NebGuide

Published by University of Nebraska–Lincoln Extension, Institute of Agriculture and Natural Resources

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G1338
(Revised June 2007)

Managing Furrow Irrigation Systems

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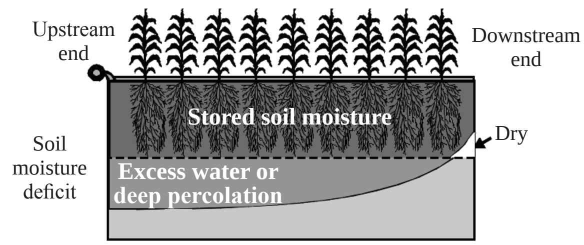
Proper furrow irrigation practices can minimize water application, irrigation costs and chemical leaching and result in higher crop yields.

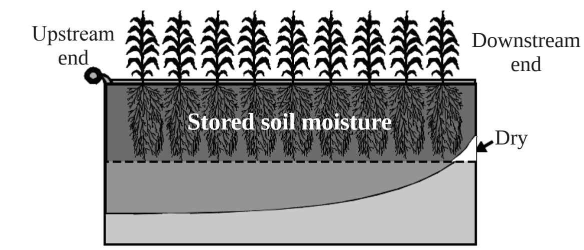
Often, irrigating an entire field as quickly as possible is the goal of a furrow irrigator. While irrigators may be satisfied just to get water to end of the furrows, they should also consider how much water is applied and how it is distributed.

The number of gates opened or tubes set — the set size — significantly impacts both how fast water advances across the field and the amount of water being applied. Evaluate soil surface conditions prior to irrigation and adjust the set size and corresponding stream size accordingly. This requires diligence, experience and flexibility on the part of the irrigator. Set size should change during the season and year-to-year to match soil intake conditions. Using a small set (relatively few gates open) and a long set time can result in excessive runoff. On the other hand, running too many furrows can result in slow water advance, causing poor water distribution and deep percolation losses *(Figure 1a)*. Either of these situations decreases irrigation application efficiency.

Efficient irrigation is obtained by almost filling the crop root zone each irrigation, applying water uniformly *(Figure 1b)* and either minimizing or utilizing runoff. Runoff and the uniformity of the water infiltrated along the furrow are related to soil conditions, field topography and the irrigator's management practices.



1a. Poor uniformity — adjust stream size and set time.



1b. Ideal infiltration pattern.

Figure 1. Infiltration profiles under conventional furrow irrigation.

Evaluating and Changing Current Practices

The correct amount of water to apply at each irrigation depends on many factors, including the amount of soil water consumed by the plants between irrigations, the water-holding capacity of the soil and root depth. Infiltration rate, the rate at which water goes into the soil, varies from one irrigation to the next and from season to season. Infiltration rate is affected by soil surface conditions. If the soil was recently tilled and the surface is loose, the infiltration rate may be very high. On the other hand, if the soil has been packed by heavy rains or by water flowing over the surface, infiltration may be reduced. One common problem in furrow irrigation is the application of too much water, especially during the first irrigation.

In general, apply water when the crop has used about one-half of the available water in the root zone. For high efficiency, do not completely fill or overfill the root zone. Overfilling leaches agricultural chemicals and fertilizers, wastes water and increases costs. Leave storage room in the soil for .5 to 1.0 inch of rainfall, except in areas with low rainfall.

The first irrigation often occurs when roots have penetrated about 18 to 24 inches. For the first irrigation, a light application is all that is needed to refill the active root zone. In Nebraska, precipitation usually replenishes the soil profile below this depth. On medium-textured soils, 1.5 to 2.0 inches of water is all that is usually necessary to replenish the soil moisture in the top 18 to 24 inches of soil.

To evaluate irrigation practices, estimate the gross depth and uniformity of application. The gross depth of water applied can be figured by calculating the rate at which water is flowing into each furrow. Divide the pump discharge in gallons per minute (gpm) by the number of furrows flowing to determine the individual stream size (gpm per furrow):

$$\text{Stream size} = \frac{\text{Pump Discharge (gpm)}}{\text{Number of Furrows Flowing}} \tag{1}$$

Note: this calculation is only accurate if leaks in the delivery system are minimal. A key to good management is to maintain pipes and ditches to minimize leaks and seepage. Once the furrow stream size is known, the average gross depth of water applied over the field area (inches of water) can be calculated as below:

$$\text{Gross Depth (inches)} = \frac{\text{1,155 x Stream Size (gpm) x Time Water Applied (hours)}}{\text{Furrow Length (ft) x Wetted Furrow Spacing (inches)}} \tag{2}$$

For example, consider the following situation:

Pump producing 750 gpm
Set size (number of furrows flowing) = 100
Water is applied 12 hours
Rows are 1,320 feet long
Wetted furrow spacing is 30 inches

Note: if irrigating every other furrow, wetted furrow spacing is doubled.

Calculate the stream size using Equation 1:

$$\frac{\text{750 gpm}}{\text{100 furrows}} = \text{7.5 gpm per furrow}$$

Calculate the gross depth applied using Equation 2:

$$\frac{\text{1,155 x 7.5 gpm x 12 hours}}{\text{1,320 feet x 30 inches}} = \text{2.6 inches}$$

The above information will help you make better management decisions and improve the overall performance of your irrigation system. To avoid completely refilling a fully developed root zone on sandy-textured soils, the gross application amounts should not exceed 1.5 to 2 inches. On medium- to fine-textured soils, application amounts should not exceed 2.5 to 3 inches.

Applying the appropriate application over the field area does not guarantee efficient irrigation. Water also must be uniformly applied from the upstream to the downstream end of the field *(Figure 1b).* Crop yields can be reduced on both ends of the field if one end receives too much water and the other end too little. Set time and stream size are perhaps the most readily "manageable" irrigation parameters. Set times and stream sizes that accommodate field conditions will improve irrigation efficiency.

Set Time and Stream Size

The appropriate set time and stream size depends on the slope, intake rate and length of run. Runoff and the uniformity of water infiltrated along the furrow are related to the cutoff ratio. The cutoff ratio is the ratio of the time required for water to advance to the end of the furrow to the total set time:

$$\text{Cutoff Ratio} = \frac{\text{Average Advance Time}}{\text{Set Time}} \tag{3}$$

Choosing the appropriate cutoff ratio depends on soil factors and irrigation system configuration. *Table I* lists the target cutoff ratios for a number of irrigation system/soil texture combinations. For example: on a loamy soil and no reuse system with a 12-hour set time, the desired advance time should be about 8.4 hours (8.4 ÷ 12 = 0.70 or 12 x 0.70 = 8.4 hours). The easiest way to change the advance time is to alter the furrow stream size (change the number of furrows flowing in each set). This will affect the cutoff ratio and hence the uniformity of water application. Altering set size without altering set time will change the gross application.

Table I. Target cutoff ratio based on soil and system considerations.

	Sandy Soils	*Loamy Soils*	*Clayey Soils*
Without Reuse	0.50	0.70	0.90
With Reuse	0.20	0.40	0.50
Blocked Ends	0.70	0.85	0.95

When selecting the furrow stream size, consider furrow erosion. In general, the maximum non-erosive stream size decreases as furrow slope increases. Estimate the maximum non-erosive stream size for a field by dividing 12.5 by that field's average percent slope. As a rule of thumb, your furrow steam size should be less than the result of this formula, but still large enough to obtain relatively uniform water application. Another limit on furrow stream size: most furrows cannot transport more than about 50 gpm without overtopping. Very small stream sizes may severely limit infiltration and should be avoided.

With the proper cutoff ratio and gross application, you can achieve uniform water application and minimize both deep percolation and runoff. Experiment with different combinations of furrow stream size and set time to find the optimum settings for a particular irrigation in a particular field. The best combination is one that moves water to the end of the furrow within the requirements of the cutoff ratio, is less than the maximum non-erosive stream size and results in gross applications that are not excessive.

To demonstrate the use of Equations 1, 2 and the cutoff ratio concept, consider an example where the first irrigation of the year has the following conditions:

Soil = sandy	System = no reuse
Pump discharge = 760 gpm	Set size = 80 gates flowing
Furrow length = 2,600 ft.	Watered furrow spacing = 30 inches
Set time = 24 hours	Observed advance time = 15 hours

First calculate the observed cutoff ratio, furrow stream size and gross application:

$$\text{Cutoff Ratio} = \frac{\text{15 hours}}{\text{24 hours}} = 0.63$$

$$\text{Stream Size} = \frac{\text{760 gpm}}{\text{80 furrows}} = \text{9.5 gpm per furrow}$$

$$\text{Gross Application} = \frac{\text{1,155 x 9.5 gpm x 24 hours}}{\text{2,600 feet x 30 inches}} = \text{3.4 inches}$$

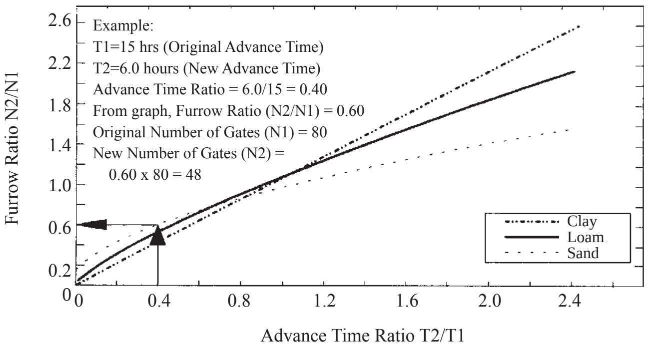


Figure 2. Graph for determining proper set size.

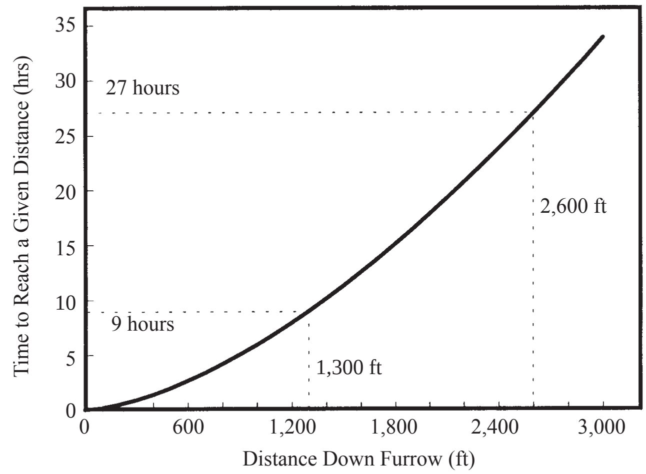


Figure 3. An example of how quickly water travels down a furrow.

These calculations indicate two items that need to be evaluated. According to *Table I,* the cutoff ratio is too high and should be reduced (from 0.63 to 0.50). Second, the gross water application (3.4 inches) is excessive for the first irrigation on a sandy soil. One way to decrease the gross application is to reduce the set time. Increasing the furrow inflow rate or stream size is one way to produce an acceptable cutoff ratio. To improve the cutoff ratio and increase the rate of water advance down the field, the furrow stream size is increased by decreasing set size (opening fewer gates per set).

Referring to calculations shown in *Table II*, we have decreased the set time from 24 hours to 12 hours. Using the *Desired Cutoff Ratio* of 0.50 *(Table I)*, we determine a *New Advance Time* of 6.0 hours. Taking a ratio of the new advance time to the original advance time yields a value of 0.40. Having found the *Advance Time Ratio*, and knowing our soil texture, we can enter *Figure 2* data and find the appropriate *Furrow Ratio*. The *Furrow Ratio* is the new number of gates to be opened divided by the original number of gates opened. In this example, the *Furrow Ratio* is 0.60. And the *New Number of Gates* that should be opened on the new set is 48. Reducing the gross water application was also a goal in this example. In order to obtain a real reduction in gross application, the ratio of original set time to the new set time (24 hours ÷ 12 hours = 2) must be greater than the ratio of the original number of gates opened to the new number of gates opened (80 gates ÷ 48 gates = 1.67).

The results in *Table II* indicate the furrow stream size was increased from 9.5 gpm per furrow to 15.6 gpm per furrow, and that the gross water application was decreased from 3.4 inches to 2.8 inches. For sandy soils, a 2.8 inch application is not unreasonably large and represents an 18 percent reduction from the prior set. Also, if the furrow slope is less than 0.8 percent, the 15.6 gpm stream size is within the non-erosive limits (12.5 ÷ 0.80 = 15.6). Changes could be made in subsequent sets to continue to decrease the gross application. In this example, we have demonstrated: 1) how to improve the uniformity of irrigation by using the cutoff ratio; and 2) how to reduce the gross depth of application by reducing the irrigation set time proportionately more than the reduction in set size.

Length of Run

Excessively long irrigation runs result in water being lost by deep percolation at the upstream end of the furrow by the time the downstream end is adequately irrigated (see *Figure 1a*). Generally the length of irrigation runs should not exceed 600 feet on sandy soils and about 1,300 feet on medium-textured soils. On some lower intake rate soils, the length of run may be as long as 2,600 feet and still distribute water uniformly.

The time required for water to advance down the furrow increases dramatically with furrow length *(Figure 3)*. Here, the time to advance water 2,600 feet is 3 times longer than the time for 1,300 feet. If you have a problem getting rows through in a reasonable length of time (as determined by the cutoff ratio) and you are using the maximum non-erosive stream size, shortening the row length is an alternative for reducing advance time.

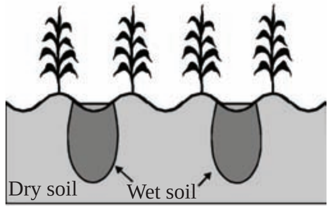
Short fields also pose a problem because application times required to infiltrate the desired amount of water may lead to excessive runoff. Again, the cutoff ratio technique will help overcome this problem. Short fields are also good candidates for runoff return systems. Non-rectangular fields present a different problem, as the length of run varies within the field. Applying the cutoff ratio technique on several sets across the field using the average furrow length for each set, may help overcome management problems on non-rectangular fields.

Table II. Example showing how the set time and cutoff ratio are used to improve the performance of a furrow irrigated set.

Parameter	*Calculation Method*	*Our Example*	*Your Example*
Desired cutoff ratio	*Table I*	0.50	
New Advance Time	Desired Cutoff Ratio x New Set Time	0.50 x 12 hrs = 6.0 hrs	
Advance Time Ratio	New Advance Time ÷ Original Advance Time	60 hrs ÷ 15 hrs = 0.40	
Furrow Ratio	*Figure 2*	0.60	
New Number of Gates	Original Number of Gates x Furrow Ratio	80 x 0.60 = 48 gates	
New Stream Size	Equation 1	760 ÷ 48 = 15.6 gpm	
New Gross Application	Equation 2	(1155 x 15.6 x 12) ÷ (2600 x 30) = 2.8 in	

Soil A

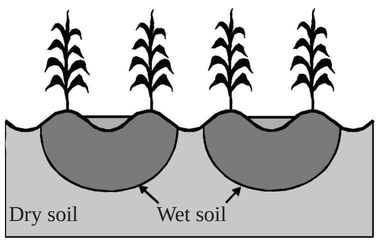
Coarse textured soil



This soil does not provide enough lateral movement for this wetted furrow spacing.

Soil B

Fine textured soil



Lateral movement okay for this wetted furrow spacing and soil.

Figure 4. Irrigated furrow wetting patterns.

Intake Rates

The water-penetration rate varies with the steepness of slope, soil texture, spacing of furrows and soil compaction. The rate at which soil will absorb water varies with time. Initially, water penetrates, or infiltrates, rapidly but within one or two hours infiltration decreases to a rate which stays relatively consistent for the remainder of the irrigation. This fairly consistent infiltration rate is called the *basic intake rate*. Longer field lengths can be used on soils with low intake rates; higher intake rates require shorter field lengths.

Every-Other-Furrow Irrigation

When irrigation is required, it is important to irrigate the entire field as quickly as possible. Irrigating every other furrow supplies water to one side of each furrow ridge. Usually, this technique applies water to more area in a given amount of time than does irrigating every furrow. Irrigating every other furrow is often beneficial on soils with high infiltration rates and low water-holding capacities. Another benefit of irrigating every other furrow is the ability to store rainfall in a recently irrigated soil. If water has been applied to every furrow, the entire root zone may have been refilled prior to rainfall. Irrigating every other furrow and applying less water per irrigation may provide more storage space within the root zone for potential rainfall.

Figure 4 shows the lateral and downward infiltration of water for two soils where every other furrow is irrigated. When the watered furrow spacing is too wide, there will be a dry area between the furrows and the crop may not get enough water (*Figure 4,* soil A). The distance between watered furrows should never exceed 6 feet. A soil probe may be used to check the penetration of water into the dry furrow after each set. Probe both the wet and dry ridge shoulders — both should be well wetted. The furrow bottom in the dry furrow should remain dry (*Figure 4,* soil B).

Every-other-furrow irrigation should not be used on steep slopes or on soils with low intake rates. On steep slopes, the water flowing down the furrow is in contact with only a limited amount of soil surface, causing low intake rates.

Research indicates every-other-furrow irrigation results in yields comparable to those achieved when every furrow is irrigated. *Table III* shows corn yields on various soil textures when irrigating every furrow and every other furrow using 12-hour irrigation sets. Irrigation water application may be reduced 20 to 30 percent by implementing every other furrow irrigation. Because of increased lateral infiltration, infiltration is not reduced by one-half compared to watering every furrow.

Table III. Corn yields (bushels/acre) on various soils when irrigating every furrow and every other furrow with 12 hour sets.

Soil	*Every Furrow*	*Every Other Furrow (same)*	*Every Other Furrow (alternate)*
Albaton Clay Loam	157	154	—
Luton Silty Clay Loam	152	159	—
Crete Silty Clay Loam	153	156	—
Holdrege Silt Loam	179	177	174
Sarpy Sandy Loam	140	143	—
Ortello Sandy Loam	118	119	120
O'Neil Sandy Loam	114	107	—

Reuse

Recirculating irrigation runoff water makes more effective use of irrigation water and labor. Reuse of runoff water decreases the amount of water pumped or delivered and can be used to improve water application efficiencies by approximately 10 percent. Reuse systems are essential for efficient surface irrigation. Often, the economic value of runoff water will be the deciding factor in installing a reuse system. However, in Nebraska, law prohibits irrigation water pumped from groundwater to leave the field. Reuse of irrigation runoff water often is more feasible than the use of additional labor to accomplish efficient irrigation and yet prohibit runoff.

Irrigators who do not have reuse systems often reduce the stream size in the furrow to a very small flow in order to minimize runoff. This causes uneven water distribution. One potential way to manage irrigation runoff while actually improving water distribution is to use surge-flow irrigation.

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1997, Revised 2003, Revised June 2007

Extension is a Division of the Institute of Agriculture and Natural Resources at the University of Nebraska–Lincoln cooperating with the Counties and the United States Department of Agriculture.