FLOOD IRRIGATION OF ALFALFA: HOW DOES IT BEHAVE?

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ABSTRACT

Flood irrigation is commonly used for alfalfa irrigation in the Central Valley of California. This irrigation method uses the soil surface to flow water down the field. Thus, its performance is highly dependent on soil properties such as infiltration rate and surface roughness. Because these properties are not known for a given field, a trial-and-error approach is used for managing these systems. Discussed herein are some options for improving the system design and its management. The effect of surface runoff from flood-irrigated alfalfa fields on water quality is also discussed along with measures to help reduce adverse water quality effects from the runoff.

Key Words: alfalfa, irrigation, flood irrigation, border irrigation, water quality, pesticide runoff

INTRODUCTION

Alfalfa is a major crop grown in California, with about 1 million acres in production. Alfalfa is primarily used for dairy feed, however some alfalfa is used by the horse industry. Because of the climate in California, alfalfa must be irrigated to obtain maximum production. The main irrigation method in California is flood irrigation, which flows water across the soil from the upper end of the field to the lower end. Fields are divided into checks separated by borders. Sprinkler irrigation is used to a lesser degree, although in the intermountan region of northern California, it is the primary irrigation method.

IRRIGATION SYSTEM CHARACTERISTICS

Border or flood irrigation flows a sheet of water across the field. The advantage of this method is that it is inexpensive, both in terms of system costs and energy costs. The disadvantage is that its performance depends strongly on soil properties such as the infiltration rate. It is the most difficult irrigation method to manage efficiently because of its dependence on soil properties and its performance characteristics, and thus, a trial-and-error approach is normally used in its management.

Border or flood irrigation designs have several common features. They usually have slopes from 0.1% to 0.2%, include small 'border checks' (or small levies) 6-20" high, which confine water to an area from 10 to 100 feet wide so that water moves down the field. Field length in the direction of flow varies, but is usually determined by field constraints and soil characteristics.

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Sometimes ‘check flood’ systems are combined with ‘corrugated’ or ‘bedded’ systems which facilitate water movement and drainage on heavy soil.

A description of the behavior of flood irrigation is as follows:

● At the start of the irrigation, the water starts flowing or advancing down the check.

● At the same time, water ponds on the soil surface. During the irrigation, the amount of ponded or stored water is substantial. The ponded water can be at least 3 to 4 inches deep. (Note: In contrast, stored water during furrow irrigation is insignificant relative to the amount applied.)

● The ponded water infiltrates the soil as water flows across the field.

● At cutoff, the irrigation water is stopped. The ponded water, however, continues to flow down the field. The ponded water continues to infiltrate the soil after cutoff and may supply all of the soil moisture replenishment along the lower part of the field.

● The stored water also causes surface runoff at the end of the field. The longer the cutoff time, the more the runoff from the stored water.

The rate at which the water flows down the field depends on the inflow rate of water into the check, slope, length of the border check, soil infiltration rate, and surface roughness. The flow of water across the field is characterized by the advance curve, which shows the time at which water arrives at any given distance along the field length (Fig. 1).

Another characteristic curve is the recession curve, which shows the time at which water no longer ponds on the soil surface at any given distance along the field length (Fig. 1). Water recession after cutoff depends on the length of the border, slope, surface roughness, and infiltration rate.

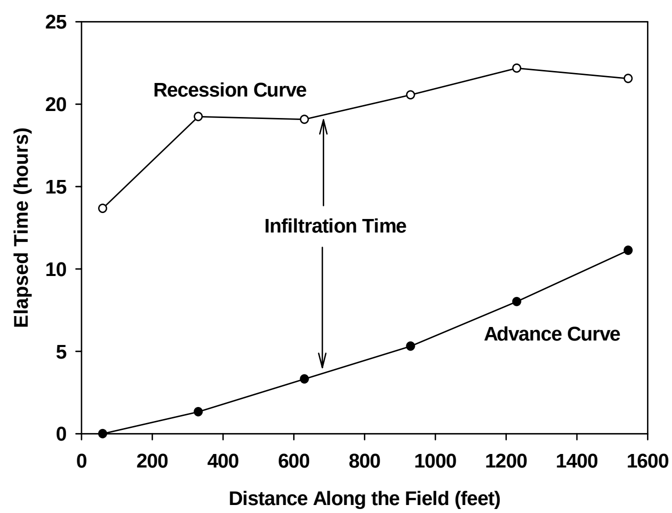

Figure 1. Advance and recession curves for a flood-irrigated alfalfa field.

The difference between advance times and recession times is the time during which water infiltrates the soil or the infiltration time. These infiltration times vary along the field length, resulting in more water infiltrating in some parts of the field compared to other areas.

Design variables for flood irrigation include slope, border length, border inflow rate, surface roughness, and infiltration rate. Table 1 lists some recommended unit flow rates (gallons per minute per foot of width) and check lengths for field slopes of 0.1% to 0.2%.

Table 1. Recommended unit flow rates and border lengths for field slopes of 0.1 to 0.2%.

Soil Type	Check Length (feet)	Unit Flow Rate (gpm/foot of width)
Clay	1300	7 to 10
Clay Loam	1300	10 to 15
Loam	1300	25 to 35
Loam	600	15 to 20
Sandy Loam	600	25 to 30
Sandy	600	30 to 40

IMPROVING FLOOD IRRIGATION SYTEMS

The objective for improving flood irrigation is to increase the irrigation efficiency by 1) reducing deep percolation below the root zone and/or 2) reducing surface runoff. However, sometimes measures to improve flood irrigation are competitive, i.e. measures that reduce deep percolation can increase surface runoff and vise versa. Some measures commonly recommended include the following:

Increasing check flow rate. This commonly recommended measure reduces the advance time to the end of the field, thus decreasing variability in infiltration times along the field length. Yet, field evaluations showed only a minor improvement in the performance of border irrigation under higher flow rates compared with lower flow rates (Howe and Heerman, 1970; Schwankl, 1990; Hanson. B. Unpublished data).

Reducing field length. This is the most effective measure for improving uniformity and for reducing percolation below the root zone. Studies have shown that shortening the field length by one-half can reduce percolation by at least 50 percent. The distribution uniformity (DU) of infiltrated water will be increased by 10 to 15 percentage points compared with the normal field length. (Note: the DU is a measure of how uniform water is infiltrated along the field length.) This measure will be effective only if the irrigation set time (hours of water application) is reduced because the advance time to the end of the shortened field generally will be 30 to 40 percent of the advance time to the end of the original field length. Failure to reduce the set time will greatly increase both percolation and surface runoff.

A major problem with both of the above measures is the potential for increased surface runoff. Studies indicate a potential increase of 2 to 4 times more runoff for the reduced length compared with the original field length.

Selecting an appropriate cutoff time. The amount of surface runoff or tailwater can be reduced by decreasing the cutoff time of the irrigation water. This is the most effective measure for reducing surface runoff. The cutoff time for a given field may need to be determined on a trial-and-error basis. Some guidelines, however, are to cut off the irrigation water when the water advance is about 60% of the field length for fine-textured soil, 70% to 80% for medium texture soil, and near 100% for coarse textured soil (Merriam, 1981). Field evaluations conducted at the University of California Desert Research and Extension Center in the Imperial Valley of California showed runoff to be about 2% of the infiltrated volume when the water advanced to about 70% of the field length prior to cutoff for alfalfa and Sudan grass in cracking clay soil (Grismer and Bali, 2001; Bali et al., 2001).

The effect of reducing the cutoff time on surface runoff was evaluated using data from an evaluation of a flood system and a computer simulation model calibrated with the evaluation data. The advance time to the end of the field measured during the evaluation was 670 minutes and the cutoff time was 800 minutes. Because the cutoff time greatly exceeded the advance time, substantial surface runoff occurred (Table 2). A cutoff time of 600 minutes, slightly less than the advance time, decreased the surface runoff by 82%, yet the evaluation data showed an adequate infiltration time at the end of the field. A cutoff time of 500 minutes resulted in incomplete advance to the end of the field, which resulted in no infiltration at the end of the field. The effect of the decreasing cutoff times on the uniformity of infiltrated water was slight until cutoff times were much less than the advance time needed for water to reach the end of the field.

Table 2. Effect of cutoff time on applied water, surface runoff, and distribution uniformity (DU).

Cutoff Time (minutes)	**Applied Water (inches)**	**Surface Runoff (inches)**	**DU (%)**
800	12.8	2.8	89
700	12.1	1.6	87
600	11.2	0.5	82
550	10.7	0.06	78
500	9.8	0	62

Recover surface runoff using recirculation systems or storage/reuse systems. Recirculation systems involve collecting the surface runoff in a small reservoir at the lower end of the field and then recirculating the water back onto the field being irrigated. The recirculated water should be used to irrigate an additional area of the field. Simply recirculating the runoff to the same irrigation set that generated the runoff results only in temporarily storing the water on the field and will result in an increased rate of runoff.

The storage/reuse system involves storing all of the surface runoff from a field and then using that water to irrigate another field at the appropriate time. This approach requires a farm with multiple fields, a relatively large reservoir, and a distribution system to convey surface runoff to the storage reservoir and to convey the stored water to the desired fields.

MANAGING FLOOD IRRIGATION OF ALFALFA

Irrigation water management involves determining 1) when to irrigate (irrigation scheduling) and 2) how much water to apply. A standard approach to irrigation scheduling is to determine the allowable depletion of soil moisture that can occur between irrigations without reducing crop yield and then irrigate when that depletion occurs. However, scheduling irrigations of alfalfa is complicated by the cutting schedule, which occurs about every 28 to 30 days in the Northern San Joaquin and Sacramento Valleys of California. The first irrigation after cutting cannot occur until the alfalfa bales are removed. A second irrigation between cuttings will need to occur at a time that provides sufficient soil drying time before the harvest, and thus, its timing is not based allowable soil moisture depletions. Thus, irrigation scheduling of flood-irrigated alfalfa is controlled by the cutting schedule, not by allowable soil moisture depletions. With check flood irrigation, growers are left with the choice of watering either once, twice, or sometimes three times between harvests.

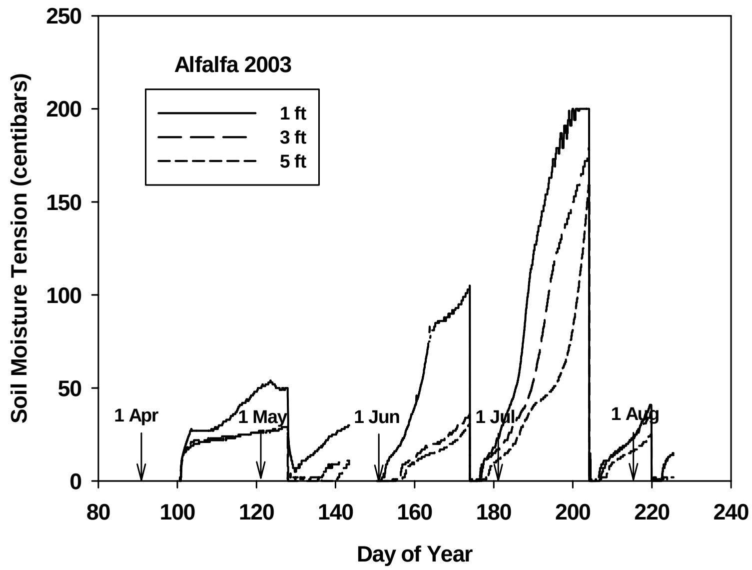

Figure 2. 2003 Watermark electrical resistance block readings at depths of 1 ft, 3 ft, and 5ft.

The irrigation schedule of alfalfa was evaluated by installing Watermark electrical resistance blocks in a number of alfalfa fields and monitoring the soil moisture tension throughout the crop season. The soil moisture tension is the tenacity at which water is retained by the soil. The higher the tension, the drier the soil. The electrical resistance blocks were connected to data loggers, which collected the data every 30 minutes. At one site, soil moisture tensions just before cuttings in June 2003 and July 2003 ranged from about 100 centibars to more than 200 centibars at 1 ft deep, suggesting excessive soil moisture depletions between cuttings, particularly in

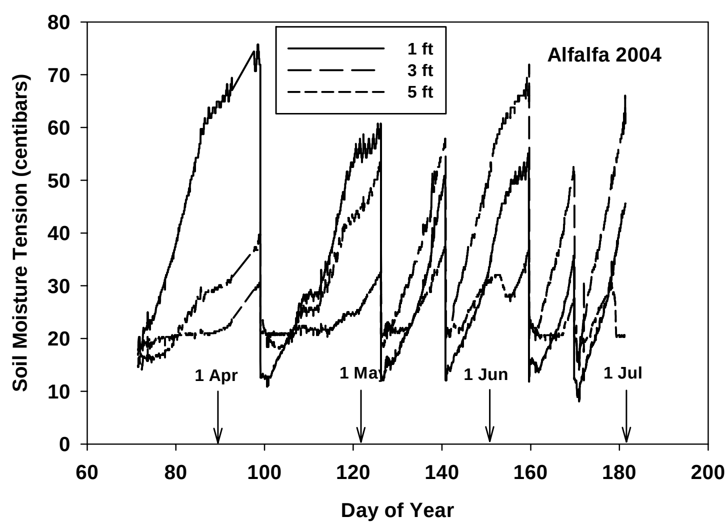

Figure 3. 2004 Watermark electrical resistance block readings at depths of 1, 3 and 5 feet .

July (Fig. 2). In 2004, two irrigations applied between cuttings at this site resulted in soil moisture tensions between 50 centibars and 70 centibars at 1 ft deep just before cutting (Fig. 3). However, these soil moisture tensions indicated that the second irrigation probably occurred before the soil moisture was depleted to an allowable value.

The irrigation time may be difficult to estimate because of the performance characteristics of flood irrigation. The irrigation time must include the time needed for the water to flow or advance to the end of the field plus the time needed to infiltrate the desired amount of water at the end of the check. The advance time can be determined only by measurements in the field. The time needed to infiltrate a desired amount of water depends on the soil infiltration rate, which in turn depends on soil texture and soil structure (including cracking characteristics). This time is small for coarse-texture soil, but is generally assumed to be large for clay loam soils. However, data from the Watermark blocks/data loggers show this not to be true, but instead water infiltration into these soils is rapid because of cracks in the soil that formed between irrigations. The data loggers allowed measurements to be made every 30 minutes, and thus, the rate at which water infiltrated the soil could be observed. These closely-spaced measurements of soil moisture tension showed that about 2 to 3 hours were needed to infiltrate water to about 5 feet deep. The evaluation data used for Fig. 1 and Table 2 showed an infiltration time of about 10.4 hours for a cutoff time of about 800 minutes (Fig. 1). Reducing the cutoff time to about 600 minutes resulted in an infiltration time of 2.7 hours at the end of the field, which was about equal to the desired time.

Limitations of the "ET" Approach for Flood-irrigated Alfalfa. A common approach for determining the amount of water to be applied during an irrigation is to estimate the crop water use or evapotranspiration between irrigations from data obtained from the California Irrigation Management Information System (CIMIS) in California, a network of weather stations that collect data used to calculate the ET. Similar networks exist in other states. This approach is appropriate for sprinkler irrigation, but it may not work very well for flood irrigation because of the time required for water to advance to the end of the field, which may greatly exceed that needed for infiltrating a desired amount of water for a given ET requirement. For example, the advance time in Fig. 1 was about 11 hours, considerably more than the required infiltration time of 2.7 hours. The limitations of the 'ET approach' using CIMIS or similar systems with alfalfa flood irrigation as constrained by cutting schedules must be considered.

FLOOD IRRIGATION OF ALFALFA AND WATER QUALITY

Concern is increasing on the effect of chemicals in surface runoff from irrigated fields on the water quality of rivers, sloughs, etc. These chemicals include insecticides and nutrients found in the runoff. Some of these chemicals such as organophosphates are water soluble while others such as pyrethroids and phosphorus are less water soluble, but are strongly attached to soil particles. Additionally, some herbicides have been found to move off of fields during irrigation or rain events, and can as a result contaminate groundwater if catchment basins are near water tables. Several of these water quality concerns, and proposed mitigation measures are discussed in more detail elsewhere (Putnam, 2003).

Surface runoff from some alfalfa fields has been found to have concentrations of organophosphates sufficiently high to adversely affect the water quality of the receiving waters (Long et al., 2002). Where this condition exists, the surface runoff must be prevented from leaving the farm. This involves reducing the amount of surface runoff and using recirculation systems or storage/reuse systems.

A different approach might be used for chemicals that are not water soluble but instead are attached to soil particles (pyrethroids, phosphorus). Erosion in the irrigated field during the irrigation is the main source of pollution from these chemicals. Studies have shown that this erosion occurs along the field length for furrow irrigation. However, for alfalfa, little or no erosion occurs as water advances down the field. Suspended solids in the irrigation water are filtered out as the water flows across the field because of the filtering effect of the alfalfa and the residual organic matter on the soil surface. Observations made during alfalfa irrigations showed that the erosion occurs at the end of the field mainly due to the surface runoff flowing into and down the tailwater ditch. Some erosion also occurs during the last 15 to 20 feet of the field, where bare soil usually exists in alfalfa fields. The effect of this erosion from alfalfa fields on water quality appears to be minimal (Long et al., 2002) although additional studies are needed to better understand the role of erosion from alfalfa fields on water quality. Where sediments leaving alfalfa fields are contributing to water quality problems, measures will need to be taken to reduce the sediment load of the surface runoff. Some options available for reducing the sediment load include:

- Reducing surface runoff
- Redesigning inlets into tailwater ditches
- Redesigning tailwater ditches
- Lining of tailwater ditches
- Injection of polyacrlamides (PAM) into the surface runoff (PAM causes fine soil particles suspended in water to flocculate and settle out of the water)
- Sediment ponds to allow sediments to settle out of the water
- Grass strips at the end of the field to prevent erosion
- Grass lined drainage ditches
- Recirculation systems or storage/reuse systems to prevent the runoff from leaving the field.

Conclusions

Managing flood irrigation systems for high irrigation efficiency (IE) coupled with adequate irrigation (least watered part of the field receives an amount equal to the desired amount) may be difficult. High efficiency will require reductions in both percolation below the root zone and surface runoff. The most effective measure for reducing surface runoff is to decrease the cutoff time. The most effective measure for reducing excessive percolation is to reduce the check length by ½ along with a corresponding reduction in cutoff time due to a decreased advance time compared to the original check length. This measure, however, may increase the surface runoff compared to that of the original length. A comparison of the performances of a 750 ft check length with a 1500 ft length showed more surface runoff for the shorter length, but a slightly higher irrigation efficiency (Table 3).

Table 3. Comparison of performance characteristics for two check lengths. The infiltration time is that needed at the end of the field. DU is the distribution uniformity. IE is the irrigation efficiency.

Performance Characteristic	**Check Length (feet)**	
	1500	**750**
Advance time (hr)	11.1	4.2
Infiltration time (hr)	2.7	2.6
Cutoff time (hr)	10.0	4.6
Applied water (inches)	11.2	9.1
Surface runoff (inches)	0.5	1.7
Deep percolation (inches)	3.3	1.5
DU (%)	82	91
IE (%)	67	72

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