INTERNATIONAL COMMISSION
ON IRRIGATION AND DRAINAGE

Fifteenth Congress
The Hague 1993

Q. 44
R. 85

IRRIGATION METHODS FOR DRAINAGE REDUCTION SUBSURFACE DRIP VS. FURROW IRRIGATION

METHODES D'IRRIGATION POUR REDUCTION DU DRAINAGE : IRRIGATION GOUTTE A GOUTTE SOUTERRAINE OU PAR RIGOLE

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ABSTRACT

San Joaquin Valley farmers apply excess irrigation water to alleviate soil salinity and to compensate for nonuniform infiltration. This practice contributes to the expansion of irrigated areas affected by shallow water tables and to the need for artificial drainage. Disposal options for subsurface drainage water are either expensive or controversial because of adverse environmental impacts. Whatever combination of disposal options are used, irrigation water conservation is the logical first step to minimize drainage volumes.

Improved furrow and subsurface drip irrigation has been used to irrigate

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cotton, on a field scale, at two sites in Western San Joaquin Valley. Annualized costs for the improved furrow irrigation system ranged from $74/ha to $149/ha as compared to about $438/ha for subsurface drip. Where water uptake from a shallow water table was significant, a well designed and managed furrow system achieved water conservation benefits greater than those with subsurface drip. Higher cotton yields obtained with subsurface drip gave some compensation for the greater system costs. In one year at one site, subsurface drip resulted in the greatest profits, $663/ha.

Long-term environmental impacts and hazards of drainage-water disposal in the San Joaquin Valley provide strong incentives for investigating irrigation strategies that could minimize drainage volumes over the long term. Pressurized irrigation systems like subsurface drip offer the greatest flexibility and control of irrigation applications and drainage water accessions. Reduced costs for drainage-water collection and disposal could increase the economic benefits to farmers with shallow water tables.

RESUME ET CONCLUSIONS

Les agriculteurs de la Vallée de San Joaquin appliquent l'excès de l'eau d'irrigation pour alléger la salinité du sol, et pour compenser l'infiltration irrégulière. Cette pratique contribue à l'élargissement des superficies irriguées qui sont touchées par une nappe phréatique peu profonde et au besoin du drainage artificiel. Les procédés d'élimination pour l'eau de drainage souterraine sont chers ou enclins à la polémique à cause de l'impact défavorable à l'environnement. Quelle que soit la combinaison de procédés d'élimination utilisée, la conservation de l'eau d'irrigation est la première étape logique pour minimiser le volume d'eau de drainage.

On a utilisé un système amélioré de l'irrigation par dérayures et par goutte-à-goutte pour irriguer le coton, à l'échelle de champ, à deux sites dans l'Ouest de la Vallée de San Joaquin. Les frais par an pour le système amélioré d'irrigation de dérayures étaient de l'ordre de $74/ha à $149/ha, en comparaison de $438/ha pour l'irrigation par goutte-à-goutte. Quand l'absorption de l'eau dirigée en haut d'une nappe phréatique était importante, un système de dérayures a réalisé des avantages de conservation d'eau plus grandes que les avantages réalisés par le goutte-à-goutte souterrain. Le rendement plus considérable de coton réalisé par goutte-à-goutte souterrain a donné de la compensation pour les frais plus hauts du système. Dans une année à un site, le goutte-à-goutte souterrain a realisé les plus grands bénéfices, $663/ha. L'impact défavorable à l'environnement (à long terme) et les dangers d'élimination de l'eau de drainage dans la Vallée de San Joaquin offrent de fortes incitations pour une enquête sur les stratégies d'irrigation qui pourraient minimiser le volume de drainage, à long terme. Les systèmes d'irrigation sous pressions comme le goutte-à-goutte souterrain suggèrent la plus grande flexibilité et le contrôle des applications d'irrigation et l'augmentation de l'eau de drainage.

L'adoption à grande échelle de ces procédés pourrait réduire considérablement l'étendue des nappes phréatiques peu profondes dans la vallée et la contamination de la nappe d'eau souterraine par les sels, les nitrates et les pesticides. Les incitations monétaires pour les cultivateurs particuliers sont spécialement importantes si elles retardent ou même éliminent le besoin d'installer un système de bassins pour l'évaporation / les tuiles de drainage. Suivant que les frais par an comprennent l'enlèvement du sel du bassin d'évaporation et la décharge dans l'Océan Pacifique, le prix d'un système de bassins pour l'évaporation / les tuiles de drainage est de l'ordre de $70 à $150/ML aux prix de 1983. Le coût par an correspondant, étant donnée une profondeur de 150mm, est à l'ordre de $105 à $225/ha.

Il faut étudier les alternatives de dessin des systèmes de goutte-à-goutte souterrain pour les assolements diversifiés. La profondeur et l'espacement des tuyaux sont des paramètres agronomiques et critiques pour la croissance des cultures, la préirrigation, et le contrôle de la salinité. L'espacement des cultures déterminera l'espacement des tuyaux de goutte, ou vice-versa. Le placement peu profond sous le centre du lit facilite la préirrigation du système goutte-à-goutte. Là où la salinité est un problème, un placement peu profond, mis au centre, pourrait simplifier l'aménagement de salinité pour la germination des graines et l'établissement des plantes. La préirrigation serait susceptible de déplacer les sels à la surface du lit où il serait possible de la mettre à côté pendant le plantage et de placer la graine à une profondeur où le sol est moins salé.

INTRODUCTION

San Joaquin Valley growers apply excess water to alleviate soil salinity or compensate for nonuniform infiltration. This practice increases land areas with shallow water tables and to the need for tile drainage and drainage-water disposal sites. Valley soils also contain selenium, arsenic, molybdenum, uranium, vanadium, and boron (Deverel, et al., 1984; Bradford, et al., 1990) that increase the environmental hazards of drainage disposal. Disposal options - such as reuse of saline drainwater (Rhoades, et al., 1989) to irrigate salt tolerant crops, discharge into underlying geological strata (Letey, 1990) or into evaporation ponds (Tanji, et al. 1985), or discharge into the ocean - are either expensive or controversial due to possible adverse effects on crop production and the environment (National Research Council, 1989). Whatever combinations of disposal options are ultimately selected, judicious use of irrigation water is a logical first step to minimize drainage volumes.

Drainage disposal costs reduce farm profits. The reduction depends on the infiltration uniformity achievable for different irrigation systems (Letey, et al., 1990.) Where disposal costs exceed about $60.00/ML, two pressurized irrigation systems - subsurface drip, and low-energy precision application (LEPA) were projected to be more profitable than furrow systems.

Phene and coworkers (Phene et al., 1988 a & b; Phene et al., 1991) have developed water/fertility management guidelines for subsurface drip irrigation of tomatoes, sweet corn, and cotton. In their small plot (91 x 18 m) studies, the drip tubing was located at a depth of 46 cm and spaced at 164 cm. Because of encouraging results obtained in yields and irrigation control, subsurface drip was included in two field scale studies to evaluate irrigation methods to minimize drainage volumes.

The University of California Salinity and Drainage Task Force and the U. S. Department of Agriculture's Agriculture Research Service funded the project conducted 16 km southwest of Stratford, California, which will be referred to as the UC-ARS project (Fulton et al., 1991). Boyle Engineering Corporation, under contract to the California Department of Water Resources, is conducting a project located 10 km southwest of Five Points, California (Smith et al., 1991; Smith and Oster, 1991). It will be referred to as the DWR project. As both projects are within the Westlands Water District, the source of irrigation water was the same, namely the California Aqueduct (EC= 0.4 dS/m). Although LEPA is one irrigation method being used in the DWR project, the data have been confounded by mismanagement and are not reported here.

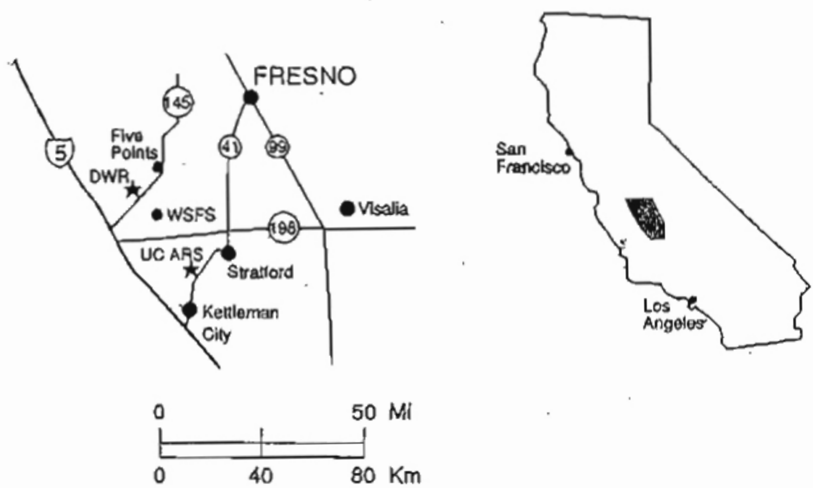

Figure 1. UC-ARS project site (Site travaux UC-ARS)

METHODS AND RESULTS

UC-ARS project

Irrigation and crop management. Continuous- and surge-flow, and subsurface drip irrigation systems were used to irrigate SJ-2 cotton on side-by-side 4-ha

plots (Fulton, et al., 1991) in 1987 and 1988. The soil, a Westhaven clay loam, had a salinity (ECe) of 1.5 dS/m near the surface increasing to about 11 dS/m at a depth of 1.8 m. The water table depth, 1.50 to 2.70 m, was nearer the surface on the east half of the field.

Furrow irrigation methods in 1988 were based on infiltration rates measured in 1987 (Hanson, personal communication) during the preirrigation (3.8 mm/h), first (1.8 mm/h) and last crop (0.5 mm/h) irrigations. For preirrigation with both furrow treatments in 1988, furrow lengths were reduced from 760 to 380 m by laying a second line of gated pipe 380 m from the head ditch. For continuous-flow, irrigation set times were reduced from 24 h to about 11 h and the inflow rate was 2.3 L/s. These changes reduced the infiltrated water during preirrigation from 196 mm in 1987 to 137 mm in 1988 (Table 1). Furrow lengths were converted back to 760 m for the crop irrigations, inflow rate was increased to 2.7 L/s, but set time remained at 12 hours.

Table 1. UC-ARS project. Depth of infiltrated water[1], for the upgraded continuous-flow furrow, surge-flow furrow, and subsurface drip systems in 1988 (Travaux UC-ARS, Profondeur de l'eau infiltrée, pour la dérayure améliorée d'écoulement continu, la dérayure d'écoulement houleux, et les systèmes de goutte-à-goutte souterrain en 1988)

	Infiltrated water			
	Furrow		Subsurface drip	
	Upgraded	Surge	East	West
	mm			
Preplant	137	142	56	58
First crop	130	124	NA	NA
Cumulative subsequent crop	345 (3)**	356 (4)**	478 *	521
Rainfall	86	86	86	86
Total	699	708	620	665

[1] Infiltrated water is the amount of applied water corrected for runoff, or the amount of water available for evapotranspiration and drainage water assession.
* Water was applied daily.
** Number in parentheses gives the number of crop irrigations.
NA denotes non-applicable.

Preirrigation with surge-flow, required four surge cycles (2.5 L/s) and 6 h to pulse the water to the furrow ends (380 m); the cutback phase (1.3 L/s) lasted about 10 h. For crop irrigations, six surge cycles were used to advance water (760 m) in 11 h; the cutback phase lasted about 9 h. For both furrow treatments, the first crop irrigation and subsequent irrigations were scheduled at -1600 kPa

and -1800 kPa leaf water potential, respectively, as determined by pressure chamber. The infiltrated water for preplant and crop irrigations were similar for both furrow irrigation treatments (Table 2).

Table 2. UC-ARS project. Profitability of the grower furrow, upgraded continuous-flow/surge-flow furrow, and subsurface drip in 1988 (Travaux UC-ARS. Rentabilité du sillon de culture, la dérayure améliorée d'écoulement continu/d'écoulement houleux, et la goutte-à-goutte souterrain en 1988)

	Furrow		Subsurface drip	
	Grower	Continuous/ Surge	1-m	2-m
	$ / ha			
Line value ($1.65/kg)	2388	2388	2640	2640
Production costs	1559	1586	3840	2376
Seed credit ($187/Mg)	190	190	240	240
Profit [loss]*	1019	992	[960]	504

* Costs of land ownership or land leasing were not deducted from return.

In 1988, the subsurface drip treatment was split into two equal areas, permitting less water application during the crop season (Table 2) to the east half. This facilitated greater water uptake from the shallower water table. The subsurface drip tubes were spaced at 1 m at about 0.46 m beneath the bed. The 198-m long drip tubes were connected to a supply submain at one end and a flushing submain at the other. The pressure compensated emitters in the drip tube were spaced 1.0-m apart and discharged water at 3.8 L/hr. Preirrigation (56 - 58 mm, Table 1) was applied in March with the drip system. Crop irrigations, between May and mid- August, were applied daily at rates calculated from climatic data obtained at a CIMIS weather station approximately 16 km northeast of the project site and crop coefficients reported by Phene, et al., 1985. During the last two weeks of August, irrigation was progressively decreased until it was stopped on August 30.

Preirrigation with the drip system and rainfall provided adequate water for cotton germination and seedling establishment in 1988. The preirrigation depths of 56 - 58 mm for subsurface drip as compared to 137 - 142 mm (Table 1) for the furrow treatments indicates the potential for drainage reduction with an irrigation system that provides sufficient control so that the applied water approximately equals the soil water depletion. The cumulative crop irrigations for the subsurface drip treatment exceeded that for furrow treatments by about 150 mm. In part, this is due to infiltration rate and aeration constraints limiting the number of furrow irrigations during the crop season. The average total infiltrated water (Table 1) for the furrow treatments (704 mm) is somewhat greater than that for the subsurface drip treatments (642 mm).

Land preparation, pest control, defoliation, and harvest were managed by the cooperator in all treatments. Nitrogen, phosphorus and zinc fertilizers were applied in the furrow-irrigated treatments at rates of 144, 45, and 6 kg/ha, respectively, in 1988. In the subsurface drip treatment nitrogen, phosphorus, and potassium rates were 197, 284, and 197 kg/ha, respectively. Zinc fertilizer was not applied in the subsurface drip plot in either year. Sodium N-Methyldithiocarbonate (Metham sodium or vapam) soil fumigant was applied during preirrigation at a rate of 280 L/ha to prevent root intrusion and control verticillum wilt and in September at 47 L/ha to assist defoliation.

Profitability, Table 2 . The cotton lint yields were 1448 kg/ha for the grower-, continuous-flow and surge-flow treatments and 1614 kg/ha for the subsurface drip treatment. The lint and seed values totaled $2578 for the furrow and $2880/ha for the subsurface drip treatments. The profits for the grower-furrow treatment were $1019/ha as compared to the $992/ha for the continuous- and surge-flow treatments reflecting the increased production costs of the latter. For the subsurface drip treatment, costs exceeded income by $960/ha.

Table 2 includes an alternative subsurface drip system based on a 2-m spacing between drip tubes and revised fertilizer and fumigant costs. Use of the wider spacing and less expensive in-line emitters [as in the DWR project (Smith et al. 1991)] would reduce annual system costs by $579/ha. Reduction or elimination of fumigation and reduction in fertilizer would lower the total annual production costs by about $978/ha. To assure drainage water control and adequate seed bed water content, preirrigation with hand move sprinklers costing about $93/ha would be required. In total, the estimated annual production costs could be reduced from $3840 to $2376/ha. This results in a projected profit of $504/ha (Table 2) which is about $490/ha less return than obtained with the furrow systems. Either a direct and sizable cost for disposal of added drainwater generated from furrow systems, substantially higher yields, or higher-value crops would be required to increase the economic viability of subsurface drip at this site.

DWR PROJECT

Irrigation and crop management . The site consists of about 65 ha equally divided into four irrigation treatments, low-energy-precision-application (LEPA), subsurface drip, improved furrow and grower managed furrow (Boyle Eng. Corp., 1990; Smith, et al., 1991). The soil, a Cieros clay, has an average soil profile salinity (0 to 0.6 m) generally less than about 4 dS/m. The project site is underlain by a shallow saline (4 to 11 dS/m) water table at depths from 0.4 to 0.75 m in spring and early summer, and from 1.80 to 2.15 m in fall and early winter.

Gated pipe was used to irrigate both the improved- and grower-furrow

irrigation treatments. Water was supplied by a buried PVC pipeline, with a flow meter, connected to Westlands Water District facilities. In 1989, both furrow treatments were preirrigated using all furrows; alternative furrows were used for the four crop irrigations. The ends of the furrows were blocked since tail-water collection facilities were not available. Thus, all the applied water either infiltrated or evaporated.

Irrigation facilities were changed for the improved-furrow treatment in 1990. A tail-water collection system, with a weir and water stage recorder, was installed to collect and measure runoff; run length was reduced to 180 m, and alternate furrows were used for crop irrigations. Also, hand-move sprinklers were used to preirrigate resulting in 97 mm of infiltrated water in 1990 as compared to 224 mm in 1989 (Table 3). The corresponding values for furrow preirrigation of the grower-furrow treatment were 239 mm in 1989 and 224 mm in 1990.

Table 3. DWR project. Infiltrated water[1] for subsurface drip, improved furrow, and grower-furrow (Travaux DWR. L'eau infiltrée pour le goutte-à-goutte souterrain, la dérayure améliorée et le sillon de culture)

Irrigation system Total	Year	Infiltrated Water Preirrigation	Crop	Irrigation
		mm		
Subsurface drip	1989	147[2]	439	586
	1990	122[2]	488	630
Improved furrow	1989	224[3]	528	752
	1990	97[2]	40	498
Grower furrow	1989	239[3]	536	775
	1990	224[3]	508	732

[1] Infiltrated water is the amount of applied water corrected for runoff, or the amount of water available for evapotranspiration and drainage water assession.

[2] Preirrigation by hand-move sprinklers.

[3] Preirrigation by furrow.

Irrigation scheduling for the four crop irrigations of the improved-furrow treatment were based on measured soil water content, leaf water potential and estimates of crop ET. Deficit irrigation was purposefully begun in late July to increase crop water use from the shallow groundwater. Soil water content was monitored weekly with a neutron probe at three locations in each treatment. Climatic data were obtained CIMIS weather station located at the University of California's Westside Field Station, approximately 10 km east of the project site. Daily evapotranspiration was estimated using crop coefficients reported by

Phene et al., 1985. Infiltrated water for crop irrigations was reduced from 528 mm in 1989 to 401 mm in 1990 (Table 3). The corresponding numbers for the grower-furrow treatment were 536 mm in 1898 and 508 mm in 1990.

The subsurface drip system used in-line emitters spaced at 1.0 m along 1.32 cm ID x 1.57 cm OD polyethylene tubing; lateral spacing between drip tubes was 2.0 m. Drip tubes were buried 0.45 m deep in nonwheel rows to minimize compaction problems. The 137-m long drip tubes were connected to a supply submain at one end, and to a flushing submain at the other. Pressure regulating valves at the submain inlets were set at 170 kPa, corresponding to an average discharge rate of 2.11 L/hr per emitter, and an average application rate of 1.0 mm/hr. Nitrogen and phosphorus fertilizers, and sulfuric acid to prevent root intrusion, are injected with a venturi connected across the discharge and inlet of the supply pump. Preirrigation was applied using hand-move sprinklers.

For the subsurface drip treatment, the number of operating hours per day needed to satisfy evapotranspiration was predicted for a week based on average climatic conditions. A water balance for the previous week, based on crop ET and total applied water, was used to make minor adjustments so the applied water matched calculated evapotranspiration over the long run. Infiltrated water for crop irrigations totaled 439 mm in 1989 and 488 mm in 1990 (Table 3). These numbers closely matched evapotranspiration from mid-May to early August, when deficit irrigation was begun. For both years, irrigation was stopped during the last week of August.

Drainage reduction . We estimated drainage by subtracting calculated evapotranspiration from total infiltrated water (Table 3). Evapotranspiration was assumed to be only a function of climate, unaffected by spatial variability of any soil property. As this is unlikely (Letey, 1985), the reader must understand that the drainage depths reported here are estimates.

Evapotranspiration was calculated for the period between March 18 and October 15, or from preirrigation of the subsurface drip treatment through harvest. Between March 18 and April 9, the approximate planting date, evapotranspiration was assumed to equal 0.25 times the reference evapotranspiration plus rainfall measured at the Westside Experiment Station. Thereafter, evapotranspiration was calculated using crop coefficients as described previously. The resulting ET's for 1989 and 1990 were 732 and 704 mm.

Grower-furrow had the highest drainage estimates, 43 mm in 1989 and 28 mm in 1990. The corresponding numbers for improved-furrow were 20 and -206 mm. Negative values indicate the estimated amount of groundwater used by the crop. For subsurface drip, negative drainage values were obtained both years, -146 mm in 1989 and -7.4 mm in 1990.

Soil based measurements were consistent with treatment effects on drainage (Boyle Eng. Corp., 1990). The soil water content, matric potential, and hydraulic gradient data obtained in the subsurface drip treatment indicate that little drainage occurred. In the furrow-irrigated plots, each irrigation increased soil water content to 137 cm. However, in the improved furrow treatment during 1990, soil water content decreased and depth to groundwater increased dramatically late in the season, responding to deficit irrigation.

Profitability. Subsurface drip irrigation had the highest net income in 1989 ($663/ha) and the lowest ($114/ha) in 1990 (Table 5). This reflects differences in crop yields and costs among treatments. Whereas crop yield for subsurface drip was higher than for furrow irrigation treatments in 1989, yields were about the same in 1990 (Table 4). Consequently in 1990, grower-furrow with the lowest production cost, had the highest net income ($583/ha) among treatments (Table 5). For the improved-furrow treatment in 1990, the production costs were $70/ha greater than for grower-furrow and the crop income was $104/ha less. Consequently, the profits for improved-furrow in 1990 were $174/ha less than for grower-furrow.

Table 4. DWR project. Crop yields for grower-furrow, improved-furrow and subsurface drip treatments in 1989 and 1990 (Travaux DWR. Rendements des cultures pour les traitements du sillon de culture, de la dérayure améliorée, et de goutte-à-goutte souterrain en 1989 et 1990)

Irrigation system	Year	Yield[1] Crop	Irrigation
		Mg/ha	
Subsurface drip	1989	3.21	1.71
	1990	3.12	1.45
Improved furrow	1989	2.42	1.19
	1990	2.79	1.37
Grower furrow	1989	2.21	1.21
	1990	2.84	1.43

[1] - Cotton seed and lint yield from grower records for each irrigation treatment.

DISCUSSION

The improved furrow treatment in 1989 in the DWR project demonstrates that it is possible to achieve comparable drainage water reductions with well designed and managed furrow systems and with subsurface drip. This is particularly true where the shallow water table is not so saline as to limit its use by the crop (Ayars and Schoneman, 1986; Wallender, et al., 1979). The long

Table 5. DWR project. Profitability of the grower-furrow, improved-furrow and subsurface drip treatments in 1989 and 1990 (Travaux DWR. Rentabilité des traitements du sillon de culture, de la dérayure améliorée, et du goutte-à-goutte souterrain en 1989 en 1990)

	Grower furrow		Improved furrow		Subsurface drip	
	1989	1990	1989	1990	1989	1990
	$/ha					
Lint value ($1.65/kg)	2003	2362	1971	2267	2829	2392
Production costs	2096	2312	2109	2382	2767	2862
Seed credit ($187/kg)	415	533	453	524	601	584
Profit	322	583	315	409	663	114

term sustainability of deficit irrigation will eventually be limited by increased groundwater salinity unless some net lateral or downward movement of groundwater occurs.

At the DWR site, subsurface drip irrigation was the most profitable of the three treatments in 1988. More responsive water management probably reduced root zone salinities and consequently increased crop yields. However, the shallow, saline water table (0.40 to 2.2 m) could make it difficult to sustain these yield increases; this is a possible reason why increased yields were not obtained in 1990.

Even with better fertilizer, fumigant, and water management at the UC-ARS site, we believe that higher profits from subsurface drip irrigation will be more difficult to achieve because this site is more productive which likely reflects the greater depth of the saline, shallow groundwater table (1.5 to 2.7 m). For example, cotton lint yields in 1990 at the UC-ARS site for the grower-furrow (1513 kg/ha), and the east and west halves of the subsurface irrigation (1904 and 1777 kg/ha) were all greater than for the DWR site in the same year. Even with the highest yield obtained from the east half of the subsurface drip in 1990, the profits are about $50/ha lower than for the grower-furrow.

The financial benefit to be derived from water conservation and reduced deep percolation losses provides an incentive for a grower to improve his irrigation practices. This is particularly true if it will delay or possibly eliminate the need to install a tile drainage/evaporation pond system. Depending on whether the annualized costs included salt removal and disposal in the Pacific Ocean, the cost ranged from $70 to $150/ML ($7 to $15/ha-cm) in 1983 prices (Knapp et al., 1986).

Long-term environmental impacts and hazards of drainage water disposal, because of its salinity, nitrate, and possible pesticide content, in the San Joaquin Valley is another incentive for evaluating strategies to reduce the irrigation and drainage volumes needed for sustained crop production. Pressurized irrigation or improved furrow systems may offer the flexibility and control needed to significantly limit water additions to the shallow groundwater table. Large-scale use of these types of irrigation systems could substantially reduce the areal extent of shallow water tables in the valley and contamination of underlying groundwater basins.

Design alternatives for diversified cropping rotations must be studied. Depth and spacing of tubing placement are critical agronomic parameters for crop growth, preirrigation, and salinity control. Crop spacings will dictate drip tube spacing or vice versa. Shallow placement beneath the center of the bed facilitates preirrigation with the drip system. Where salinity may be a problem, a centered, shallow placement could simplify salinity management for seed germination and plant establishment. Preirrigation would tend to move the salts to the bed surface where it subsequently could be moved aside during planting and the seed placed at a depth where the soil is less saline.

CONCLUSIONS

- Good irrigation design and water management are needed to conserve water and reduce drainage. With them, both furrow and subsurface drip irrigation can give comparable results.
- Pressurized irrigation and improved furrow systems are more expensive to install, operate, and maintain than furrow systems commonly used in the San Joaquin Valley of California.
- Greater yields, and consequently income, can compensate for the increased costs.
- Costs reductions for subsurface drainage-water disposal and increases in the ability to sustain irrigated agriculture in the Western San Joaquin Valley would be additional economic benefits.
- Subsurface drip systems need further evaluation under San Joaquin Valley crop and soil conditions to develop a better understanding of the long-term management requirements and costs/benefits.

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