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Scientific Irrigation Scheduling for Salinity Control of Irrigation Return Flow

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ABSTRACT

Basic principles of irrigation water management and irrigation scheduling are presented. Commercial and agency groups expanded rapidly in the 1970's providing field-by-field scheduling services to over 600,000 acres in 1976.

The leaching fraction used on projects can effect return flow quality. Most leaching fraction/return flow models hypothetically assume uniform water applications of exact quantities to attain targeted leaching fractions. The average or effective leaching fraction for a field is dependent on the irrigation uniformity coefficient. The effects of nonuniform water application on average leaching fractions will be presented, along with the probable effects of expected improvements in irrigation efficiency on return flow. Also, estimates of the accuracies in estimating evapotranspiration and measuring water will be presented. Substantial improvements can be made in irrigation efficiencies before minimum leaching fractions are reached on most western irrigated projects.

INTRODUCTION

The annual return flow volume from an irrigation project is dependent on the annual irrigation water volume diverted to the project, precipitation, and the project evapotranspiration (ET). The average project return flow quality is influenced by precipitation, the quality of the irrigation water, the proportion of irrigation water in the return flow, the integrated project leaching fraction (LF), and salt pick-up. The salt pick-up is influenced by the volume of project deep percolation and seepage from canals and laterals.

The title of this paper implies that the variables affecting the quantity and quality of return flow can be controlled by irrigation scheduling, but the potential degree of control has not been delineated. The purpose of a detailed study conducted in 1975 (Jensen, 1975) was to evaluate the probable effects of implementing scientific irrigation scheduling on return flow quality. The results of that study and another presented at the California Conference on Salt and Salinity Management (Jensen, 1976) are summarized in this paper.

What is Irrigation Scheduling?

Irrigation scheduling is predicting the time and amount of the next irrigation. This process is dependent on the precipitation and ET since the last irrigation, the allowable soil water depletion, and the expected precipitation. Irrigation scheduling can significantly influence the volume of water diverted to a project. Thus, scheduling can potentially influence the LF, and to a limited extent canal seepage. Irrigation scheduling will have little effect on ET when crops are irrigated for maximum, or for optimal yields.

Reducing the salt load from an irrigation project requires a minimum leaching fraction (LF*) permissible for the crops and water quality involved. The average LF will be greatly dependent on the attainable irrigation uniformity. Thus. even though irrigation scheduling technology can be refined and implemented, attaining low average LF's will require both irrigation scheduling and significant improvements in irrigation systems to uniformly apply water.

Need for Irrigation Scheduling

If the management objective is to minimize the salt load in return flows, then minimum leaching fractions must be achieved on each irrigated field. It is difficult to manage the soil water reservoir of complex soil-crop-climate systems because many variables are involved, and the soil water status is not readily apparent. The quantity of water applied at each irrigation is important because a single overirrigation during a growing season can drastically decrease the seasonal irrigation efficiency and prevent achieving the targeted field LF.

Accurate water control is easier to achieve with irrigation systems that have limited opportunities for overirrigation. With sprinklers, for example, the amount of water applied is controlled by the system and not the soil when the application rate is less than the intake capacity. Thus, a targeted application can be achieved by regulating pressure and hours per set, especially with systems that apply water while moving. Moving systems usually apply water more uniformly than those with stationary heads.

Specific amounts of water can be applied with surface irrigation systems if modern technology is used, but most surface systems are operated today as they have been for the last two or three decades. Stream sizes normally are not increased and set times reduced enough to achieve the targeted uniform irrigation when intake rates change after tillage. Facilities do not permit these detailed changes at each irrigation, especially with older systems that do not have water measuring devices, adjustable water control structures, and lined channels or enclosed distribution systems. The duration of each irrigation set is often based on some convenient period such as 12 or 24 hours because of the labor required to change sets. When coupled with long length of runs, light irrigations are difficult to achieve on most existing surface systems. The time of irrigation can easily be changed with these systems, but controlled water applications will require improved facilities. There is an emerging demand for new innovations, instrumentation, and equipment to modernize surface irrigation systems to meet the 1983 goals of Public Law 92-500 for best available technology to control the quantity and quality of irrigation return flow.

Typically, observed irrigation efficiencies on surface irrigated lands in the U.S. are low. Early studies in the 1890's cited overirrigation as the first and most serious mistake made by early settlers in Wyoming (Buffum, 1892). This situation has not changed much on many older projects. Until recently, only limited progress has been made in modernizing surface irrigation systems because there have been few incentives for change because water costs in most areas are low and represent a relatively small percentage of annual farming cost. Also, excessive water application effects on both crop yield and quality normally are not as apparent as the effects of water deficits and salinity caused by inadequate irrigation.

Most older surface irrigation systems require much labor to be operated efficiently. Increasing labor costs generally have reduced labor input, thus offsetting the effects of improvements in irrigation facilities. Similarly, with low cost nitrogen (N) fertilizer, it has been easier and more economical to compensate for poor water management by applying excess N. New regulations on N in return flows and increasing N costs are now beginning to influence irrigation and fertilizer practices. The costs of correcting drainage problems that emerge after several years of excessive water use are often distributed uniformly to all water users in a project and not just to those using excessive water. Sometimes drainage costs are cost-shared, which in essence subsidizes excessive water use. All of these practices have not been conducive to improving irrigation practices and systems.

Today the ecomonics of irrigation are rapidly changing, and new constraints are emerging. Fertilizer costs are increasing. More important, energy costs are spiraling and the certainty of continuing energy supplies for irrigation is diminishing. These and other emerging economic incentives will have a major impact on irrigation water management practices during the next decade. Pending state and federal return flow regulations, involving both water quantity and quality, coupled with increasing labor and energy costs will be changing irrigation farming objectives. New management technology will be needed for irrigation farming to remain solvent and competive with rainfed agriculture. Increased capital investments will be needed to achieve better water control with less labor, and increased technical skills will be needed to service complex irrigation systems. Farm management must place greater emphasis on maximizing net returns and yield per unit of water and less emphasis on maximizing yield per unit area.

As the amount of irrigation water diverted to irrigation projects approaches the consumptive irrigation water requirement, more accurate consumptive use or ET data will be needed to optimize system operations. The demand for irrigation management services will increase which should stimulate the development of more rapid and ecomonical means for monitoring the soil water content and its distribution on individual fields.

Attainable Irrigation Efficiency and Leaching Fractions

Optimum irrigation water management will require more accurate water applications for both consumptive and nonconsumptive uses. Essential or minimum amounts needed for nonconsumptive uses (frost protection, leaching hydrating a root crop before harvest and seed germination) are easy to specify, but may be difficult to achieve because of nonuniform water distribution inherent with many existing systems. For example, if target minimum LF's of 0.05 to 0.1 were acceptable and the management objective was to maintain these LF's on the 10% of each field that regularly receives the least amount of water, the average LF for the field may be three to five times the mimimum LF when using existing sprinkler systems (Table 1, Jensen, 1975). The areas normally receiving the least amount of water are the lower ends of uniformly graded surface irrigated fields and the area between sprinkler laterals that are not moved during the irrigation season.

The water distribution uniformity within individual fields is an important variable that must be considered in estimating the potential effects of minimum LF's on the quality of return flow. This is a very important variable that cannot be neglected because the relationship between the LF and the precipitation of salts within the root zone is nonlinear. The prospects of achieving cummulative seasonal uniformity coefficients (U_c) that exceed 90% by 1983 is very remote for most projects even though the cummulative U_c increases with successive irrigations.

Another important variable that must be considered, except with automatic systems operated by sensors, is the probable accuracy of applying targeted amounts of water. When using values suggested by Jensen and Wright (1976), the coefficient of variation (estimated standard deviation/drainage, expressed in percent) during a 30-day period is about 10 percent with a LF of 0.5 and an average ET of 6 mm/day (0.24 in./day). It increases to about 50 percent as the LF approaches 0.1 (Table 2). The probable error is even greater with shorter time periods because the standard error in estimating ET decreases proportional to $1/\sqrt{t}$.

TABLE 1

Average leaching fraction (LF) for a field for various targeted minimum LF (LF*) in relation to the uniformity coefficient (U_c) of water applications (From Jensen, 1975).

			Average LF with a LF of:*		
U_c	s	α_d	*0.05*	*0.10*	*0.15*
%	%				
100	0	1.00	0.05	0.10	0.15
95	6.25	.89	.15	.20	.24
90	12.50	.79	.25	.29	.33
85	18.75	.69	.34	.38	.41

Assumptions:

Average depth of water applied in the 10% of a field regularly receiving the lease amount of water is (1 + LF) ET; the application of water by a sprinkler system is normally distributed with a standard deviation, s, estimated from the equation* $U_c = [100(1 - 0.8s/100]$, *and is independent of the amount applied; the distribution coefficient,* α_d, *at 5% of the area represents the relative depth of water applied to 10% of the area that receives the least amount of water; irrigations are timed exactly so that only LF*(ET) drains through the soil; and ET is not affected by soil salinity level.*

TABLE 2

Estimated coefficient of variability in applying water to achieve various targeted leaching fractions for 10-, 20-, and 30-day periods (From Jensen and Wright, 1976).

	Period, days		
Target leaching fraction	*10*	*20*	*30*
	%		
0.1	94	58	48
.2	42	27	22
.3	25	16	14
.4	17	11	10
.5	12	8	7

Assumptions:

Mean ET = 6 mm/day (0.24 in./day) estimated from daily climatic data.

Surface runoff (15%) and applied water measured with an accuracy of ± 5%, or $s_Q = 0.025Q$.

Traditional and Modern Irrigation Scheduling Practices

Traditional irrigation scheduling methods are based on tensiometers, electrical resistance units, pan evaporation data, and general fixed irrigation dates and amounts for given crops within a local area. A few farmers now use the neutron probe for measuring soil moisture and scheduling irrigation. Traditional approaches usually require the farmer to use some type of instrument, take soil samples, or use evaporative data. Thus, he must first understand ET and soil moisture depletion. If a tool or instrument is needed he also must understand how it functions and its relationship to the soil water depletion to use it correctly.

Traditionally irrigation scheduling methods have not been very effective in the past, perhaps because there have been insufficient incentives to warrant significant improvements in irrigation management practices. Basically, traditional methods essentially require a "do-it-yourself" approach to irrigation scheduling. Thus, promoting only traditional methods has limited the farmers access to information needed to improve irrigation scheduling decisions. Alternative procedures for providing this information on a real time basis have not been seriously considered, developed and evaluated.

Modern irrigation scheduling services provide farm managers with estimates of the current soil water status on each field, and predicted irrigation dates and amounts to be applied on each field to avoid adverse effects on plant growth. With this information farmers can modify their irrigation practices and schedule irrigations more accurately. The increasing demand for commercial irrigation scheduling services during the past five years is indicative of a long standing need for such information.

A modern irrigation scheduling service (ISS), utilizes the latest irrigation science and technology to provide current information on the available water status in individual fields and projected irrigation dates based on expected climatic conditions. The ISS may provide the daily rate that high frequency systems should apply water to maintain the desired soil water level in each field. When water supplies are limited or another variable, like fertilizer, limits production, the ISS should also recommend the optimum times and irrigation amounts to achieve these goals. An effective ISS recommends needed improvements in irrigation systems to achieve greater irrigation uniformity, reduce water losses, and maintain a favorable salt balance in the soil. Services like these increase the farmer's managerial skills and should increase his net returns (Jensen, 1975).

The irrigation scheduling approach developed by Jensen et al. (1969, 1971) known as the USDA-ARS Computer Program, has been widely accepted because it does not require farmers to obtain technical knowledge and training to apply modern irrigation technology. Periodic updating of the current soil water status, ET rates and projected irrigation dates provide information that greatly increases the farmers' understanding of the soil-plant-atmosphere system. Experience gained in testing this concept in 1968 and 1969 indicated that even though farmers had been irrigating for many years, information provided by this program increased their understanding of processes influencing and controlling this complex system.

Many commercial and agency service groups have adopted the program without change or have modified the USDA-ARS Computer Program to suit their special needs. New commercial firms have been established, and many firms have purchased their own small computers for routine calculations and record keeping on hundreds of fields. The professional staff of an ISS group must be trained in irrigation science and technology for successful application of the program. They must monitor the soil water status and sometimes measure precipitation on each farm to periodically tune the computer results to field conditions. Most companies recommend and provide updated irrigation dates at least weekly. Some fields are inspected twice weekly during the growing season. Some service groups also design improved irrigation systems and provide plant nutrient, pest, control and other services. Service companies must maintain active communications with the farmer, sometimes on a 24 hour basis, and they must have a crew of trained and experienced field technicians. If ISS groups are to provide unbiased recommendations to maximize net returns to the farmer, they should not sell products they recommend. This practice represents a serious potential conflict of interest.

Table 3 is a summary of the general irrigation practices and management options along with the information needed and provided by service groups to improve irrigation management. Such information is needed for all irrigation methods and management options, except, perhaps, fully automated systems that operate with soil-water sensors or a combination of sensors and timed controllers. Periodic monitoring of saline control may still be needed with automatic systems, unless salt sensors are used.

TABLE 3

General irrigation practices and management options and the types of scheduling information needed (from Jensen, 1976).

Irrigation practices and management options	*Types of irrigation scheduling information needed*
A. High frequency	
1. Maintain nearly constant soil water level and target leaching fraction.	Daily evapotranspiration (ET) and rate of water application. Periodic soil water monitoring for content, distribution, and salinity.
2. Planned gradual depletion of available soil water during the crop season with target leaching fraction provided during the noncrop or some other crop season.	Same as for A.1.
3. Combination of A.1 and A.2	Same as for A.1.
B. Normal periodic irrigations	
1. Irrigate to bring the soil to field capacity at each irrigation and provide target leaching fraction.	
a. Constant or fixed application amounts.	Daily ET, earliest next irrigation date permitting efficient irrigation along with the latest next irrigation date to avoid significant adverse effects on crop production. Periodic soil water monitoring for content distribution, and salinity.
b. Fixed irrigation intervals	Daily ET, irrigation amounts for efficient irrigation, and periodic soil water monitoring for content, distribution, and salinity.
2. Planned gradual depletion of soil water during the crop season with target leaching fraction provided during the noncrop or some other crop season.	
a. Constant or fixed application amounts	Same as B.1.a.
b. Fixed irrigation intervals	Same as B.1.b.
3. Combination of B.1 and B.2	Daily ET, earliest next irrigation date and amount for efficient irrigation along with the latest date and corresponding amount to avoid significant adverse effects on crop production and permit efficient irrigation. Periodic soil water monitoring for content, distribution and salinity.
C. Limited and supplemental irrigation	
1. Limited irrigations applied to optimize production or net returns per unit volume of water.	Expected ET, and optimum times and amounts of irrigation considering expected rainfall to maximize production per unit of irrigation water. Periodic soil water monitoring for content and distribution.
2. Alternating shallow, well-watered and deep rooted, nonirrigated crops.	Expected ET and production from alternative sequences.

Monitoring the soil water status in each field may not be required during the entire growing season if excess water is applied at each irrigation, or if the amount of water applied and rainfall are known with reasonable accuracy. However, soil water monitoring is usually required to calibrate or tune the computer calculations, since the error of measuring soil water either gravimetrically or with a neutron probe is generally less than the error in estimating the amount of irrigation water applied. Since the confidence limits of predicted irrigation dates are dominated by the component with the greatest uncertainty, the amount of water applied by surface irrigation systems usually causes the greatest uncertainty and widens the limits until the field can be monitored again.

When irrigation service groups first begin, they provide irrigation schedules without recommending changes in existing systems. Later as they become acquainted with the characteristics and constraints of the systems, and as they and the farmers gain experience, components that need improvemnt can be identified and system improvements scheduled. As labor costs increase, or skilled labor becomes less available, ISS groups will play a more important role in applying modern irrigation science and technology in irrigation water management.

ISS also must be economical, with sufficient accuracy to be compatible with the system's ability to apply specific amounts of irrigation water. Irrigation scheduling information only supplements, and does not replace, the farmers' experience.

Adoption of Irrigation Scheduling Services

Jensen (1975) evaluated ISS provided in 1974 and found that ten western U.S. commercial firms had 1 to 10 years of experience and seven of the ten had five years or less. ISS was provided for a fee to about 4450 fields involving over 100,000 ha (250,000 ac.) of summer crops in eight western states. All 10 firms provided plant nutrition services, seven provided plant pest management services, and six provided engineering services. Technicians, who monitored soil water-depletion in each field once or twice weekly, serviced an average of 5800 acres and traveled an average daily distance of 195 km (120 mi.). Agency or project services were similar to commercial services except the customers paid only part of the direct cost. The balance was distributed uniformly to all water users in the projects. Of 22 agency service groups, 21 had five or less years' experience. These groups provided ISS for about 3500 fields involving 54,000 ha (133,000 ac.) of summer crops in 12 western states. Only about 25% of these groups provided plant nutrition services, 20% provided pest management services, and 15% provided engineering services. Besides field-by-field services, the U.S. Bureau of Reclamation provided weekly estimates for major crops based on early, medium and late planting dates for different general soil types. General irrigation guides for major crops were provided for about 10,000 fields involving about 94,000 ha (233,000 ac.). The Alberta Department of Agriculture in Canada provided ISS to about 140 fields comprising 4,500 ha (11,000 ac.) on a field-by-field basis and provided guides for about 100 fields totaling about 3,200 ha (8,000 ac.).

In 1976, a comparison of seven commercial groups that provided field-by-field services in 1974 and 1976 added over 1,000 fields or 34,000 ha (85,000 ac.) per year. In 1976 ET estimates based on current climatic data were used on 95% of the area served. Most technicians serviced 1,400 to 1,600 ha (3,500 to 4,000 ac.). The capacity of these seven companies in 1976 was only about 6,200 fields or about 174,000 ha (430,000 ac.). These groups could not expand immediately, mainly because of a lack of trained personnel.

Fees varied widely depending on the method of charging. Most prices ranged from $6 to $11 per ha ($2.50 to $4.50 per ac.) for irrigation scheduling, or a flat fee of $175 to $250 per field.

Commercial and agency irrigation scheduling service expanded from less than 40,000 ha (100,000 ac.) on a field-by-field basis in 1971 to over 243,000 ha (600,000 ac.) in 1976. These services are expanding as rapidly as new staff members can be trained and new companies can be established.

The Role Of Irrigation Scheduling and Salinity Control

This assessment of irrigation scheduling and salinity control indicated that substantial improvements in irrigation water management and efficiency can be made before minimal leaching fractions needed to maintain a favorable salt balance in the soil are reached on most western irrigated projects. Only about 10 percentage points improvement in average farm irrigation efficiencies can be expected by 1985 without significantly increasing energy requirements for irrigated agriculture. This change is not expected to significantly influence salinity in return flows except where salt pickup is a major factor. New emerging ecomonic incentives may bring about more rapid changes.

Continued improvement in irrigation water management is needed, but general implementation of new scheduling technology may require one or more decades. Irrigation system improvements to permit uniform applications of specific amounts of water also will be required. With scientific irrigation scheduling and systems that apply uniform known amounts of water, significant reduction in salt loads in return flows can be achieved. Both components are needed because potential efficiencies of new irrigation systems and salt control probably cannot be achieved without scientific irrigation scheduling.

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