over time as the importance of other crops has diminished. These changes may be caused by both technological and market factors, in addition to the effects of salinity and high water tables. A closer look at acreages and yields, by time period, suggests which crops may be responding to soil salinity and drainage conditions.

We divided the years 1962 through 1986 into four periods to examine possible changes in productivity. These periods, corresponding to distinct changes in cropping patterns, subsurface drainage installations, and drainage outlet availability in the Broadview Water District, are 1962 through 1970, 1971 through 1976, 1977 through 1982, and 1983 through 1986.

The first period includes the years before subsurface drains were installed in the district. Barley, cotton, and melons were the major crops grown initially. Alfalfa seed acreage increased during this period, while melons and barley gradually declined. Tomatoes were introduced in the late 1960s, but acreage of this crop declined briefly, before the installation of subsurface drains.

In the second period, leaching fractions (the portion of water applied in excess of

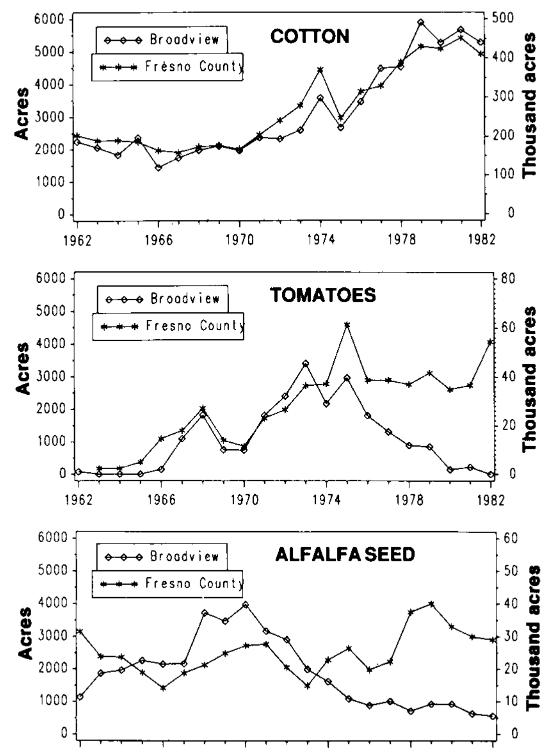

Fig. 1. During 1962-82, cotton acreage increased in both the Broadview Water District and all of Fresno County. Tomato acreage remained constant and alfalfa seed acreage increased countywide after the early 1970s, but both decreased in Broadview.

plant requirements) increased as subsurface drains were installed and the flushing of salts became feasible. Tomato acreage reached a peak in 1973 and remained high through 1975. Alfalfa seed acreage declined throughout the period, while cotton plantings increased moderately, The third period, 1977 through 1982, was dominated by cotton production as tomato and alfalfa seed acreage declined to near zero.

The first drain water releases from Broadview occurred in January 1983, after construction of the district's drainage outlet. The fourth time period includes the next four years of crop production. The quality of irrigation water delivered to growers improved markedly as smaller amounts of drain water were blended into the delivery canal. The average salinity of delivered water fell from 1,809 ppm total dissolved solids in 1982 to 592 ppm in 1983 and remained in the 400 ppm range for the next three years (table 1). This drop occurred as the portion of mingled drainage water in total deliveries declined from 41 percent in 1982 to 18 percent in 1983 and near 20 percent in the following years.

The average salinity of mingled tailwater and subsurface drain water fell from 2,713 ppm in 1982 to 2,284 ppm in 1983. The average rose again in 1984, but declined in both 1985 and 1986. This downward trend in drain water salinity may indicate that soil salt concentrations were declining as accumulated salts were finally being removed from district soils.

Broadview tomato acreage increased from zero in 1982 to 750 acres in both 1985 and 1986. Melon plantings increased from 455 acres in 1982 to 790 in 1985 and 670 in 1986. Acreage in alfalfa seed grew from 560 in 1982 to 630 in 1985 and 705 in 1986.

Average Broadview yields of selected crops during the four time periods are compared with those for Fresno County in table 2. Cotton, alfalfa seed, barley, and wheat yields followed similar time trends in each area, with higher average yields in Broadview than in the county. Average yields of tomatoes and sugarbeets followed different trends. The tomato yield in Broadview declined in both the second and third periods while increasing in Fresno County. The sugarbeet yield declined in the third period in Broadview and rose in the rest of the county. Average yields of all crops increased between the third and fourth periods in both locations.

Such changes in average crop yields represent one of the factors that determine the relative profitability of crop alternatives. Other factors include changes in relative prices. Prices reported for crops in Fresno County, over time, are generally similar to those received by Broadview growers.

Average per-acre revenues for the selected crops were calculated by multiplying average yields by the average prices received (table 3). Cotton and wheat revenues were consistently higher in the district than in Fresno County. Broadview returns from alfalfa seed production were at or above the county average in all periods. Tomato, barley, and sugarbeet returns fell below the county average in the third period. Revenues for all crops were greater in Broadview than in Fresno County, following improvements in the drainage situation.

The average per-acre cotton revenue increased by 57 percent in Broadview between the second and third periods, while tomato returns declined by 8 percent. These trends may indicate a change in the relative profitability of growing tomatoes and cotton in Broadview during these periods. Alfalfa seed and sugarbeet revenues were also rising at a slower rate than cotton returns between periods two and three.

We obtained one estimate of the economic value of a drainage outlet in Broadview by examining the yield improvements between the third and fourth periods. These increases were adjusted downward to reflect percentage improvements in county average yields that also occurred during those years. This was done to allow for improvements in technology, prevailing weather conditions, and/or reductions in pest problems. The net yield increase in Broadview was then attributed to improved soil and water conditions.

Percentage yield increases were greater in Broadview than in Fresno County for all crops except cotton (table 4). In Broad-

TABLE 1. Summary measurements of irrigations and drain water quality in the Broadview Water District, 1980-86

Year	Average salinity: Fresh canal water	Mingled drain water	Deliveries to growers	Drain water in total water delivered
	ppm total dissolved solids			%
1980	308	2,880	2,004	55
1981	346	2,962	2,158	42
1982	328	2,713	1,809	41
1983	256	2,284	592	18
1984	243	2,572	431	na
1985	292	2,226	400	na
1986	249	2,100	414	na

NOTE: The percentage of total water deliveries that is tailwater and subsurface drain water is not available for 1984 through 1986, but is probably about 20%.

TABLE 2. Average yields per acre for selected crops in the Broadview Water District (BWD) and Fresno County (FC), 1962-86

	Cotton		Tomatoes		Alfalfa seed		Barley		Wheat		Sugarbeets	
Period	BWD	FC	BWD	FC	BWD	FC	BWD	FC	BWD	FC	BWD	FC
	—bales—		—tons—		—pounds—		—tons—		—tons—		—tons—	
1962-70	2.4	2.2	30.3	20.5	776	na	1.9	1.6	1.9	1.6	20.8	20.4
1971-76	2.2	1.9	26.8	24.7	743	560	2.2	1.6	2.2	1.9	30.2	25.0
1977-82	2.3	2.1	19.3	28.3	601	530	1.8	1.7	2.6	2.5	25.5	27.2
1983-86	2.6	2.5	34.8	31.2	938	711	2.4	1.8	3.2	2.8	30.1	30.0

TABLE 3. Average per-acre revenues from crop production in Broadview Water District and Fresno County, 1962-86

	Cotton		Tomatoes		Alfalfa seed		Barley		Wheat		Sugarbeets	
Period	BWD	FC	BWD	FC	BWD	FC	BWD	FC	BWD	FC	BWD	FC
	$ (not adjusted for inflation)											
1962-70	403	338	954	608	295	na	86	77	98	87	254	258
1971-76	486	420	1,092	1,032	528	414	177	144	256	178	620	601
1977-82	762	665	1,004	1,513	625	625	166	187	345	307	771	834
1983-86	886	816	1,798	1,623	779	747	287	201	393	337	1,039	1,008

TABLE 4. Increases in average per-acre yields between the third and fourth time periods, Broadview Water District and Fresno County

Crop	Broadview: Actual	Percent	Fresno County: Actual	Percent
Cotton	0.3 bales	13.0	0.4 bales	19.0
Tomatoes	15.5 tons	80.3	2.9 tons	10.2
Alfalfa seed	337.0 lb	56.1	181.0 lb	34.2
Barley	0.6 tons	33.3	0.1 tons	5.9
Wheat	0.6 tons	23.1	0.3 tons	12.0
Sugarbeets	4.6 tons	18.0	2.8 tons	10.3

NOTE: The third time period includes years 1977 through 1982, and the fourth period 1983 through 1986.

TABLE 5. Estimated value of yield improvements after installation of a drainage outlet in Broadview Water District

Crop	Net yield increase per acre*	Dollars per acre†
Tomatoes	13.5 tons	698
Alfalfa seed	131.0 lb	109
Barley	0.5 tons	60
Wheat	0.3 tons	37
Sugarbeets	2.0 tons	69

*Estimated maximum yield increase due to improvement in soil and water conditions.
† Value of the yield increase at average prices for the period 1983-86, not adjusted for inflation.

view, the net yield increase, or portion of the 15.5-ton increase in tomato yields attributed to drainage improvements, was 13.5 tons (table 5). The value of this increase, at the average price received during 1983 through 1986, was $698 per acre. Similar values ranged from $37 per acre for wheat to $109 for alfalfa seed.

Conclusion

Increases in average crop yields in the four years after installation of a drainage outlet in the Broadview Water District provide compelling evidence of crop responsiveness to improvements in drainage conditions. Average yields of the six crops examined in this study exceeded county averages during those years. Yields of salt-sensitive tomatoes and alfalfa seed responded by 80 percent and 56 percent, respectively. Average yields of salt-tolerant barley, wheat, and sugarbeets also improved in Broadview, at a rate exceeding Fresno County yield increases, during the most recent period. This finding suggests that even crops considered to be tolerant of soil salinity may be adversely affected by continuous recycling of all drain water over a prolonged period. Yields of these crops responded positively to improvements in the quality of irrigation water and reductions in soil salinity made possible by improving the drainage situation in Broadview.

Our data, while pertaining specifically to salinity conditions and yields of selected crops in the Broadview Water District, indicate the costs associated with salinity and high water tables and the value of obtaining the drainage outlet and improving soil and water conditions.

These results agree with those of other researchers regarding yield responses in regions with saline high water tables. They also indicate that the effectiveness of leaching programs may be limited in an area that does not have a drainage outlet. Cotton and wheat yields remained constant or increased after subsurface drains were installed in Broadview, but yields of tomatoes, alfalfa seed, and sugarbeets declined before installation of the drainage outlet. This finding supports the belief that leaching and recycling are temporary solutions to salinity problems. An outlet for collected drain water is required to maintain productivity in the long run.

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Bench-top heating required less energy than the conventional perimeter heating system in this commercial greenhouse, but provided less uniform temperatures in the plant canopy.

A comparison of bench-top and perimeter heating of greenhouses

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Soil, floor, and bench-top (root-zone) heating systems for greenhouses have been reported to conserve energy compared with conventional hot air or radiation systems. Since plant growth and development have been found to proceed normally at temperatures below otherwise optimal air temperatures if the root zone is maintained at a higher level, energy savings would occur from heating the relatively smaller region. If the inside air temperature next to the walls and roof of the greenhouse is reduced through zone heating, the heat loss from the greenhouse to the outside will be reduced.

In this study, we compared two types of heating systems: a bench-top system with hot water carried through tubes arrayed in continuous loops fixed to the benches, and a conventional perimeter heating system that circulates hot water through finned tubes along the lower inside perimeter of the greenhouse. Temperature and energy consumption data for both systems were recorded over the 1986-87 heating season to compare temperature distributions and heating costs.

Methods

A grid of thermocouples was installed in a cross-section of a 195-square-meter (2,100-square-foot) greenhouse on the University of California campus at Davis to record the heating patterns of the bench-top and perimeter systems (fig. 1). On alternating days, the grid was moved along the length of the greenhouse so that, in a period of two weeks, temperature distributions for approximately seven locations were obtained for each heating system.

The bench-top system consisted of eight small-diameter plastic tubes laid along each of the 10 benches in the greenhouse, with each tube making four passes over the bench. Each tube was connected to supply and discharge manifolds along the north wall of the greenhouse. The manifolding was arranged so that the total water transport distance (and pressure drop) was approximately constant for every tube in the system. Flowmeters were installed in the water delivery lines of each of the two heating systems. Thermocouples were installed at the water inlets and outlets to monitor temperature drop across each system.

Experiments usually started at 4:30 p.m. and continued through 8:30 a.m. the following day. During normal perimeter heating, jet-tube fans are activated to improve air mixing and achieve more uniform temperatures in the greenhouse. For these experiments, however, the fans were switched off, because they led to increased infiltration losses and excessive heat transfer coefficients in the greenhouse studied.

For each experiment we recorded the day, time, and average temperatures from 52 thermocouples, 44 on the sensor grid and 8 others placed in pots and other selected points in the greenhouse. Thermocouple readings were sampled every 5 seconds, and 15-minute averages were stored. We also monitored the average flow rate of water through the heating system and average temperatures of water