IRRIGATION MANAGEMENT OF COTTON IN THE PRESENCE OF A CONTROLLED DRAINAGE SYSTEM

James E. Ayars[1] Richard W. Soppe[2]

James Oster[3]

ABSTRACT

A three year project evaluating management of shallow saline ground water was conducted on four 30 acre plots located in the Tulare Lake Basin of California. Cotton was grown in a clay soil using flood irrigation, sprinkler irrigation, and a combination of sprinkler followed by flood irrigation. The water table was controlled to a depth of 4 feet below the soil surface at the outlet of the subsurface drain which was installed at a depth of approximately 5 feet below the soil surface. Irrigation scheduling used leaf water potential with the depth of application based on soil water content measured with a capacitance type soil water sensor. Yields were not negatively impacted in the managed area compared to the farmer's field. The ratio of yield to applied water was greater in the research plots in the controlled drainage area than in the farmer managed plots in the controlled area. Total water application was reduced in the test plots. Maximum potential ground water contribution to crop water use occurred in the flood irrigated research plots.

INTRODUCTION

Drainage is considered a necessity for maintaining productivity in irrigated agriculture. A functioning drainage system provides salinity control, aeration, improved trafficability, and improves timeliness of agricultural operations. However, it also creates environmental problems associated with the transport of salt, nitrate, and potentially toxic trace elements, i.e., selenium and boron, into surface water. Drainage systems in irrigated areas are designed for rapid removal of drainage water and for maintaining the water depth at least 4 feet below the soil surface. This last requirement often results in over drainage, a condition in which more water is removed than is needed to maintain an aerated root zone (Doering et al, 1982) . When this occurs the potential for crop water use from shallow ground

---

[1] Agricultural Engineer, USDA-ARS, 2021 S. Peach Ave., Fresno, CA. 93727

[2] Visiting Scientist, USDA-ARS, 2021 S. Peach Ave., Fresno, CA, 93727

[3] Soil and Water Specialist, University of California Cooperative Extension Service, University of California, Riverside, CA 92521

water is limited. Alternatives proposed for correcting this condition include using a shallow drainage design concept (Doering et al., 1982) for new construction and controlling the water table depth in existing subsurface drainage systems (Doty et al., 1975; Doty, 1980). These options have been proposed for systems in semi-humid, semi-arid, and humid areas which are not affected by salinity.

In the San Joaquin Valley (SJV) of California, drain discharge has been prohibited on 40,000 acres of irrigated land with installed subsurface drainage systems and severely constrained on an additional 90,000 acres. The San Joaquin Valley Drainage Report identified source control, land retirement, and drainage water reuse as principal methods of reducing or eliminating drain water discharge from the affected areas. Water table control to increase crop use of shallow ground water has not been extensively evaluated in arid areas and was not recommended.

Other studies demonstrated that crop use of ground water is not affected until the ground water salinity is greater than twice the Maas-Hoffman (Maas and Hoffman, 1977) salinity threshold for yield reduction in the crop (Hutmacher and Ayars, 1991). Salt tolerant crops such as cotton and sugar beet are grown extensively in the drainage impacted area of the San Joaquin Valley. Ayars and Hutmacher (1994) demonstrated that cotton will obtain nearly 50% of its water requirement from shallow ground water provided irrigation was with good quality water initially until the root system develops enough to take advantage of the ground water and then the irrigation interval is extended. This technique is most effective if the water table is maintained at a depth of approximately 4 feet below the soil surface. As the depth to water is increased the total ground water contribution is decreased (Ayars and Hutmacher, 1994). The management goal is to control the drainage discharge and maintain the water table depth.

In arid irrigated areas, the primary source of water in the shallow ground water is deep percolation from irrigation (generally surface methods) and lateral flow from other areas, either irrigated or larger watershed contributions. Research in the SJV has shown that most of the deep percolation occurs during pre-plant irrigation and the first irrigation after planting (Ayars and Schoneman, 1984). Unless this water is controlled, it will not be available later in the growing season when the crop can make use of it.

A project was developed to control the water table in an irrigated area with a saline (15 mmhos/cm) ground water to determine the potential for crop water use and the impact on soil salinity. Cotton was the crop. This paper will report on 3 years of operation of a controlled drainage system in the Tulare Lake basin in the southern part of the SJV.

MATERIALS AND METHODS

The research site was on Westlake Farms section 2, T22S, R19E located in Kings County, California. The soil in the field is classified as a Tulare clay [Fine montmorillonitic (calcareous) thermic Vertic Haplauoll]. The soil cracks to a width of 2 to 5 inches when drying and to depths of 25 to 50 inches. The average clay content ranges from 40 to 60 % and has a permeability less than 0.008 in/day. The available water is given as 0.11 - 0.12 in/in and the average pH is between 7.9 and 8.4.

The field size is approximately 570 acres and is subdivided into bays of approximately 30 acres for purposes of irrigation. A bay is approximately 270 feet wide and 5000 feet long and is irrigated using a tractor mounted pump system which delivered water at 35 to 50 cubic feet per second. Cotton was planted on the flat. The field is drained using subsurface drains installed at a depth of 5 feet with a lateral spacing of 100 feet. Approximately 200 acres is drained by the system on the south end of the field and the remainder of the field is drained by a system that drains to a sump on the north end of the field. The laterals on the south end come to a common collector main which discharged at a sump located on the east edge of the field at the south end. A control structure was placed in the sump to control the water table at a single discharge point (Schoneman and Ayars, 1999).

The field surface has a slope of 0.0004 feet/feet, resulting in a drop of approximately 2 feet in elevation over the length of the field from west to east. The water table was controlled at a depth of 4 feet on the east end of the field in 1997 and 1998. This resulted in a depth to water table of approximately 4 feet on the east end of the field and 5.5 feet on the west end of the field. The drainage system was free flowing in 1996.

There were two irrigation treatments in the first year of the experiment and three irrigation treatments in the next two years. In the first year, one bay was flood irrigated for the entire season, and the second was flood irrigated during pre-plant and with sprinklers after planting. In the following years an additional treatment was added in which the first irrigation after planting was by sprinkler and all subsequent irrigations were by flood. This was designated the combined treatment. In the first year the sprinkler irrigation was done using two laterals each a half mile long from a main located in the center of the field. In the next two years the lateral lengths were reduced to quarter of a mile with a total of 4 laterals being used off two sub-mains. The application rate both years was approximately 0.25 inches per hour. Irrigation was initiated when the leaf water potential reached approximately -14 to -18 bars. Irrigation with the flood system took approximately 5 hours compared to the one week required with multiple sets using the sprinkler system.

Depth to ground water was measured using observation wells made of 2 inch PVC pipe installed to depth of 7 feet at 3 locations in each plot. Depth to water was measured weekly and water quality samples were taken at the same time. Flow advance data were taken on the flood plots each year as were pressure distributions on the sprinkler systems. Soil water content was measured to a depth of 3.6 feet at three locations in each plot using capacitance type (frequency domain response) equipment.

Cotton (Gossypium hirsutum L) was grown in each of the three years with variety MAXXA in the first and second year and variety SJ-2 in the third year. Plant measurements included plant density, plant height, boll numbers, yield, and total number of nodes. Plant density was measured over three 20 foot long sections. Sampling at the end of the growing season determined biomass in each of the treatments. Yield measurements were determined by machine harvest. The harvested area needed to fill a module was determined and the module weight and gin turnout were used to determine lint yield.

Soil salinity was measured twice annually by soil sampling at locations near the observation wells. Sampling was done in the spring just after planting and in the fall after harvest. The soil samples were taken in 6 inch increments to a depth of 6 feet or until the water table was reached. Samples were analyzed with a 1 to 1 extract for electrical conductivity (EC), boron (B), and chloride (Cl) by the U.S. Salinity Laboratory. Bulk soil salinity distribution was determined using an EM-38[1] electromagnetic induction meter. Several transects were taken across each field .

RESULTS

Water table response, yield, soil salinity, and drainage flows are summarized in this paper. Figures 1a and 1b show the water table depth over three years of measurement. Because the drainage flow was not restricted in 1996 (Fig. 1a), the groundwater level was lower than in the two following years. In 1996 the water table position was always lower than the field drain which is not the case in the following years. The water table was highest after the first irrigation and became progressively lower over the season. The highest water table occurred under the flood irrigated plot during the entire season in 1997. The combined and sprinkler treatments were similar. Previous research has shown that the largest deep percolation occurred during pre-plant irrigation and the first seasonal irrigation. The water applied with the sprinkler systems matched the depleted soil water

---

[1] Mention of trade names is provided for the benefit of the reader and does not imply endorsement by USDA-ARS.

better than was possible with the surface irrigation system. The decline in water table resulted from less applied water in 1997 and 1998 and poor control of the water table height at the drainage system outlet in 1998.

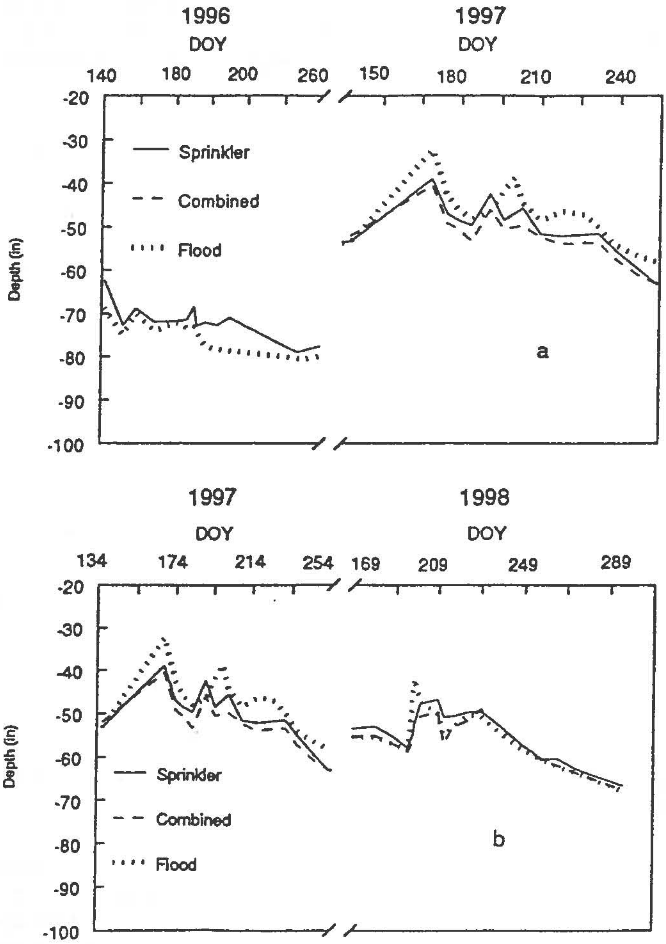

Fig. 1. Water Table Response to Irrigation Treatments at Westlake Farms as a Function of day of year (DOY) in 1996, 1997, 1998.

Figure 2 shows the drainage outflow for each cropping season. In 1996, drainage outflow was much larger than in 1997 and 1998. In 1996 the drainage outflow was not restricted and there were more irrigations applied than in either 1997 or 1998. In 1997 and 1998 one irrigation was eliminated at the end of each season. the cotton growth simulation model CALGOS indicated that this irrigation was not needed to bring the crop to maturity. Eliminating the last irrigation during the season created a larger soil water storage capacity for winter rain and pre-plant irrigation, thus reducing the drainage flow created by these water applications.

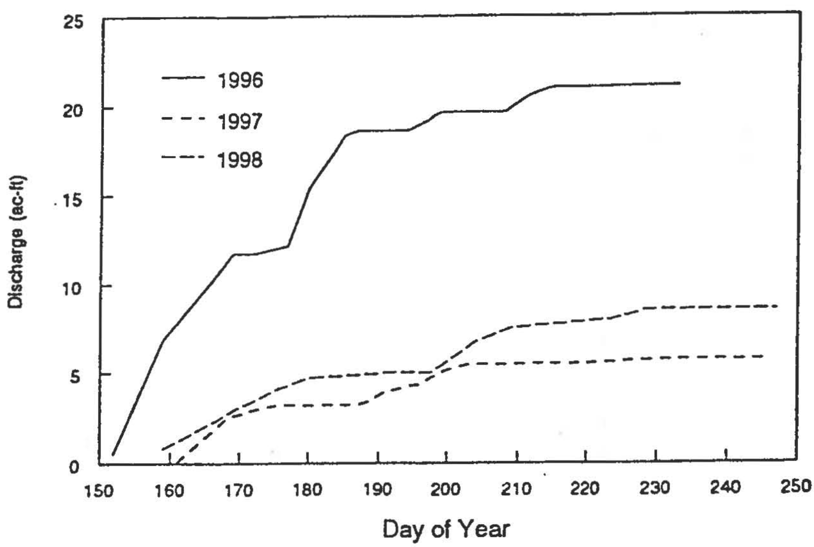

Fig. 2. Cumulative drainage From Research Plots at Westlake Farms in 1996, 1997, and 1998.

Figure 3 shows that the largest flows from approximately 200 acres of irrigated land occurred during fallow periods, both as a result of pre-irrigation and very wet winters in 1997 and 1998. Implementation of ground water control during the fallow period will help to reduce total drainage discharge. The EC of the ground water in this field is approximately 15 dS/m and is suitable for only the most salt tolerant of crops such as cotton and sugar beet.

Figure 4 shows the soil water content on the east side of the flood treatment. In the first year, soil moisture depletion between irrigations was less than in the two years. This did not have a direct effect on the cotton yield. Seed cotton yield from the flooded field was 2160, 3120 and 1997 lbs/ac for 1996, 1997 and 1998 respectively. The yield in 1998 was not really comparable with the yields in 1996 and 1997, due to a shorter growing season.

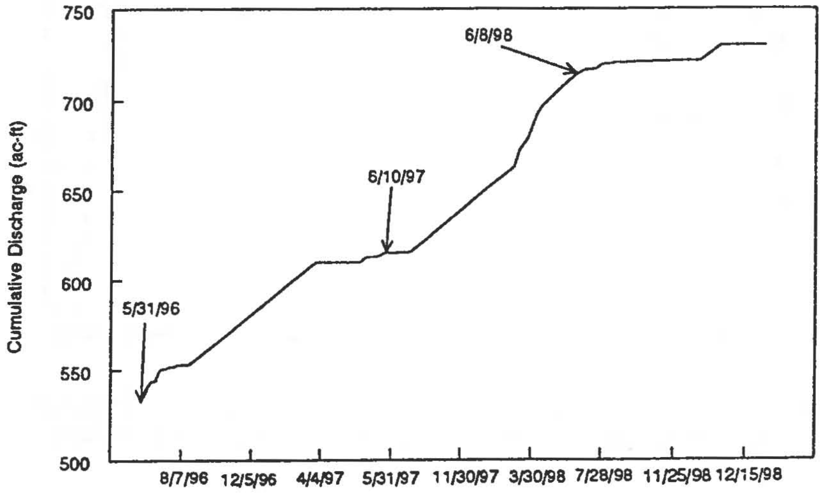

Fig. 3. Cumulative Discharge From Drains Under Research Plots and Adjacent Field at Westlake Farms.

Extending the irrigation interval was a result of using the leaf water potential instead of the calendar as the method to initiate irrigation. This resulted in more use of stored soil water and greater use of shallow ground water. More of the applied water was stored in the soil profile as a result of the increased soil water depletion, deep percolation losses were reduced, and so was drainage.

The yields are summarized in table 1. In 1996 and 1997 the flood plots had yields comparable to the yields on plots managed by the farm (farm flood). The combined plot in 1997 had the highest yield of all the plots. In 1998, the farm managed field had the highest yield followed by flood and combined plots with the sprinkler plot have the lowest yield of all. The reduced yield in the sprinkler plot was a result of water stress which occurred because the irrigation wasn't begun soon enough. Also, the yields were down in 1998 because of a late planting (an extremely wet winter). This resulted in a shorter growing season and reduced yields in general. Water applications are summarized in table 2.

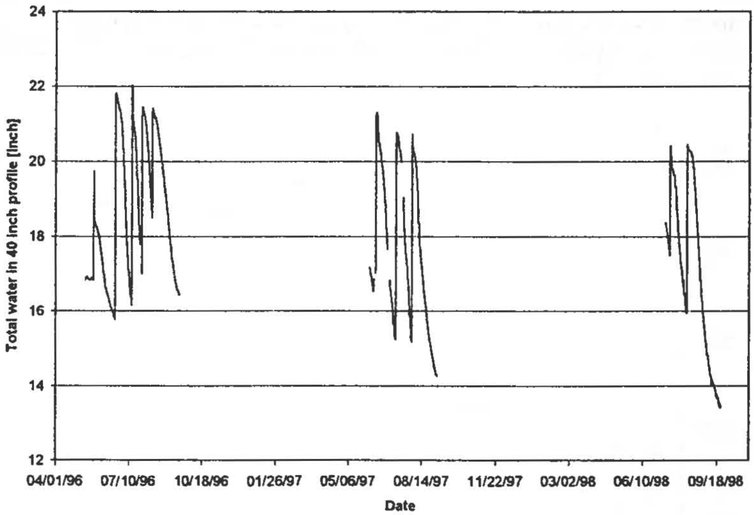

Fig. 4. Change in Soil Water Content in 3.1 Foot Profile in the Flood Irrigated Plots During Irrigation Seasons in 1996, 1997, and 1998 at Westlake Farms.

Table 1. Seed Cotton Yields (lbs/ac) on Research Plots at Westlake Farms in 1996, 1997, and 1998.

Treatment	1996	1997	1998
Sprinkler	2550	3260	1496
Combined		3310	1845
Flood	2160	3120	1977
Farm Flood	2160	3094	2040

In 1996, the sprinkler field received approximately 4 inches less water and had the highest yield of each of the plots. In 1997, the sprinkler applied the most water followed by the combined, the farm flood, and the flood plots. The sprinkler and combined plots each received one more irrigation than the flood field and the farm flood field. At the end of the season the leaf water potential values in the sprinkler and combined field indicated that one more irrigation was needed to mature the crop. This was not the case with the flood field. The farm managers

Table 2. Total Seasonal Applied Water (in) on Research Plots at Westlake Farms in 1996, 1997, and 1998.

Treatment	1996	1997	1998
Sprinkler	21.6	23.2	6.3
Combined		21.6	7.1
Flood	25.0	13.9	8.7
Flood Farm	25.0	18.1	12.6

elected to apply an additional irrigation on their fields which induced vigorous growth but no additional harvested cotton. In 1998, the total yields corresponded to the total applied water, i.e. with more water there was increased yield. There was a large increase in yield from the sprinkler to the combined and flood, but the same increase was not observed from the flood to the farm flood. What is most interesting in 1998 is the fact that relatively good cotton yields were obtained with such little applied water in all the treatments. Another way of evaluating the system is to look at the ratio of yield to acre inch of applied water. These data are summarized in table 3.

In 1996 the ratio was increased as a result of the improved irrigation schedule which included both timing and depth of application. In 1997, the ratio for the flood plots in the controlled area was the highest as a result of skipping the last irrigation. It should be noted that the farm flood field was adjacent to the test flood field and was in an area with controlled water table. Even though the yield was highest in the combined plot, the ratio wasn't the highest because of the additional applied water. The 1998 data show high ratio values because of the small applications of water. In the test plots with the controlled water table, the ratio was improved over the farm management in all three years. With some modifications of the irrigation schedule and use of controlled drainage, the farm can improve the overall efficiency of the existing irrigation system.

Table 3. Ratio of Seed Cotton Yield to Applied Water (lbs/ac/in) of Cotton Grown on Research Plots at Westlake Farms in 1996, 1997, and 1998.

Treatment	1996	1997	1998
Sprinkler	118	140	237
Combined		153	259
Flood	86	224	227
Farm Flood	86	171	162

The water balance data are given in table 4. The Et_{cp} is the potential crop water use assuming no stress during the growing season. This is not the case for the sprinkler plots in some of the years of the study. The column Et_{cm} gives the crop water use measured using the applied water, the change in water content, the runoff, and estimated drainage. The last column gives the potential ground water (PGW) contribution to crop water use and is the difference between Et_{cp} and Et_{cm}.

The maximum PGW occurred in 1998 which was a shorter growing season and had less applied water across all treatments. The flood irrigation treatments of both the research flood and the farm flood, had the largest potential contribution of shallow ground water in 1997 and 1998. There was a larger potential in the research plots than the farm managed plots due to the elimination of the last irrigation of the season on the research plots. Both of the plots were in an area with controlled drainage.

CONCLUSIONS

The results from a three year project on 4 thirty acre plots located in the Tulare Lake basin of California demonstrated the effectiveness of shallow ground water management in heavy clay soils with saline ground water. The seed cotton yield data demonstrated no loss of yield in the flood irrigated and combined sprinkler and flood irrigated plot compared to the farmer flood irrigated fields. In one of three years the sprinkler irrigated plot had a lower yield than the comparison plot, a result of excess water stress in the sprinkler plots. The ratio of yield to applied water of the research plots was comparable to or greater than that of the comparison farmer field. The controlled drainage improved the potential for ground water use from shallow ground water by maintaining a higher water table for a longer period of time and providing for one less irrigation. The maximum potential water use in all plots occurred in 1998 when the cropping season was drastically shortened due to weather conditions.

Managing shallow ground water in arid conditions with saline ground water is feasible and provides one more management tool to reduce the volume of saline drainage water requiring disposal.

Table 4. Water Balance Summary for Controlled Drainage Plots on Westlake Farms for 1996, 1997, and 1998.

Year	Et_{cp} (in)	Applied Water (in)	Drainage + Runoff (in)	Δ SW (in)	Et_{cm} (in)	PGW (in)
Sprinkler						
1996	27.6	22.0	2.0	8.0	28.0	0
1997	30.6	23.3	0.7	8.0	30.6	0
1998	29.0	6.2	0.0	8.0	14.2	14.8
Combined						
1996	27.6	0	0	8.0	0.0	0
1997	30.6	21.6	0.7	8.0	28.9	1.7
1998	29.0	7.1	0.2	8.0	14.9	14.1
Flood						
1996	27.6	25.0	6.0	8.0	27.0	0.6
1997	30.6	14.0	0.6	8.0	21.4	9.2
1998	29.0	8.7	0.6	8.0	16.1	12.9
Farm Flood						
1996	27.6	25.0	6.0	8.0	27.0	0.6
1997	30.6	18.2	0.6	8.0	25.6	5.0
1998	29.0	13.0	0.6	8.0	20.4	8.6

REFERENCES

Ayars, J.E., and R.B. Hutmacher. 1994. Crop coefficients for irrigation cotton in the presence of groundwater. Irrigation Science, 15(1):45-52.

Ayars, J.E., and R.A. Schoneman. 1984. Managing irrigation in areas with a water table. p. 528-536 *IN* J.A. Replogle and K.G. Renard (ed.) Proc. ASCE Irrigation and Drainage Spec. Conf.:Water Today and Tomorrow. American Society of Civil Engineers, New York.

Doering, E.J., L.C. Benz, and G.A. Reichman. 1982. Shallow-water-table concept for drainage design in semiarid and subhumid regions. p. 34-41 *IN* American Society of Agricultural Engineers (ed.) Advances in Drainage, Proceedings of the Fourth National Drainage Symposium. Vol. ASAE Publication 12-82, American Society of Agricultural Engineers, St Joseph, Mich.

Doty, C.W. 1980. Crop water supplied by controlled and reversible drainage. Transactions of the ASAE, 23:1122-1126, 1130.

Doty, C.W., S.T. Currin, and R.E. McLin. 1975. Controlled subsurface drainage for southern plains soil. Journal of Soil and Water Conservation, 30:82-84.

Hutmacher, R.B., and J.E. Ayars. 1991. Managing shallow groundwater in arid irrigated lands. Paper 912119, Proceedings, ASAE International Summer Meeting, Albuquerque, NM, 17 pp.

Maas, E.V., and G.J. Hoffman. 1977. Crop salt tolerance-current assessment. Irrigation and Drainage Division, ASCE, 103:115-134.

Schoneman, R.A. and J.E. Ayars. 1999. Continuous measurement of drainage discharge. Applied Engineering in Agriculture. 15(5):435-439.