

# DOUBLE YOUR YIELD WITH HALF THE WATER: IS IT POSSIBLE?

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## ABSTRACT

Yield is directly related to crop evapotranspiration and applied water. The higher the uniformity of the applied water, the higher the yield for a given amount of water. The higher the uniformity, the smaller the drainage losses below the root zone. Methods for improving uniformity and irrigation efficiency are presented herein.

**Key Words:** irrigation, evapotranspiration, flood, sprinkler

## INTRODUCTION

Can you double your yield with half the water through better irrigation water management? The answer is, "Not likely!". However, in arid and semiarid areas, irrigations must be efficient to stretch limited water supplies, yet at the same time, apply sufficient water to meet the crop's evapotranspiration requirements and any leaching requirements for salinity control. This means that irrigation systems must be properly designed, managed, and maintained to supply the needed water at a high irrigation efficiency.

The performance of an irrigation system is described by its uniformity and efficiency. Uniformity refers to the evenness at which water is applied or infiltrated throughout the field and depends on system design and maintenance. Efficiency refers to the amount of water needed for crop production versus that applied.

## UNIFORMITY AND EFFICIENCY

### *Uniformity*

A uniformity of 100% means that all parts of a field received the same amount of water. However, no irrigation system can apply water at 100 percent uniformity. Regardless of the type of irrigation method, some areas of a field receive more water than other areas. If the least-watered areas of the field receive an amount equal to that needed for crop production (referred to as an adequately irrigated field), excess amounts of water will be applied to other areas. These excess amounts cause drainage below the root. The larger the nonuniformity, the larger the differences in applied or infiltrated water throughout the field, and the more the drainage below the root zone. For a distribution uniformity of 93 percent, about 10 percent of the applied water drains below the root zone, while for a DU of 74 percent, drainage is about 34 percent of the applied water.

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## *Irrigation Efficiency*

Irrigation efficiency is defined as the ratio of the amount of water needed for crop production to the amount of water applied to the field. The amount of water needed for crop production is the beneficial use. Another term frequently used is the application efficiency, defined as the ratio of the amount of irrigation water stored in the root zone to the amount of applied water.

Crop evapotranspiration is the largest beneficial use of irrigation water. This is water that evaporates from the plant leaves and from the soil surface. More than 95 percent of the water uptake is evapotranspiration. Other beneficial uses include leaching for salinity control, frost protection, and climatic cooling.

Loss affecting irrigation efficiency include drainage below the root zone, surface runoff, and evaporation from sprinklers. Drainage occurs when the amount of infiltrated water exceeds the soil moisture storage capacity of the soil. Surface runoff when the application rate of the irrigation water exceeds the infiltration rate.

The distribution uniformity equals the irrigation efficiency when the irrigation system is properly managed. Table 1 lists potential practical irrigation efficiencies developed from distribution uniformities using data analyzed by Hanson (1995). A practical irrigation efficiency is one that is technically and economically feasible.

Table 1. Practical potential irrigation efficiencies. Surface runoff is assumed to be beneficially used.

Irrigation Method	Irrigation Efficiency (%)
Sprinkler	
Continuous-move	80-90
Periodic-move	70-80
Solid-set	70-80
Microirrigation	80-90
Furrow	70-85
Border	70-85

## **EVAPOTRANSPIRATION, APPLIED WATER, AND CROP YIELD**

Crop yield is directly related to crop evapotranspiration. Maximum yield occurs when the evapotranspiration is maximum, while reduced evapotranspiration caused by inadequate irrigation decreases crop yield. Many row and field crops exhibit a linear relationship between yield and evapotranspiration, illustrated in Figure 1.

Climate factors affecting the crop evapotranspiration include solar radiation, temperature, wind, and humidity. Plant factors affecting evapotranspiration include plant type, stage of growth, and health of the plant. However, from an irrigation water management viewpoint, soil moisture is

the most critical factor that limits crop evapotranspiration. Crops that are deficit-irrigated may experience yield decreases because of the limited soil moisture.

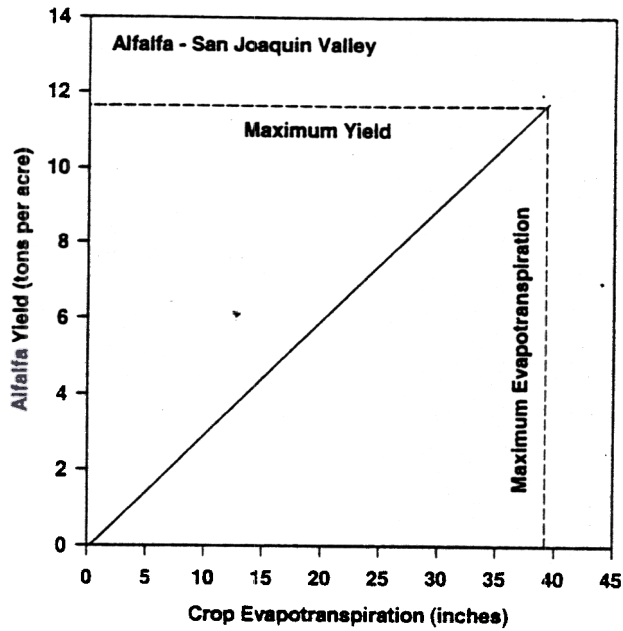


Figure 1. Evapotranspiration versus alfalfa yield.

Figure 2 shows alfalfa yield versus evapotranspiration relationships for several locations. Reasons for the different responses are not well-understood.

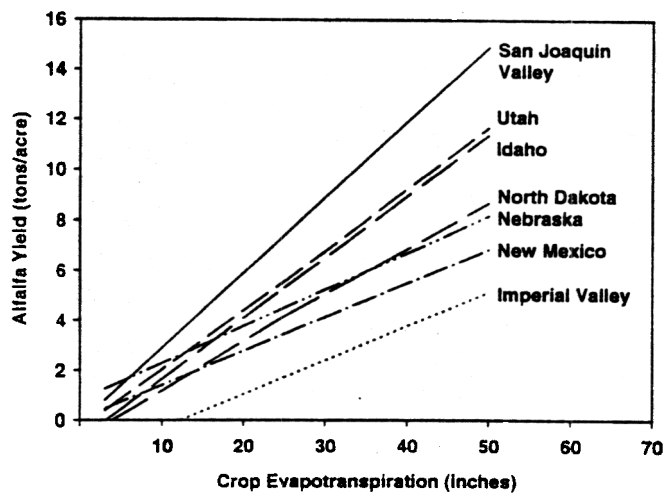


Figure 2. Alfalfa yield versus evapotranspiration for various locations.

The amount of applied water needed for a given yield will exceed the amount of evapotranspiration because of the losses in the irrigation system unless water applications are very uniform.

Some yield-applied water relationships are shown in Figure 3 for a location in the intermountain area of California. Little response of yield to applied water occurred for the first cutting simply because stored soil moisture from winter and spring precipitation was sufficient for crop growth. For the second cutting, yield increased linearly with applied water up to about 6 inches. Thereafter, little or no increase in yield occurred with applied water caused by climatic conditions which limited the maximum evapotranspiration rates. The third and fourth cuttings show a linear response of yield to applied water. More water was required to reach high yields for these cuttings than for the second cutting. However, for the latter cuttings, about two to three inches of water was needed before any yield occurred. During the time periods of these cuttings (July and August), little or no stored soil moisture from the winter and spring precipitation apparently existed causing this behavior.

The relationship between yield and applied water can be affected by many factors such as soil fertility and other nutrients, irrigation water quality, disease and insect problems, restricted root zone, soil moisture from precipitation, and improper irrigation scheduling. Figure 4 shows two different yield responses to applied water for fields in the intermountain area of northern California. A significant response of yield to applied water occurred in Figure 4a, but in Figure 4b, a poor response occurred. The poor response is believed caused by nutrient deficiencies.

## **METHODS FOR IMPROVING IRRIGATION**

Methods for improving irrigations include:

1. Improved management and irrigation scheduling.
2. Improve system uniformity.
3. Impose deficit irrigation on the crop.

### **Improve Management and Irrigation Scheduling**

Irrigation scheduling involves two questions: When to irrigate? and How much water to apply? While the answers to these questions would appear to be relatively simple and straight forward, they are often quite difficult to determine. This is especially true for alfalfa. Alfalfa production practices and irrigation system constraints make precise irrigation scheduling difficult. The basic approaches to irrigation scheduling, limitations to their implementation in alfalfa production systems, and a compromise practical approach to irrigation scheduling in alfalfa is presented below.

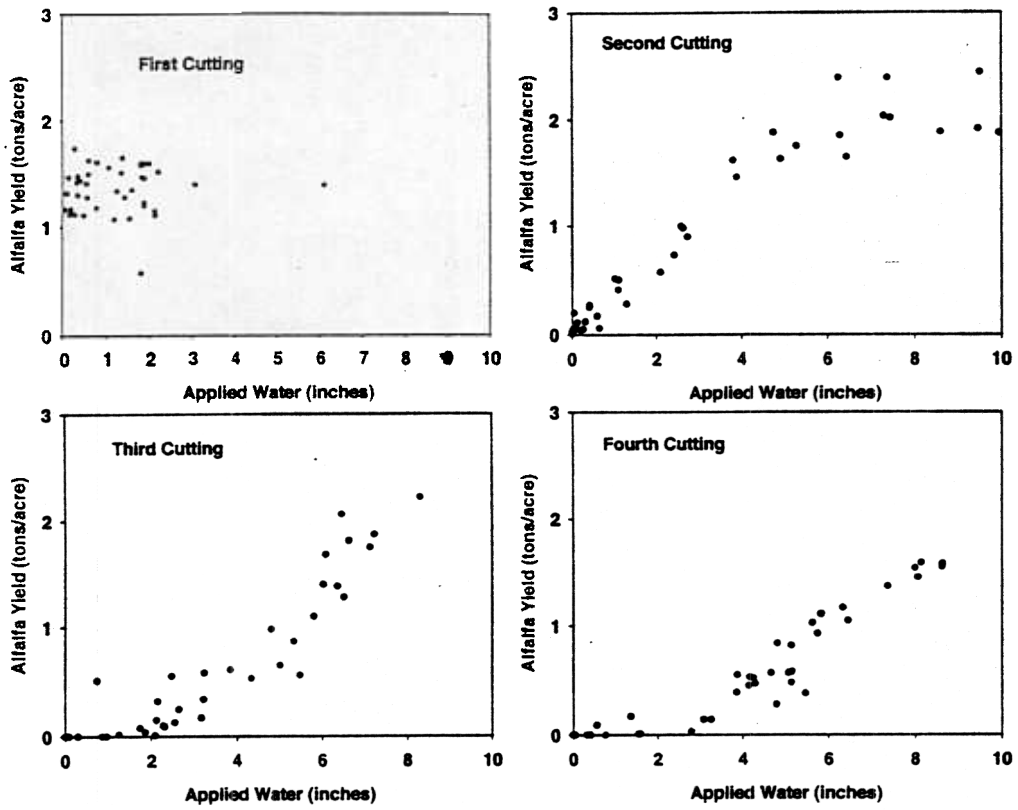


Figure 3. Yield versus applied water for four cuttings.

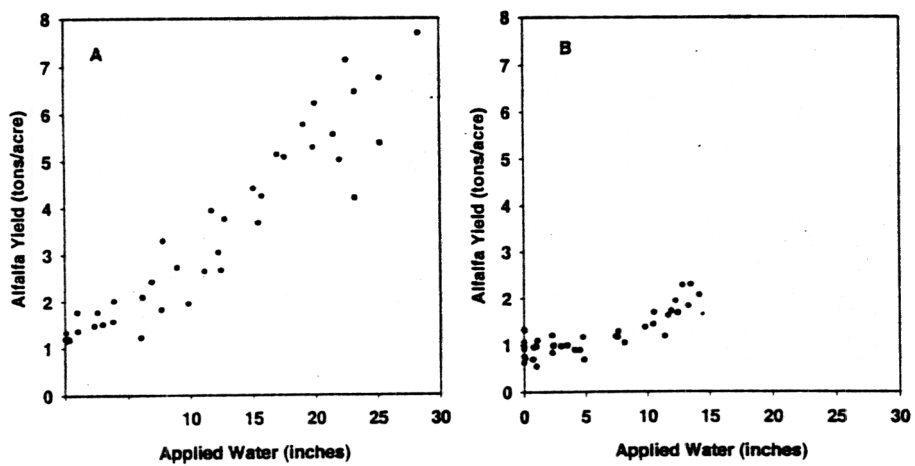


Figure 4. Yield response to applied water for two locations.

## Water Budget

The water budget method of irrigation scheduling is weather-based and involves tracking additions and losses and balancing them. The losses are due to crop water use and inefficiencies in the irrigation system. The additions are irrigation and rainfall. The objective of the water budget method is to maintain soil moisture near the optimum level by keeping track of crop water use and then irrigating to replace the water used.

Knowledge of crop water use is essential to use the water-budget method of irrigation scheduling. Current daily crop water use (also called ET or evapotranspiration) figures can be obtained through Department of Water Resource's California Irrigation Management Information System (CIMIS). Long-term historical daily water-use values are also available. Whether using actual daily water-use figures or historical averages, the key is to keep track of daily crop water use and maintain a running total. Once total crop water use equals or approaches the allowable depletion, the field should be irrigated to replenish the water used by the crop.

Allowable depletion is the amount of water loss that can occur before crop yield is reduced appreciably (the allowable depletion level generally used for alfalfa is 50% of the available water). In other words, once the alfalfa crop has depleted 50 percent of the available water, it is time to irrigate. An example of the water budget approach to irrigation scheduling is presented in Figure 5. In this example, the allowable soil water depletion is reached after seven days. The net amount of irrigation water to apply is 2.0 inches (the actual amount applied is greater to compensate for inefficiencies and nonuniformity of the irrigation system). After the field is irrigated and the soil profile refilled, daily alfalfa water use is again monitored and the field irrigated accordingly.

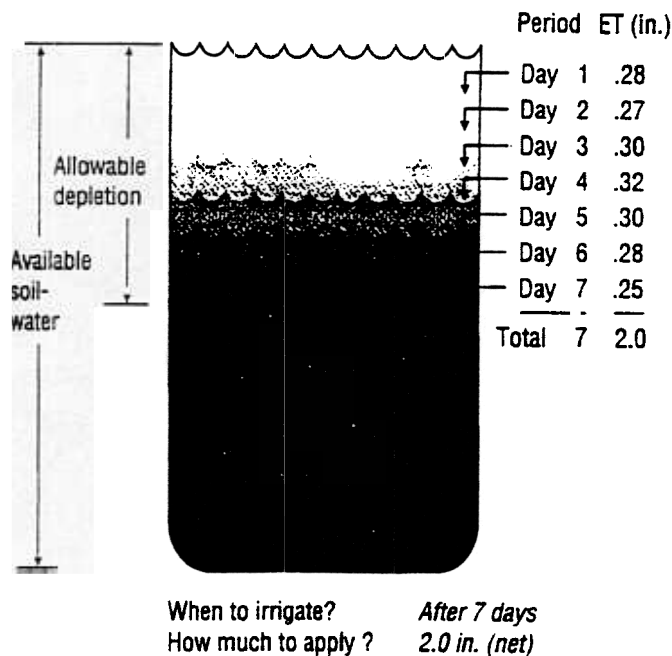


Figure 5. Water budget method.

### *Constraints to Using the Water Budget Method*

A major obstacle to employing the water-budget method in alfalfa is that the crop is cut every 26 to 45 days (cutting frequency depends on the production area and season). It can be difficult to fit irrigations around cuttings. The water budget method may indicate that an irrigation is needed around the time a field is cut. However, as alfalfa growers are well aware, irrigation water cannot be applied too close to a cutting because of the difficulty in curing hay on wet soil and compaction problems associated with running hay harvesting equipment on wet soil. In addition, an alfalfa field obviously cannot be irrigated while the hay is curing. Therefore, there is typically a 6- to even 20-day period during which fields cannot be irrigated. For this reason, it can be difficult to adhere to a strict water budget. When the water budget indicates an irrigation will be needed around the time of cutting, an early partial irrigation can be applied to maintain the soil moisture at an acceptable level through the cutting and curing phase. Unfortunately, a "partial" irrigation is not possible with some irrigation systems.

Another difficulty applying the water budget method to alfalfa irrigation scheduling is related to the fact that entire fields are oftentimes not irrigated at once. This is especially true with sprinkler irrigation where fields are usually irrigated in sets. In theory, a water budget would have to be maintained for each section of the field.

The water budget is perhaps the most accurate method of irrigation scheduling. However, because of the obstacles mentioned above, the water budget it is sometimes considered impractical for alfalfa fields. However, just because it is difficult to adhere precisely to the water budget method, does not mean that it is useless for alfalfa growers. The water budget concept can be used to evaluate whether current irrigation practices satisfy or exceed crop needs in a typical year and if fields are irrigated often enough. With knowledge of the soil type, water holding capacity of the soil, alfalfa rooting depth, and average daily crop water use it can be determined how often alfalfa should be irrigated in a typical year. Table 2, located at the end of the text, indicates the maximum number of days between irrigations for different soil types during different months of the year in the San Joaquin Valley, Sacramento Valley, and Intermountain area. For example, in the San Joaquin Valley, alfalfa grown on sandy loam soil should be irrigated every 15 days during the month of July. If your irrigation schedule differs significantly from the appropriate values in the table, reasons for the differences should be investigated.

It is important to realize the seasonal variation in alfalfa water use; alfalfa uses nearly twice as much water per day in mid summer than in spring or fall. Irrigation practices should reflect these seasonal fluctuations in water use. The number of days between irrigations in should be greater in spring and fall than in summer or the irrigation set time should be reduced.

### *Soil Based Measurements*

Soil moisture measurements can also be used to schedule irrigations and/or assess the adequacy of current irrigation practices in alfalfa. Soil moisture content in alfalfa fields often goes unchecked. If soil moisture is monitored at all, it is usually only done using a shovel or soil auger. Using a shovel or auger is imprecise and is only useful for a gross evaluation of the soil moisture content in the upper foot or less of the soil profile.

More sophisticated monitoring devices have been developed so growers can get a more accurate estimate of soil moisture content at different depths throughout the root zone. These include the neutron probe, dielectric soil moisture sensors, tensiometers, and soil moisture blocks. Of these different soil moisture-monitoring devices, the authors feel that the soil moisture blocks have the greatest potential for use in alfalfa fields. Neutron probes and TDR devices are very expensive and, in the case of the neutron probe, require special licensing and permits. Tensiometers are more suited to orchards and other high-value crops where soil moisture must be maintained at relatively high levels.

Soil moisture sensors (commonly called gypsum blocks or resistance blocks) are not a new invention; they have been available for decades but as yet have not been widely adopted by alfalfa growers. Recent developments have improved their accuracy and ease-of-use. Moisture blocks evaluate soil moisture by measuring the electrical resistance between two electrodes. The blocks take up and release moisture as the soil wets and dries. The higher the water content of the blocks, the lower the electrical resistance.

It is recommended that growers install two or three sensors per location. One sensor should be located in the upper one quarter of the root zone of the crop. The other should be placed toward the bottom of the root zone. For alfalfa, install sensors at 1 ft., 2 ft., and 3.5 or 4 ft (depending on the depth of the soil). The upper two sensors are used to determine when to irrigate. The deep sensor is useful to evaluate the depth reached by the last irrigation. The deepest sensor is also useful to make sure that you are not excessively depleting moisture reserves deep in the root zone of the crop.

The best way to apply soil-moisture measurements to irrigation scheduling is to plot the measurements on a graph. The plotted data present a picture of how fast the soil is drying. As alfalfa grows, it draws on the soil-water and the moisture sensor readings begin to rise. After a few points have been plotted, you can estimate approximately how many days it will take for the soil to dry before irrigation is needed. For sandy soils irrigate when the upper sensor(s) reads 60-70 centibars. Clay soils retain more water and centibar readings over 100 can be obtained without a significant yield reduction.

Even if soil moisture sensors are not used to "schedule" irrigations, they can be used to evaluate current irrigation practices. The soil moisture sensors are helpful to indicate if current irrigation practices allow the soil to become too dry between irrigations. This is especially common after a cutting. Alfalfa is most sensitive to water stress after a cutting when regrowth is initiated. The sensors may indicate that alfalfa should be irrigated closer to a cutting or sooner after the bales

are removed to avoid moisture stress to alfalfa regrowth. Similarly, soil moisture sensors may indicate that the soil has sufficient water when irrigation is planned. Irrigation can be skipped or delayed until soil moisture sensors indicate an irrigation is needed. Soil moisture sensors are also very useful to determine when to start irrigating in spring.

Since you don't want to destroy the soil moisture sensors with a swather, it is advisable to make a buried reading station. A 4-6 inch length of 2-inch PVC with a screw-on cap works well to house the wire leads. A shallow (3-6 inch) trench is dug for the wire leads coming from each sensor to the PVC housing. You can color code the wires to keep track of the depth of the sensors by tying a small piece of colored wire to each lead.

The sensors must be installed in an area that is representative of the field (i.e., soil type typical of the field and an area that receives full sprinkler or flood-irrigation coverage). Two sites per field are recommended. A more detailed explanation of the sensor installation procedure can be found in the literature from manufacturers.

### *Practical Approach to Irrigation Scheduling*

Use a simplified water budget approach together with soil moisture monitoring to develop an irrigation schedule. Start by determining the soil type of the alfalfa fields. Use Table 2 for your area and select the appropriate soil type to determine the suggested minimum irrigation frequency. Compare the irrigation frequency suggested in Table 2 to your actual irrigation schedule. The accuracy of this table can be improved by developing your own table. Substitute the values in the table with actual values for your area and recalculate the appropriate irrigation frequency. For example, if you have historical evapotranspiration (ET) data for your specific area or more precise information on the water holding capacity of your soils, those values can be used in place of those used to develop the table. If historical ET values are used, be sure to adjust the irrigation frequency in a given year to account for any deviation in weather from historical average values (i.e., irrigate more frequently if there has been an abnormally warm or dry period).

Use soil moisture sensors to ground truth the water budget. The water budget only provides an estimate of crop water needs, especially when historical ET values are used. Soil moisture monitoring is needed to verify the water budget and to be certain that current irrigation practices satisfy, but do not exceed, the needs of the crop. The soil moisture sensors can be used to evaluate soil moisture content between irrigations to assure that soil moisture is maintained near optimum levels. The soil moisture sensors also help determine the soil depth reached with each irrigation and can be used to decide when to start irrigating in the spring..

### *Know How Much is Applied*

A flow meter is required to know the amount of applied water. The depth of the applied water is calculated using the following equation:

$$D = \frac{KQT}{A}$$

where  $Q$  is the flow rate,  $T$  is the time required to irrigate the field, and  $A$  is the area irrigated.  $K = 0.0022$  where the units are gallons per minute for  $Q$ , hours for  $T$ , and acres for  $A$ .

Irrigation scheduling of alfalfa also depends on the cutting schedule. The first irrigation after a cutting should occur as soon as possible to prevent an excessive yield reduction of the next cutting. One study in Israel showed that the yield was reduced by 15 percent for a 4-day interval between the cutting and the next irrigation, and was reduced by nearly 30 percent for a 6 day interval. Because the last irrigation before a cutting must allow sufficient time to dry the soil for trafficability reasons, irrigation scheduling techniques normally used for low-frequency irrigation methods must be modified to accommodate the cutting schedule.

## **Improve System Uniformity**

### *Border or Flood Irrigation*

The main components of the field-wide uniformity of border or flood irrigation are varying infiltration opportunity times along the field length and variable infiltration rates. Other components include different day and night set times, varying inflow rates during the irrigation, and water temperature differences between day and night irrigations.

Improving the uniformity of surface irrigation requires reducing the variability in infiltration throughout the field. Strategies for improving uniformity include decreasing the water advance time to the end of the field and reducing the infiltration rate. Measures commonly recommended for improving the uniformity of surface irrigation are as follows:

#### **1. Shorten the field length**

This is the most effective measure for improving uniformity and for reducing drainage below the root zone. Studies have shown that shortening the field length by one-half will generally reduce the drainage by at least 50 percent. The DU will be increased by 10 to 15 percentage points compared with the normal field length. This measure will be effective only if the irrigation set time 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. The reduction in irrigation set time is equal to the difference between the original advance time and the new advance time. Failure to reduce the set time will greatly increase both drainage and surface runoff.

Reduce border lengths can cause increased surface runoff. Cutback irrigation can alleviate this problem provided that the irrigation district will allow a decrease in the field inflow rate. Other measures for coping with this problem are to use tailwater recovery systems to recirculate the water back to the head of the field or to use the runoff on lower-lying fields. Reservoir storage is needed for both scenarios.

## 2. Increase the unit inflow rate

This commonly recommended measure reduces the advance time to the end of the field, thus decreasing variability in infiltration opportunity times along the field length. Yet, field evaluations showed only a minor improvement in the performance of border irrigation under high flow rates compared with lower flow rates.

## 3. Improved slope uniformity.

### *Sprinkler Irrigation*

Uniformity under sprinkler irrigation depends on factors such as pressure changes throughout the field caused by friction losses and elevation changes, catch-can uniformity, and minor factors such as mixed nozzle sizes, malfunctioning sprinkler heads, non-vertical sprinkler risers, and leaks. Catch-can uniformity describes the pattern of applied water between adjacent sprinklers. It depends mainly on sprinkler spacing, pressure, wind speed, and sprinkler head and nozzle type. Different day and night set times can also affect the field-wide uniformity.

Recommend distribution uniformities under low wind conditions range between 70 and 80 percent for hand-move wheel-line, and solid set sprinkler systems. Some measures for improving the uniformity of these systems include the following:

#### Minimize Pressure Variation

Minimize pressure variation using the proper combination of pipeline lengths and diameters  
Limit field-wide pressure changes to less than 20 percent of the average pressure.

## 2. Install Flow Control Nozzles

Use flow control nozzles where the pressure variation exceeds 20 percent. These nozzles contain a flexible orifice that changes diameter as pressure changes.

## 3. Use Appropriate Sprinkler Spacings

Use appropriate sprinkler spacings. Some rules-of thumb for spacings (Soil Conservation Service, 1983) are: rectangular spacings equal to 40 by 67 percent of the effective wetted diameter based on the average wind speed; square spacings equal to 50 percent of the effective wetted diameter; equilateral spacings equal to 62 percent of the effective diameter.

The effective diameter under low-wind conditions is defined as 90 percent of wetted diameter listed by the sprinkler manufacturer. Generally, the manufacturer's wetted diameter is for no-wind condition. For each wind speeds exceeding 3 miles per hour, reduce the effective diameter by 2.5 percent for each 1 mile per hour over 3 miles per hour.

#### 4. Maintain Adequate Sprinkler Pressure

Maintain appropriate sprinkler pressure. Low pressures cause a doughnut-shaped pattern of applied water. Very high pressures cause much of the water to be applied very close to the sprinkler because of excessive spray breakup. Nozzles specially designed for low pressures are available, but field tests have revealed little difference in catch-can uniformity between those nozzles and the standard circular nozzles.

#### 5. Offset Laterals

Offset lateral locations of periodic move sprinkler systems such that the lateral positions of the succeeding irrigation are midway between those of the preceding irrigation. The distribution uniformity resulting from this measure is:

$$DU_o = 10\sqrt{DU}$$

where  $DU_o$  is the distribution uniformity of the offset moves and  $DU$  is the distribution uniformity of the normal system.

#### 6. Proper maintenance

Avoid mixing nozzle sizes, repair malfunction sprinkler and leaks, and maintain vertical risers.

#### 7. Convert to center-pivot or linear-move sprinkler machines.

Distribution uniformities of center-pivot and linear-move sprinkler machines should be higher than those of the previously mentioned sprinkler systems. The more-or-less continuous movement of these machines reduces the effect of wind on uniformity. Recommended distribution uniformities of these machines are 80 to 90 percent.

Rotator sprinklers can improve the uniformity of applied water for center-pivot and linear-move sprinkler machines. Field evaluations have shown a much higher uniformity with these sprinklers compared with the spray nozzles used on low-pressure machines (Hanson and Orloff, 1996).

#### **Impose Deficit Irrigation**

Irrigating at amounts of applied water less than that needed for maximum yield will improve the irrigation efficiency. At the same time, crop yield will be reduced. The effect on crop yield will depend on the amount of the deficit and on the crop's tolerance to water stress.

A study in the Imperial Valley of California investigated the effect of various irrigation cutbacks on alfalfa yield (Robinson, et al., 1994). The treatments ranged between optimal irrigations and no irrigations during July, August, and September. Results, in Table 3, showed that yield was reduced substantially as applied water was decreased.

Table 3. Effect of irrigation reductions on alfalfa yield.

Relative Water Application (%)	Relative Yield (%)
100	100
98	89
81	71
69	60

A study in the intermountain area of northern California investigated the economics of deficit irrigation (Hanson, et al., 1989). Results showed that maximum profit occurred for a seasonal application of about 20 inches of water for that area. Applications less than 20 inches would reduce the profitability of alfalfa production.

### SUMMARY

Improved irrigation requires understanding that yield is related to evapotranspiration and applied water and that irrigation efficiency is related to the uniformity of the applied water and the management of the irrigation system. Maximum yield and minimum water losses occur for properly-managed irrigation systems operated at a high uniformity.

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Table 2. Approximate recommended days between irrigations.

Root Depth (feet)	Daily Evapotranspiration (inches/day)							
	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45
Sand								
2	7	5	4	3	2	2	2	2
3	11	7	5	4	4	3	3	2
4	14	10	7	6	5	4	4	3
5	18	12	9	7	6	5	5	4
6	22	14	11	9	7	6	5	5
Loamy Sand								
2	10	6	5	4	3	3	2	2
3	14	10	7	6	5	4	4	3
4	19	13	10	8	6	5	5	4
5	24	16	12	10	8	7	6	5
6	29	19	14	12	10	8	7	6
Sandy Loam								
2	13	9	7	5	4	4	3	3
3	20	13	10	8	7	6	5	4
4	26	18	13	11	9	8	7	6
5	33	22	17	13	11	9	8	7
6	40	26	20	16	13	11	10	9
Loam								
2	18	12	9	7	6	5	5	4
3	27	18	14	11	9	8	7	6
4	36	24	18	14	12	10	9	8
5	45	30	23	18	15	13	11	10
6	54	36	27	22	18	15	14	12
Silt Loam								
2	20	14	10	8	7	6	5	5
3	31	20	15	12	10	9	8	7
4	41	27	20	16	14	12	10	9
5	51	34	26	20	17	15	13	11
6	61	41	31	24	20	17	15	14

Table 2 continued.

Sandy Clay Loam								
2	12	8	6	5	4	3	3	3
3	18	12	9	7	6	5	5	4
4	24	16	12	10	8	7	6	5
5	30	20	15	12	10	9	8	7
6	36	24	18	14	12	10	9	8
Sandy Clay								
2	11	7	5	4	4	3	3	2
3	16	11	8	6	5	5	4	4
4	22	14	11	9	7	6	5	5
5	27	18	14	11	9	8	7	6
6	32	22	16	13	11	9	8	7
Clay Loam								
2	16	10	8	6	5	4	4	3
3	23	16	12	9	8	7	6	5
4	31	21	16	12	10	9	8	7
5	39	26	20	16	13	11	10	9
6	47	31	23	19	16	13	12	10
Silty Clay Loam								
2	19	13	10	8	6	5	5	4
3	29	19	14	12	10	8	7	6
4	38	26	19	15	13	11	10	9
5	48	32	24	19	16	14	12	11
6	58	38	29	23	19	16	14	13
Silty Clay								
2	17	11	8	7	6	5	4	4
3	25	17	13	10	8	7	6	6
4	34	22	17	13	11	10	8	7
5	42	28	21	17	14	12	11	9
6	50	34	25	20	17	14	13	11
Clay								
2	16	10	8	6	5	4	4	3
3	23	16	12	9	8	7	6	5
4	31	21	16	12	10	9	8	7
5	39	26	20	16	13	11	10	9
6	47	31	23	19	16	13	12	10