OVERVIEW OF SALINE WATER IRRIGATION IN FAR WEST TEXAS[1]

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ABSTRACT: Saline waters containing dissolved salts up to 6000 ppm have been used for irrigation in far west Texas. This paper outlines successful examples and several on-farm management problems encountered. A salt tolerant crop, cotton, has been grown successfully with gypseous saline waters having 8 mmho/cm (dSm^{-1}) with modified cultural practices e.g., alternate furrow irrigation, double row plantings or decapping of salt crusts. Sprinkler irrigation of cotton using water of about 5 mmho/cm has also been successful when used in night or dawn hours. Alfalfa and several forage crops have been grown with water of 3 to 5 mmho/cm with moderate yield reductions in the areas of abundant saline water supplies. Pecans which are grown primarily in the middle Rio Grande Basin using water of 1.1 mmho/cm began to show salt damage due to gradual accumulation of salts in spatially variable fields irrigated by border or basin methods. Tomatoes and various melons have been grown with gypseous saline waters having 3 to 5 mmho/cm and chile peppers with water of 1.1 mmho/cm. Obtaining reliable stands of chile and tomatoes has been a problem because of hypocotyl and seedling mortality caused by surface accumulated salts. These examples point out the importance of crop selection in successful uses of saline waters. Once crop selections are made within a limit of salt tolerance, irrigation management, cultural practices and soil permeability including its spatial variability may dictate the success or failure of crop production with saline waters.

Introduction

Department of the Interior estimates that two-thirds of the nation's groundwater supply contains dissolved salts of 1000 to 3000 ppm (Unpublished report, USDI, 1983). With dwindling reserves of fresh water, it seems imperative that future irrigated crop production needs to rely more on saline waters. In far west Texas, highly saline waters containing 6000 ppm of dissolved salts have already been used for irrigation. The salinity of these irrigation waters is among the highest in the western USA. This paper presents successful examples as well as several on-farm management problems encountered in utilizing saline waters for irrigation in this region.

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Description of the Area

Far west Texas encompasses the middle Rio Grande river east to the Pecos Basin covering approximately 3150 sq. miles (8160 km^2), Fig. 1. The elevation ranges from 2640 ft (800 m) at Pecos to 3800 ft (1140 m) at El Paso. The climate is semi-arid continental with annual rainfall ranging from 7.8 inches (20 mm) at El Paso to 10 inches (250 mm) at Pecos. The summer daily maximum temperature often exceeds 100 F (38 C) and the winter minimum temperature occasionally drops below 10 F (-12 C). The average frost free days are from April through October, but late spring freezes (about April 15) and early fall freezes (about Oct. 5) are common.

Fig. 1. Irrigated areas (shaded area), annual rainfall in inches and the major aquifers in far west Texas.

The region contains four major irrigated areas along the narrow strip of the Rio Grande (30,000 ha), at Dell City (20,250 ha), near Van Horn and Valentine (8,900 ha), and at Pecos (40,000 ha). The area along the middle Rio Grande consists of two irrigation districts: El Paso and Hudspeth. The El Paso portion receives irrigation water from the Rio Grande project. Quality varies with location and season, but averages about 1.1 mmho/cm (dSm^{-1}) in electrical conductivity (EC) and 3.6 in sodium adsorption ratio (SAR) at El Paso, Table 1. During the years of short water supplies, saline well waters are used as a supplement. The Hudspeth portion of the Rio Grande is outside of the Rio Grande project and receives a small quantity of return flow and drainage waters. The major source for irrigation is saline well waters having an EC of 5 to 9 mmho/cm (Table 1). Both areas are irrigated by surface methods, and most fields have recently been laser leveled. Soils are extremely variable with textures ranging from sand to clay.

The Trans-Pecos region is irrigated with well waters by surface and in some areas using sprinkler or drip methods. Water quality varies: Van Horn and Valentine areas have been irrigated with water low in total salts, but relatively high in Na (Table 1). Most soils are sandy loam. Dell City areas have been pump-irrigated by gypseous saline waters from the Victorio Peak Limestone formation. The soils are generally sandy, and in places gravelly containing native gypsum besides calcium carbonates. Pecos areas have been irrigated with various saline waters. Salinity ranges from 2 to 8 mmho/cm, but sodicity is relatively low, because of the gypseous nature (Table 1). The aquifer (the Cenozoic Alluvium deposit) has a known reserve of 40 million acre ft (49,000,000 m^3), but two-thirds of the reserve is estimated to have an EC greater than 4.0 mmho/cm. Ft. Stockton areas have been irrigated with waters of 1 to 2 mmho/cm and SAR of 2 to 6 by pumping from the Edwards-Trinity aquifer.

Table 1. Qualities of irrigation waters used in the major irrigated areas of far west Texas. (Data from Texas Dept. of Water Resources)[1/]

	EC dSm^{-1}	TDS ppm	SAR	Na	Ca	Mg	HCO_3	Cl	SO_4
				- - - - - -	-meq/liter-	- - - - - -			
The Middle Rio Grande									
Project water	1.1±1	800	3.6	6.0	4.3	1.3	3.8	3.0	5.0
Well Water									
(EL Paso)	3.8±1	2800	8.2	21.0	9.8	3.2	4.4	19.0	13.0
(Hudspeth)	7.0±2	5140	12.0	43.0	16.0	9.5	3.7	48.0	15.0
Trans-Pecos									
Van Horn-Valentine	0.6±0.3	380	4.7	4.3	1.2	0.5	2.4	1.0	1.8
Dell City	3.7±1	2720	3.0	13.0	20.0	14.0	2.7	17.0	25.0
Pecos	4.4±2	3230	4.3	18.0	23.0	11.0	1.8	16.0	34.0

[1/] The listed values are the average of 100 water samples, except for samples from the Van Horn and Valentine area where 79 samples were used. Note that EC of 1 mmho/cm is equivalent to about 735 ppm of dissolved salts in gypseous saline waters.

Crop Selection and Performance

Because of a short growing season, severe winter and high salinity of irrigation waters, types of crops grown in this region are relatively limited. The principal crop has been cotton (Upland and/or Pima varieties). Cotton yields are considerably lower than those in the lower desert region, primarily because of a short growing season. Irrigation waters in the Hudspeth district and the Dell City area are highly saline, but cotton yields in these areas show no major reduction from those of the El Paso Valley irrigated with low salt waters (Table 2).

Successful growing of cotton with saline water requires changes in cultural practices, such as alternate furrow irrigation and double row plantings on wide-beds or decapping of salt crusts as discussed later in more detail. These measures may be needed when salinity of irrigation water exceeds about 2.7 mmho/cm (8), depending upon soil types, weather conditions and varieties to be grown. Successful growing with saline water also necessitates the use of greater quantities of water for leaching as well as a greater quantity of nitrogen fertilizers to compensate for leaching losses. To accommodate sufficient leaching, soil permeability needs to be maintained, thus requiring increased use of deep plowing, chiseling, and other measures. These practices add to production costs while potential yields are low due to the short growing season. Research toward reducing production costs as well as developing cultivars that yield fibers with a higher market value is becoming increasingly important to sustain saline water irrigation of cotton.

Table 2. Average cotton yields in El Paso and Hudspeth portions of the middle Rio Grande Basin. (Data from the Bur. of Reclamation)[1/]

	1975	76	77	78	79	80	81	82	avg
	- - - - - - -	- bales/acre	(540 kg/ha)	- - - - - - -					
Upland									
El Paso	0.93	1.26	1.28	1.54	0.70	1.05	1.22	1.18	1.14
Hudspeth	0.73	1.18	1.46	1.16	0.81	1.07	1.42	1.14	1.00
Pima									
El Paso	0.44	0.99	-	1.16	0.89	1.13	0.83	1.31	0.96
Hudspeth	0.47	0.94	1.11	0.60	0.69	0.72	1.09	1.33	0.87

[1/] Acreages involved in El Paso and Hudspeth districts are on the average 3000 and 1500 ha for upland, and 6500 and 1500 ha for pima, respectively.

Alfalfa and other forage crops have been important in supporting large livestock industries in far west Texas. Alfalfa yields in saline areas of Dell City have been 5.5 to 6 tons/acre (12.3 to 13.4 Mg/ha), using about 5 ft (150 cm) of water, whereas yields of 8 to 9 ton/acre are common in Van Horn areas. Alfalfa yields in this region increase linearly with increasing irrigation up to about 75 inches (190 cm) (5). Since pumping is generally the single largest cost item in alfalfa and forage productions, a yield reduction of this magnitude is often offset by reduced pumping costs when abundant saline waters are available at shallow depths.

Because of a relatively poor return from cotton, area agriculture has been shifting toward production of high value horticultural crops. Pecans are already the single most important crop in the middle Rio Grande with its total cash value exceeding that of cotton since 1981. At the onset of pecan plantings in the middle Rio Grande, salinity problems appeared to be ruled out, because water from the Rio Grande is of relatively good quality (Table 1). Within 7 to 15 years after planting, salt problems began to appear mostly in silt clay and clay loam soils due to gradual salt accumulation (11). Salt damage ranges from marginal leaf-tip burn to complete die-back of trees. Tree growth appears to be reduced when salinity of the saturation extract exceeds about 3.5 mmho/cm in the surface 60 cm rootzone (11). Young orchards irrigated by drip methods with saline waters of 2 to 3 mmho/cm are common in the Trans-Pecos, but it is premature to make definitive assessments on its potential for success. Ground surface manipulation to concentrate rain water (18) around tree trunks may help reduce salt accumulation as well as water requirements.

Chile peppers are another important cash crop grown in the middle Rio Grande basin. Extensive breeding programs have developed high yielding and high color chile peppers, many of which can potentially yield 7000 lb dry chile per acre (7.8 Mg/ha). The actual yields, however, vary from 2500 to 6000 lb/acre (2.8 to 6.7 Mg/ha) depending primarily upon management. Chile peppers are exceptionally sensitive to water stress, but excess water triggers devastating chile wilts (14). Chile peppers are also sensitive to salt stress, although there are considerable varietal differences in tolerance (4). Under furrow irrigated conditions, fruit yields may be reduced by half when irrigated with water of 2.2 mmho/cm (ongoing field tests, this laboratory). For this reason, chile peppers are grown only in the El Paso Valley and Van Horn areas. Even with the Rio Grande water, crop failures associated with high seedling mortality are common. Chile peppers usually germinate, but emerged seedlings are sensitive to foliar salt damage (10) especially when seedlings are physically scarred by strong spring wind (ongoing test, this laboratory). Drip irrigations are ideally suited for irrigation of chile peppers (6), yet it has not been used in the El Paso Valley, mainly because irrigation water from the project is not continually provided.

Melons and tomatoes are more tolerant to salinity than chile peppers (19). These are grown successfully in gypseous soils of the Dell City area with modifications of cultural practices. Tomatoes are established through alternate furrow irrigation and cantaloupes with off-centered plantings. Obtaining a good stand has been difficult with tomatoes due to seedling mortality by excess salts. The introduction of new crops such as jojoba and guayule (a rubber producing shrub) has also been attempted. Jojoba can not tolerate severe winter temperatures, and guayule can not withstand salts at the emergence and seedling growth stages, although it is relatively tolerant to salts after establishment. The introduction of pistachio and asparagus is being considered because of known tolerance to high salinity (16).

Soil Permeability and Salt Leaching

Low soil permeability is one of the many factors that limit drainage, thus leading to soil salinization. This problem appears primarily in pecan and to a lesser extent in alfalfa fields established on clay and clay loam soils of the middle Rio Grande Basin. Traditionally, permeability of these clay textured soils has been maintained by deep plowing and subsequent soil drying. Following the conversion to these crops, such measures were not utilized due to root-bound soil conditions. Irrigation water then began to stand on the field, leading to gradual salt accumulation.

In addition to the lack of physical manipulation of slowly permeable orchard soils, spatial variability in soil permeability existing within a border strip or basin appears to compound salt accumulation in clay portions (11). Since soils in flood plains vary in an irregular fashion, each border strip often contains multiple soil types. Ponded water, of course, penetrates primarily into sandy portions of the strip, thus leaving the clay portions poorly leached. A consequence is disproportionally large accumulation of salts in the clay portion. An example of uneven salt accumulation observed in a border irrigated orchard in the El Paso Valley is shown in Table 3.

Table 3. Salinity of the saturation extract of three soil types appeared in a 50 ha pecan orchard in the El Paso Valley irrigated for 11 years with water of EC = 1.1 dSm^{-1} and SAR = 3.5 (Miyamoto and Gobran, 1983).

Depth	Harkey loam	Harkey silt clay loam	Glendale silt clay	Glendale backhoed[1]	silt clay native
	- - - - - EC of saturation extract (dSm^{-1}) - - - - - - -				
cm					
0-30	1.2	3.3	6.0	2.2	5.6
30-60	1.5	5.5	5.5	3.2	5.5
60-90	3.2	4.5	6.5	3.1	5.8
90-100	5.0	4.5	6.5	5.6	6.0

1/ This area was disturbed with a backhoe to a depth of 160 cm five years prior to the soil sampling.

Numerous laboratory data and limited lysimeter data (e.g., 15) suggest that the quality of the Rio Grande water should not adversely affect permeability of well-leached soils. However, when soils are salinized, the sodicity of soils increases 15 to 25% in ESP due to precipitation of Ca and an increase in the total salt concentration. Then, the leaching of salts and exchangeable Na from clay textured soils with the Rio Grande water becomes difficult because of extremely slow movement of leaching water. One way to aid salt and sodium leaching is to use chemical amendments. Field experience shows that the traditional gypsum amendment is of limited value in enhancing the speed of reclamation when soils are initially loaded with sulfate salts. Chemicals of higher solubility such as $CaCl_2$ and H_2SO_4 provide faster leaching and greater removal of exchangeable Na per unit amount of Ca (or H^+) applied (17, 20).

Another chemical factor that may reduce soil permeability is pore plugging by precipitated salts. Frenkel et al., (3) estimated that 10% of the effective pore space present at a rootzone depth of 60 to 90 cm may be occupied by precipitated gypsum and calcium carbonate after about 14 years when alfalfa was grown with water containing 20 meq/liter of Ca and SO_4, and 9.2 meq/liter of HCO_3. If the water is saturated with gypsum (solubility of 32 meq/liter in distilled water), the time duration would be shortened considerably. At present, it is difficult to estimate the effect of 10% pore plugging on soil permeability, since the mode of precipitation is not well understood. If the precipitation occurs in large pore spaces, the effect would be significant. Keren and Shainberg (7) reported 50% reduction in hydraulic conductivity when analytical grade gypsum powder was mixed into sandy loam and loam soils at 3% by weight. The Dell City area has been irrigated with gypseous water for about 30 years, yet no major drainage problem has been reported. Coarse textured soils and a relatively low rate of water percolation required to maintain the salt balance are probably moderating this problem.

Irrigation Management

Traditionally, most field crops in far West Texas have been irrigated by furrow methods. When saline water is applied to every furrow, the highest salt concentration is known to occur in the ridge of the bed and the lowest concentration in the water furrow. This surface accumulated salt often becomes the source of hypocotyl and seedling mortality or of reduced germination, especially after light showers. One method of minimizing salt accumulation in the crop bed is to use alternate furrow irrigation. Under this system, salts are pushed into nonwatering furrows. This method has been adopted widely in Trans-Pecos areas. In the Hudspeth irrigation district where salinity of irrigation waters is extremely high, this method is usually used for the first one or two irrigations, then every furrow is irrigated so as to leach salts accumulated in dry furrows. Dragging the salt crust developed on the top of the single bed with drag-chain or metal rods shortly before crop emergence is another practice used in the El Paso valley. This method also eliminates the soil crust that develops in clay textured soils after spring rains or excessive irrigation. This method appears to work well with cotton and chile peppers, but not with fast-emerging shallow seeded crops such as lettuce.

Double row plantings on flat beds have been practiced with lettuce, onions and in some cases with cotton. Seeds are planted on the sloped shoulder portion of the bed where salt accumulation is minimal. Longenecker et al (8) reported an excellent stand and production of cotton using this system with water of 5.4 mmho/cm. This practice can not prevent seedling damage caused by saline splash associated with light showers, because of the presence of high surface accumulated salts near seedlings. It also makes mechanical weed control somewhat difficult. Planting seed in water furrow is advantageous from the view of having the lowest salinity, but has serious disadvantages. Soil in the water furrow crusts badly, seedling diseases and weed infections are worse, and soils are colder. This method is used only in extremely saline areas for establishment of some forage crops.

Border and basin irrigations with saline waters require good land leveling not only for improving water distribution efficiency, but also to minimize uneven salt leaching. Most of the orchards in the El Paso valley have been laser-leveled in recent years for this reason. When a border strip or a basin consists of multiple soil types, uneven salt leaching, as discussed earlier, becomes a problem. Modification of border settings or the use of high leaching irrigation helps minimizing this problem (11, 12).

Sprinkler irrigation has been used mostly for irrigation of alfalfa and forage crops in the Trans-Pecos region. When salinity of irrigation water is as high as those found in this region, foliar-induced salt damage becomes a problem or at least a concern. Alfalfa leaves grown in the Dell City area sometimes show margin leaf-burn, but no major yield reductions are reported after the conversion from a border to a center pivot sprinkler using water of 3.0 to 5.0 mmho/cm. Alfalfa is fairly tolerant to saline water sprinkling (2) even though some leaves may show leaf margin necrosis at an EC as low as 1.5 mmho/cm (10). Sprinkler irrigation of cotton is used in several areas of the Trans-Pecos. Busch and Turner (1) reported a 15% reduction in lint yield when sprinkler irrigated during the day time with water of 4 mmho/cm, while Moore and Murphy (13) reported severe leafburn and extremely poor yields by daytime

sprinkling of saline water having 5.0 mmho/cm. In both cases, no significant yield reduction was observed when irrigated during night hours. Sprinkler irrigation of pecans resulted in severe salt damage including complete defoliation when irrigated during daytime with water having 0.8 mmho/cm in El Paso (Personal Observation). Many tree crops are sensitive to foliar salt absorption of Na and Cl (2).

Recently Lyle and Bordovsky (9) developed an irrigation system that utilizes low energy precision application (LEPA) techniques. This is a linear mobile system that delivers water into the furrows at low pressure of 5 to 8 psi (34-55 kPa) through drop tubes rather than spraying it through the air with conventional sprinklers. Consequently, the contact of foliage with highly saline water is avoided. Yields of cotton under this system have been equal to or greater than furrow irrigated cotton, using water having 8 mmho/cm (ongoing field tests at Pecos). Long-term salt accumulation under this system is unknown.

Irrigation scheduling is known to affect the extent of salt hazard. Scheduling for cotton and alfalfa have been fairly well established. A computer model for scheduling pecan irrigation considering salinity and spatial variability, was also developed and used in a large orchard (12). Irrigation scheduling of pecans and chile requires special care, because of their low tolerance to both salt and water stress.

In summary, the experience in far West Texas points out excellent potentials for crop production with highly saline waters. Proper crop and variety selections are the first step toward successful use of saline waters. Once a crop is selected within a limit of salt tolerance, soil types, irrigation methods and their management begin to dictate the success or failure of saline water irrigation.

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New Strategy For Using Saline Waters For Irrigation

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ABSTRACT

A way to use brackish waters for irrigation of suitably tolerant crops that should result in little, if any, loss of yield as well as increase the opportunity to use the same land to grow salt sensitive crops without special equipment or techniques has been conceived and is now under test in two field projects. The proposed management strategy which meets such requirements is to substitute the saline (such as drainage) water for the "good" (river) water when irrigating certain crops in the rotation when they are in a suitably tolerant growth stage; the "good" water is used at the other times. The maximum soil salinity in the rootzone resulting from continuous use of brackish water will not occur when such water is used for only a fraction of the time. The timing and amount of substitution will vary with the quality of the two waters, the cropping pattern, the climate, and the irrigation system. Whatever salt build up occurs in the soil from irrigating with the brackish water can be alleviated in the subsequent cropping period when a more sensitive crop is grown using the normal (low-salinity) water for irrigation. The yield of the sensitive crop should not be reduced if proper pre-plant irrigations and careful management are used during germination and seedling establishment to leach salts out of the seed area and shallow soil depths. Subsequent "inseason" irrigations leach the salts farther down in the profile ahead of the advancing root system and "reclaim" the soil in preparation for the next time when the brackish water will be used again to grow a suitably tolerant crop. This cyclic use of waters of "low" and "high" salinity prevents the soil from becoming saline while permitting, over the long period, substitution of a brackish water for a better quality water for a large fraction (>50%) of the irrigation water needs. The proposed strategy is under evaluation in two experiments and general findings (which have been positive) are reviewed.

INTRODUCTION

The projected increase in cropland for the final quarter of this century is only 10 percent; yet the world demand for food is expected to approximately double between 1975 and 2000, according to the U.N. World Food Conference Report (1974). If these projections are valid, then world agriculture must produce a greater yield per unit land area than ever before and limited land and water resources must be used more efficiently. Furthermore the unevenness in year-to-year production

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related to variations in weather patterns must be attenuated. Irrigated agriculture takes on special importance in this regard because it yields more per unit area and is less dependent on the vagaries of weather. Expansion of irrigated agriculture would contribute significantly towards achieving and stabilizing world food and fiber needs. Expanding irrigation, however, runs headlong into competition for ever more limited water supplies. In my opinion, by reassessing the standards for suitability of water (and land) for irrigation, the available supplies can indeed be expanded significantly. In the past, very conservative standards have been used. Waters generally classified as too saline for irrigation are used successfully to grow crops without hazardous long-term consequences to crops or soils, even with the use of "conventional" farming practices (van Schilfgaarde and Rhoades, 1983). The adoption of new crop/water management strategies will further facilitate the use of saline waters for irrigation and crop production. Irrigated agriculture could be expanded considerably through the adoption of such strategies. Considerable saline water is available, including drainage waters from irrigation projects and shallow ground waters, in many places in the world.

Many brackish waters not now used for irrigation because they are deemed too salty can, in fact, be used effectively for irrigation, especially if properly adapted management practices are applied (Rhoades, 1977, 1984). With the future in mind, it behooves us to learn to find ways of learning to live with these higher salinity waters. The ultimate goal should be to maximize the use of an irrigation water supply in a single application with minimum drainage (Rhoades, 1983). Of course, there are practical constraints which now prevent this, as well as economic disincentives. To the extent that the drainage water still has value for crop use, it could be used again for irrigation. In fact, whether inadvertent or planned, such reuse is common in many places; however, it could be carried much further by successively irrigating a sequence of crops of increasing salt tolerance. This has little appeal to most farmers because they do not want to be restricted to growing only salt-tolerant crops nor do they want to have to deal with the special management practices or invest in the special equipment involved in obtaining good "stand" as is required to grow crops on saline land. The receptivity and practicality of using saline waters (such as drainage waters) for irrigation will be appreciably enhanced if these limitations can be circumvented.

A new crop/water management strategy to enhance the usability and practicality of irrigating with relatively high salinity water is discussed in this paper. The goal of the strategy is to use brackish waters for irrigation of suitably tolerant crops with little, if any, loss of yield while preventing the soil from becoming excessively saline and permitting the same land to be used to grow salt sensitive crops, in both cases, without special equipment or techniques.

STRATEGY CONCEPT

Implementation of this strategy would not only increase water conservation and resource base for crop production, it also could minimize the drainage disposal (and associated) problems where drainage waters are the saline waters recycled for use for irrigation within or contiguous to the project area, as well as the salt loading of our water supplies (Rhoades, 1984).

The strategy is to substitute the saline water for the normal (low salinity) irrigation water when irrigating certain "salt-tolerant" crops in the rotation when they are in a suitably tolerant growth stage; the normal water is used at the other times. The timing and amount of substitution possible will, of course, vary with the quality of the two waters, the cropping pattern, the climate, certain soil properties and the irrigation system. Whatever salt build up occurs in the soil from irrigating with the brackish water can be alleviated in the subsequent cropping periods when a more sensitive crop is grown using the normal (low-salinity) water for irrigation. A soil will not generally become unduly saline from use of a saline water for a part of a single irrigation season and often not for several seasons. The maximum soil salinity in the rootzone resulting from continuous use of brackish water will not occur when such water is used for only a fraction of the time. Furthermore, the yield of the sensitive crop should not be reduced if proper pre-plant irrigations and careful management are used during germination and seedling establishment to leach salts out of the seed area and shallow soil depths. Subsequent "inseason" irrigations will leach the salts farther down in the profile ahead of the advancing root system and "reclaim" the soil in preparation for the next time when the brackish water will be used again to grow a suitably tolerant crop. This cyclic use of waters of "low" and "high" salinity waters prevents the soil from becoming too saline while permitting, over the long period, substitution of a brackish water for a better quality water for a substantial fraction of the irrigation water needs.

EVIDENCE OF THE CREDIBILITY OF PROPOSED STRATEGY

The suggested strategy for using brackish waters for irrigation is under evaluation in two field experiments. One is a forty-acre field experiment which was begun on a cooperator's farm in the Imperial Valley in January, 1982. Two cropping patterns are under test there. One is a two-year successive-crop-rotation of wheat, sugar beets, and melons. In this rotation Colorado River Water (900 mg L^{-1} TDS) is being used in the preplant and early irrigations of wheat and sugar beets and for all irrigations of melons. The remaining irrigations are made using the Alamo River (drainage water of 3500 mgm L^{-1} TDS). The other is a block rotation of cotton (a salt-tolerant crop) for two years followed by wheat (a crop of intermediate salt tolerance) and then by alfalfa (a more sensitive crop) for a block of several years. Drainage water is being used for a large part of the irrigations of cotton; beginning with the wheat crop only Colorado River water is being used. It was hypothesized that wheat would withstand the salinity build up in the soil achieved from irrigating the cotton with the brackish water and yield well when irrigated with Colorado River water and that sufficient desalination of the soil would occur during its irrigations with Colorado River water to subsequently permit alfalfa to be grown (also with Colorado River water) without loss of yield.

To date, one wheat crop, one sugar beet crop and one melon crop have been grown, i.e. one cycle has been completed in the successive crop rotation, and two cotton crops have been harvested, in the first two years of the block-rotation, using the proposed "cyclic" crop/water management strategy. No losses in yields occurred in any of these crops where the Alamo River water was substituted for the Colorado River water following seedling establishment. The percentages of substitution of Alamo River for Colorado River used in the test were 76 for wheat, 82 for sugar beets and 54 for cotton. Melons (a salt-sensitive crop) were subsequently grown on the same land farmed to wheat and sugar beets with substitution of Alamo River water without yield loss (compared to the control, i.e. use of Colorado River water only for all crops and irrigations) using Colorado River water for irrigation.

A second field experiment has been underway near Lost Hills in the San Joaquin Valley of California for five years. In this case a very saline water (6000 mg L^{-1} TDS) has been successfully used to irrigate cotton following seedling establishment with California aqueduct water (300 mg L^{-1} TDS) for four consecutive years. Wheat was then grown with aqueduct water for desalination purposes. Sugar beets are now being grown with the "cyclic" strategy, to be followed by cotton. This is a demanding test since a very saline ground water has existed beneath the test area at a depth varying between 1.5 and 4 feet for the last three years, eliminating the opportunity for leaching and causing the soil salinity to increase to abnormally high levels. In spite of these problems, 1982 cotton lint yields were good: 2.8 bales per acre (aqueduct water only) and 2.3 bales per acre (drainage water after seedling establishment). This experiment, upon completion, should provide appropriate data to evaluate the long-term effects of the strategy.

These results support the credibility of the proposed strategy, but it can not be claimed that its validity has been established because the long-term consequences have not yet been fully evaluated.

BLENDING

Blending of saline and non-saline waters is frequently recommended as a procedure to use saline waters productively. Frequently, drainage water is inadvertently recovered and used for irrigation elsewhere because drainage often returns by diffuse flow to a water supply system. Both the intentional and unintentional blending processes may have deleterious effects on water quality without adding to the water supply that contributes to crop production. This may be seen in the following explanation. A plant must expend bio-energy (that would otherwise be used in biomass production) to extract water from a saline (low osmotic potential) soil solution. When a water of excessive salinity for crop production is mixed with a low-salinity water and used for irrigation, the plant can only remove the "good water" fraction (actually less than this amount) from the mix before the salinity again becomes excessive, i.e. until the fraction of the mix made up of the excessively saline portion is left. This fraction is just as unusable at this point as it was before mixing because it requires more energy to separate the pure water from such a low osmotic potential solution than the plant can muster. Thus, diluting excessively saline water with less saline water does not stretch the water supply for

crops which could not use the water prior to dilution. This "saline water" component is only usable on crops that are sufficiently salt-tolerant to use the water undiluted. Mixing saline water back with a receiving water can increase the latter's salinity sufficiently to limit its usability for sensitive crops and for other uses as well. One has, in this process of mixing, simply mixed the usable and unusable waters into one blend which must be separated again during the use by the plant. Blending a non-excessively saline water with a "good water" will stretch the water supply if the crop could use the water before dilution. Greater flexibility and opportunity for crop production results, however, if the two water types are used separately and cyclically in the crop/water management strategy described herein. Once the waters are mixed, this alternative is lost. Cyclic use allows the soil salinity to be lower during the critical periods of germination and seedling establishment and provides the plant with saline water at a time when it is most able to use it. Of course, it may not always be feasible or practical to prevent natural mixing of saline and non-saline waters and the cylic system may not always be practical; however, intentional mixing should be carefully evaluated for benefit before undertaking it and the opportunity to prevent mixing and implement the cyclic crop/water management strategy should be pursued wherever practical.

CONCLUSION

Use of saline water for irrigation can increase the resource base for irrigated agriculture and help meet the increasing biomass needs of the world. Such use can be made more practical and appealing when used cyclically with low-salinity waters. When the saline water is a drainage water such use could convert a "waste" product into an asset, reducing the volume of drainage water needing export, reducing the deleterious impact of drainage disposal, and increasing the amounts of water available for irrigation and crop production. As with anything, the advocated strategy will not be appropriate for all conditions, but it should be given careful consideration.

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Roadway Salting Effects on Snowmelt Water Quality

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ABSTRACT: The effects of roadway salting on snowmelt water quality were studied up and down stream from a major high-elevation interstate highway in the Sierra Nevada of northern California. Water samples were analyzed for alkalinity, pH, sulfate, sodium, and chloride. Chloride and sodium concentrations were more than one order of magnitude higher below the roadway and reached levels of 104 mg/l and 46 mg/l. Fractionation during snowmelt was not well sustantiated, but dilution was clearly effective. Chloride and sodium concentrations were inversely related to stream discharge.

During heavy snowfall, high-elevation roadways are often salted to control ice formation and increase traffic traction. During and after a snow storm, rotary snow blowers throw the piled snow away from highways. If the highway lies next to streams, the contaminated snow flows into the stream channels and mixes with the surface water flow.

Studies have shown that sodium and chloride concentrations are elevated by roadway salting. After the onset of midwinter thaws at urban water courses in Toronto, Ontario, sodium concentrations reached over 2000 mg/l--50 times greater than baseline values (7). Concentrations decreased rapidly as snowmelt runoff augmented base-level flows. In rural Vermont, maximum chloride concentrations on road-salted sites were more than one order of magnitude greater than on non-salted sites (3). Chloride concentration varied inversely with streamflow. Although sodium chloride delivery rates, measured in kg/day, peaked during the main spring thaw period, chloride concentrations were highest during the low-flow summer months. In Syracuse, New York, road-salted water draining suburban lands with low population density contained chloride at the 1000- to 5000- mg/l level, with spot samples exceeding 11,000 mg/l (2).

This paper reports a study of stream chemistry up and down stream from a salted section of a high-elevation interstate highway in California, and relates the results to current safety standards for human health. The data were also examined in connection with refining hypotheses about fractionation and changes in sodium and chloride levels over time. Formal statistical methods were not used because hypotheses were not yet specifically enough defined to allow choices of particular statistical techniques.

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