FURROW IRRIGATION MANAGEMENT

Israel Broner
Extension Agricultural Engineer
Department of Agricultural and Chemical Engineering
Colorado State University
Fort Collins, Colorado 80523

Joel Cahoon
Research/Extension Water Management Engineer
University of Nebraska-Lincoln
Clay-Center, Nebraska 68933

Furrow irrigation management encompasses all the decision making processes encountered by furrow irrigators and the effect of those decisions on the effectiveness of an irrigation event. Some management decisions are relatively routine and are not associated with a large capital outlay, for example: should I irrigate now, or later? (irrigation scheduling), how many furrows should I run in each set? (furrow stream size), how long should I run each set? (application time). Other decisions are made less frequently and often represent substantial changes in the irrigation system, for example: should I split the field in two and reduce the length of run? (furrow length), should I install a runoff recovery system? (system alteration), should I have my field leveled to a better grade? (field slope). While not all these topics are addressed herein, this workshop is designed to provide basic information to assist in important management decisions.

This workshop deals with the basics of furrow irrigation management. The discussions are aimed at irrigators using traditional graded furrow irrigation systems. Basic knowledge such as how the soil absorbs and holds water, the effect of stream size on irrigation performance and how to calculate how much water is applied (application depth) is needed to increase irrigation efficiency. There are several different definitions of irrigation efficiency. The definition used herein is that of the application efficiency, defined as the ratio of the amount of water stored in the root zone after irrigation to the amount of water applied to the field during the irrigation. More terminology will be defined in the appropriate sections of each discussion.

The workshop is divided into four sections. Section A provides background information on how soils absorb and hold water. This information provides the cornerstone for many water management decisions. Section B describes techniques for determining irrigation amounts and describes the fate of irrigation water after it is applied. Section C provides guidelines for determining the most effective furrow stream size. Section D wraps up the discussion with information concerning every other (alternate) row irrigation. This written material is designed to be used as a set, or as individual topics for less intense workshops.

SECTION A. HOW SOILS ABSORB AND HOLD WATER[1]

Israel Broner[2]

Understanding how soil absorbs and holds water is crucial for irrigation management purposes. In furrow irrigation the soil is the distribution system where water moves over the land surface in open channel flow. To understand, how some of the water is absorbed by the soil while some continues to flow, and how water is held (retained) by the soil for future use by the plants, we need to understand the physical and chemical *soil properties* and *soil characteristics*.

Soil Properties

A unit volume of soil contains solids, liquid and gas (air) as depicted in Fig. A.1. Solids (soil particles) are mineral particles derived from weathering of parent materials mixed with organic matter. Soil properties of particular importance to irrigation management include: texture, structure, organic matter content, and soil chemical properties.

<u>Soil texture</u> - The soil solids are divided into three major groups according to particle size: sands (0.08 - 0.002 in average particle diameter), silts (0.002 - 0.00008 in) and clays (<0.00008 in). Mineral particle larger than 0.08 inch in diameter are gravel, cobble or stone as size increase, and are not useful and just occupy space. Soils are grouped into 12 textural classes according to the proportional amount of sand, silt and clay in the soil. *Loam* is a soil that exhibits approximately equal properties of sand silt and clay. It does not necessarily contain equal percentages of sand silt and clay. Field personnel tend to use the following terms: light soils - contains high amounts of sand, and heavy soils - contains high amounts of clay.

<u>Soil Structure</u> - How soil particles (sands, silts, clays) are grouped together into stable collections or aggregates. Aggregates are composed of many soil particles bound or cemented together by organic matter and clays. *Peds* are natural aggregates and *clods* are soil masses broken into any shape by artificial means such as by tillage.

<u>Soil Chemical Properties</u> - Includes the translocation and concentration of soluble salts and nutrients due to the movement, use, and evaporation of the soil water. Saline soils are soils having an excess of soluble salts. If the soil has an excess of exchangeable sodium, it is termed a sodic soil.

---

[1] Prepared for presentation at the 1991 Central Plains Irrigation Short Course, North Platte, NE.

[2] Extension Agricultural Engineer, Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, Colorado, 80523.

Soil Characteristics

The terms defined above are soil physical and chemical properties that determine the soil characteristics. Some soil characteristics that are important to furrow irrigation management are the capacity of the soil to hold water and the capability of water to pass through the soil (infiltration). Using the schematic of a unit volume of soil shown in Figure A.1 and the schematic of different levels of water content shown in Figure A.2, some of these characteristics that are important for irrigation management are defined.

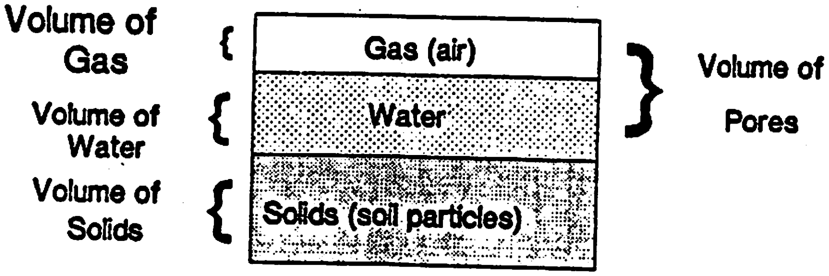


Figure A.1. Schematic of a unit volume of soil.

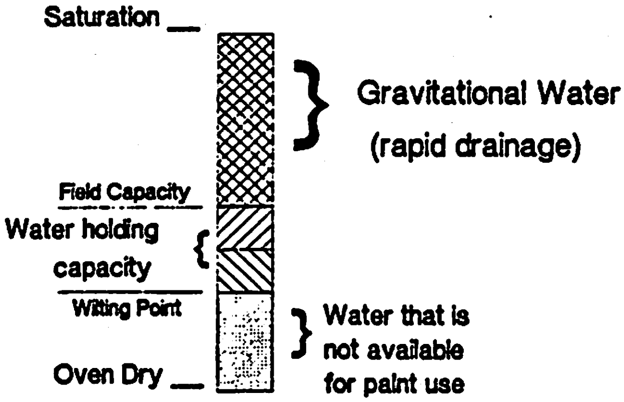


Figure A.2. Schematic of the descriptions of water in soil.

<u>Water Content</u> - Water content (moisture content) is the ratio of the volume of water in a soil volume to the total volume of the soil. Water content is often measured in inches of water per foot depth of soil.

<u>Bulk Density</u> - The weight per unit volume of soil as it exists naturally, measured in lb/ft^3. Bulk density can be used to estimate differences in soil compaction for a given soil, since compaction will increase the weight per unit volume.

Field Capacity - The water content of the soil when rapid drainage has essentially ceased. Usually occurs one (for light soils) to three (for heavy soils) days after the field was fully irrigated.

Permanent Wilting Point - The water content at which the plant suffers non-reversible or permanent damage. The remaining water is strongly held by the soil and cannot be extracted for plant use.

Water Holding Capacity or Total Available Water - The water that is available to the plant, defined as the difference between the water content at field capacity and that at the permanent wilting point. These water contents are shown schematically in Figure A.2.

Porosity - The ratio between pore volume (voids) and the total volume of the soil unit. Pore volume is that portion of the soil volume not occupied by solids, either mineral or organic.

Infiltration (intake rate) - The most crucial factor affecting furrow irrigation. It controls the amount of water entering the soil and affects the advance rate of the overland flow. Infiltration is the rate at which water enters the soil or is absorbed by the soil and is measured in in/hour. Figure A.3 shows a typical curve of infiltration rate (I) and cumulative infiltration (Z).

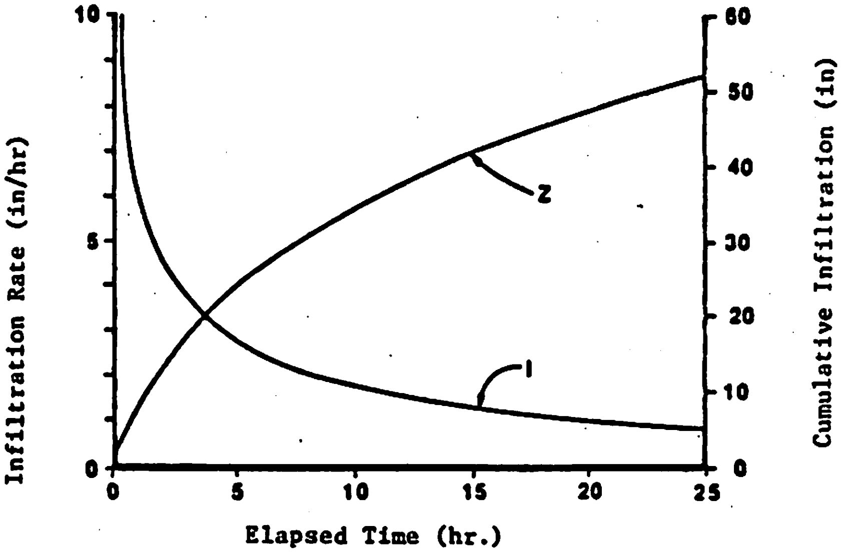


Figure A.3. Typical infiltration curves, I = infiltration rate, Z = cumulative.

The infiltration rate has a very high initial value but rapidly decreases with time, until it reaches a steady state rate (no change with time). This steady state rate is often termed the *basic infiltration rate.* These curves can be mathematically represented by different equations. A commonly used infiltration equation is the Kostiakov-Lewis equation:

$$I = k\,T^{a} + f,$$

where T is the elapsed time (min), k and a are empirical parameters, and f is the empirically determined basic infiltration rate. The three empirical parameters can be found from field experiments or from the SCS irrigation guide, which classifies soils according to intake family groups and assigns these parameters to each family.

Terms Important for Irrigation Management

Soil Moisture Deficit - The amount of water depleted from the root zone, or amount depleted below field capacity. Often measured in inches or percent of field capacity.

Management Allowable Depletion - The portion of the water holding capacity that is allowed to be depleted before irrigation is applied, measured in inches or percent.

Effective Root Zone - The depth of soil explored by roots, or the soil depth from which the crop can extract water.

Effects of Soil Properties on Soil Characteristic

Soil texture, structure and chemical properties affect and determine the soil characteristics. Soil texture is the main property that affects water content at field capacity, permanent wilting point, and water holding capacity. Improved soil structure can increase the water holding capacity of a given soil by changing soil porosity. Light soils will hold less water than heavy soils, as shown in Table A.1. However, the capillary and attractive forces resulting from the close contact of soil particles in heavy soils, are larger than in light soils. Therefore more water is available for plant use in medium textured soils such as loams than in heavier soils which contain larger amounts of clays.

Porosity - Primarily affected by soil structure and texture and thereby the permeability of soils to air, water and roots. Water drains by gravitational force from pores larger than 0.002 inches. In soils where most pores are smaller than 0.0012 inches attraction forces in the soil retain the water within the fine pores causing waterlogged soil and poor aeration. Thus, for the growing plant pores, sizes are of more importance than total pore space.

Infiltration - A complex process dependent on soil properties and other factors such as initial soil moisture content, previous wetting history, cultivation practices, type of crop and climatic effects (freezing and thawing action during winter). For furrow irrigated fields infiltration changes dramatically between irrigations. Usually the infiltration will be higher during the first irrigation after the soil was cultivated. Soil tillage helps to improve infiltration especially in fine-textured soils.

Table A.1 Water holding capacities of different soils

Texture	Water Holding Capacity (in/ft)
Sandy loam	1.68
Loam	2.40
Sandy clay loam	2.28
Silt loam	2.64
Clay loam	1.92
Silt clay loam	2.40
Silty clay	2.04
Sandy clay	1.68
Clay	1.44

In some cases (long runs) high infiltration is a problem because it takes large stream sizes for long periods of time to complete advance. In such situations smoothing and compacting the furrows will reduce infiltration and speed up advance. Surge irrigation also affects infiltration by reducing the infiltration rate, or bringing the infiltration rate to the basic rate faster than under continuous furrow irrigation. Infiltration is also affected by the amount of exchangeable sodium in the soil. Sodic soils tend to have poor soil structure, due to swelling or dispersion of particles which can reduce the infiltration rate of the soil.

SECTION B. CALCULATING IRRIGATION APPLICATION AMOUNTS[1]

Joel Cahoon[2]

The ability to calculate the amount of water applied during an irrigation event is a fundamental part of successful on-farm water management. These calculations are necessary for decisions concerning irrigation scheduling and other management practices that influence irrigation effectiveness. Further information on this topic may be found in a Nebraska Cooperative Extension publication, "Water Measurement Calculations", NebGuide G78-393, by Dean Eisenhauer and Paul Fischbach.

Water Measurement Descriptions

The terms that are commonly used to express water amounts are volume and depth. The term flow refers to the rate at which a volume of water is moved. Each of these concepts may be represented by a number of units. Water amounts are further described using average values or by showing a distribution over a length or area.

Volume A volume of water indicates the amount of space (length x width x depth) occupied. Typical units of volume are gallons, acre-feet, acre-inches, or cubic feet.

Depth Water is expressed as a depth when it is considered as a volume spread over a given area. A depth may also refer to a volume of water that has infiltrated over a given area. Typical depth units are inches or feet.

Flow Flow is the rate at which a volume of water is moved with respect to time. Typical flow units are gallons per minute or cubic feet per second. Flow should not be confused with pressure. Pressure is the force that a fluid exerts over a given area. For example, water may be under high pressure while it is standing still. Conversely, a large flow may occur under very little pressure.

Averages vs. Distributed Values Application amounts are often expressed as averages over the area of a furrow, set, or the entire field. For example, water does not infiltrate uniformly over the length of a furrow. The amount infiltrated can, however, be expressed as an average depth by dividing the total infiltrated volume by the area of the furrow. If more detailed information is needed, the infiltrated volume in each of many small segments (areas) of the field may be calculated, each divided by the area of the segment. These may then be graphed to show how the infiltrated depth varies down the length of the furrow.

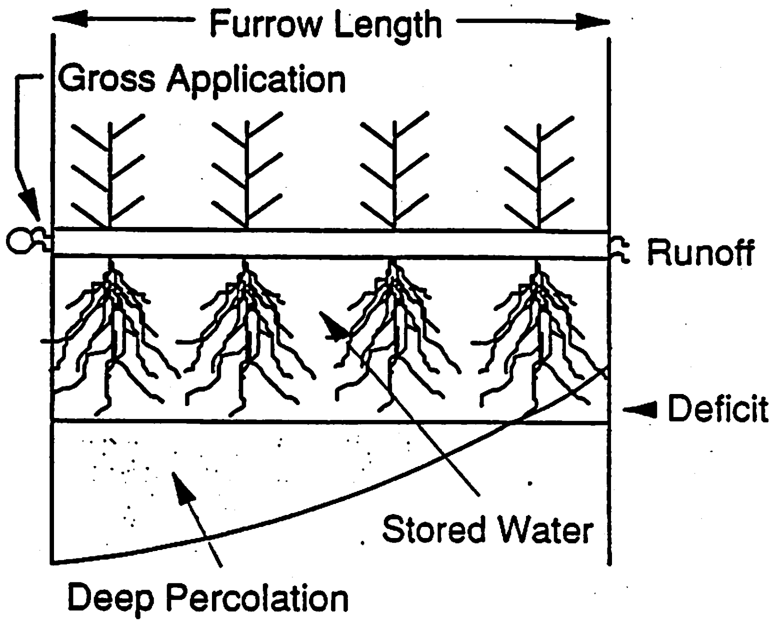
---

[1] Prepared for presentation at the 1991 Central Plains Irrigation Short Course, North Platte, NE.

[2] UNL Research/Extension Water Management Engineer, Clay Center, Nebraska.

Components of a Furrow Irrigation Application

The water that is applied during a furrow irrigation event may be described by breaking it down into components. These are; gross application depth, runoff, infiltration, deep percolation and net application depth. An irrigation event is often described by components to facilitate calculations of key statistics, such as the application efficiency. Many of these components are labeled in the graph shown in Figure 1.



Infiltration = Stored water + Deep percolation

Figure 1. Graphic depictions of the components of a furrow irrigation application.

Gross Application Depth The gross application depth represents the amount of water applied at the upstream end of the field averaged over the area to which it is applied. This is calculated by dividing the applied volume by the area to which the volume is delivered, and then applying conversion factors to obtain the desired units. When using gated pipe or mainline supply pipe, a propeller type flowmeter may be used to determine the volume applied (Eisenhauer, 1984). A weir or flume is often used to determine the total volume of water applied from an open ditch or canal.

Runoff Runoff is the amount of water that exits the furrow at the downstream end of the furrow. This occurs only on furrow systems that do not have blocked or diked ends. Runoff is usually expressed as a volume, or as a depth averaged over the area on which the water was applied. The runoff volume is a difficult component to estimate. One method is to place small flumes or weirs at the downstream end of several furrows to monitor the runoff. Another method is to place a large flume or weir in a location that catches the runoff from several furrows.

Infiltration Infiltration is usually expressed as a depth, and is the average amount of water that has passed through the soil surface over a given area. Infiltration is sometimes measured by taking the difference between pre- and post- irrigation soil moisture estimates using techniques described by: Kranz and Eisenhauer, 1989; Kranz, et al., 1989; Yonts and Klocke, 1985; Klocke and Fischbach, 1984. Another method is to estimate the infiltration characteristics of the soil and monitor the advance and recession of water in the furrow. From these observations, the infiltration profile may be calculated. In any case, the infiltrated depth associated with an irrigation event is very difficult to determine in a production agriculture situation.

Deep Percolation Deep percolation is the amount of water infiltrated that is in excess of the soil moisture deficit at any given point down the furrow. The soil moisture deficit indicates the amount of water that may be added to and stored in the root zone. If the amount of water infiltrated is greater than the soil moisture deficit, some will pass through the root zone and deep percolate to soil depths below the root zone. The soil moisture deficit is often determine using the techniques referred to above.

Net Application Depth The net application depth is the amount of water that infiltrates and is retained in the root zone. For a full application (soil moisture deficit replenished throughout the field), the net application equals the soil moisture deficit. The net application is less than the soil moisture deficit if the deficit was not replenished throughout the field.

Typical Calculations

From the above discussion, it is apparent that many irrigators do not have the time, equipment or patience to break down an irrigation event into components. Irrigators are typically concerned primarily with the gross application depth. If the gross application depth and the soil moisture deficit are known, the application efficiency may be determined if the root zone is fully replenished throughout the field.

Example

As an example, we will assume that an 80 acre field having a 3.5 inch soil moisture deficit is irrigated using gated pipe having a propeller type flowmeter. After irrigating, the downstream end of the field is probed. Using the appearance and feel method to the effective root depth, it is determined that the soil moisture deficit is replaced at the downstream end, and thus, throughout the field. The totalizer on the flowmeter was read before and after the irrigation. Before irrigating, the flowmeter read 13,417,700 gallons, and after irrigating the totalizer showed 24,605,100 gallons. It is desired to determine the gross application depth and an estimate of the application efficiency.

1. Determine the volume applied:

$$\begin{array}{lr} \text{after} & 24{,}605{,}100 \\ \text{-before} & -13{,}417{,}700 \\ \hline & 11{,}187{,}400 \text{ gallons} \end{array}$$

2. Determine gross application by dividing by the area and converting units:

$$11{,}187{,}400 \text{ gal} \times \frac{1 \text{ ac-inch}}{27{,}154 \text{ gal.}} \times \frac{1}{80 \text{ acres}} = 5.17 \text{ inches}$$

3. Since the soil moisture deficit has been replaced throughout the entire field, we may determine application efficiency be dividing the soil moisture deficit by the gross application:

application efficiency = (3.5 inches/5.17 inches)(100%) = 68%

References

Eisenhauer, D. E. and P. E. Fischbach. 1984. Water measurement calculations. Nebraska Cooperative Extension publication. NebGuide G78-393.

Eisenhauer, D. E. 1984. Selecting and using irrigation propeller meters. Nebraska Cooperative Extension publication. NebGuide G78-392.

Klocke, N. L. and P. E. Fischbach. 1984. Estimating soil moisture by appearance and feel. Nebraska Cooperative Extension publication. NebGuide G85-753.

Kranz, W. L. and D. E. Eisenhauer. 1989. Irrigation scheduling using soil moisture blocks in silty soils. Nebraska Cooperative Extension publication. EC89-723.

Kranz, W. L., T. W. Dorn, and D. E. Eisenhauer. 1989. Irrigation scheduling using tensiometers in sandy soils. Nebraska Cooperative Extension publication. EC89-724.

Yonts, C. D. and N. L. Klocke. 1985. Irrigation scheduling using crop water use data. Nebraska Cooperative Extension publication. NebGuide G85-753.

SECTION C. EFFECTS OF STREAM SIZE ON FURROW IRRIGATION PERFORMANCE[1]

Joel Cahoon[2]

Irrigators have steadily become more concerned about the effectiveness of their furrow irrigation systems. This is often the result of restrictions on ground and surface water availability, increased energy costs for irrigation pumping, or increased awareness of environmental concerns. Some simple and cost effective management practices can dramatically enhance the effectiveness of a furrow irrigation system. Two management practices that are easily changed are the furrow stream size or flow rate, and the set (application) time. Irrigators are usually not receptive to changing application times, but may consider using different stream sizes. For this reason, this paper concentrates on discussions concerning the most effective furrow flow rate. It is recognized that there are other innovative furrow irrigation management techniques (eg. surge irrigation, cablegation, automated systems, etc.), but this paper focuses on options for traditional graded furrow irrigation systems that require no significant cost or labor increase.

Determining Furrow Flow Rate

The average furrow flow rate is equal to the supply flow rate divided by the number of furrows in the set. When using gated pipe, the supply flow rate may be determined using an in-line propeller type flowmeter (Eisenhauer, 1984). If a pump is used with canals or head ditches that are not lined, the pump flow rate must be adjusted for infiltration losses in the supply system. For systems in surface water irrigation districts, an open channel weir or flume may be used to determine the total flow rate at the turnout. This method assumes that the losses between the metering point and the upstream end of the furrows are insignificant or may be estimated, and that the furrow flow rate does not vary between furrows. While there is substantial evidence that gated pipe furrow stream sizes vary significantly within an irrigated set (Trout and Mackey, 1988), irrigators have little choice but to work with average values. There are more accurate techniques for estimating furrow flow rate (Eisenhauer et al., 1985; Regier, 1981; Trout, 1986a; Trout, 1986b), but these methods are research oriented and not well adapted to production agriculture.

Graded Furrow System Classification

Graded furrow irrigation systems may be classified by three general types that warrant separate discussions; blocked end systems, free flowing end systems, and

---

[1] Prepared for presentation at the 1991 Central Plains Irrigation Short Course at North Platte, Nebraska and the 1991 Nebraska Irrigation Short Courses at Blue Hill and Alliance, Nebraska.

[2] UNL Research/Extension Water Management Engineer, Clay Center, Nebraska.

systems with runoff recovery facilities. A cutback cycle may be incorporated into any of these systems. Cutback systems are omitted from this discussion because the labor expenditures involved with manually activating the cutback phase render them less common.

Methods and Results

An example is used to demonstrate the effects of furrow stream sizes that are above and below ideal. Using this example field, the SIRMOD (Utah State University, 1989) furrow irrigation evaluation computer program was used to generate the effects of altering the furrow flow rate. The example field chosen has the following characteristics:

Size: 80 acres
Furrow Length: 1/4 mile
Pump Flowrate: 920 gpm
Soil Moisture Deficit: 3.25 inches
Slope: 0.5% (0.005 ft/ft)
Manning's n: 0.04
Kostiakov-Lewis Infiltration Parameters: $k = 0.0075\ m^3/min^a/m$
$a = 0.35$
$f = 0.000106\ m^3/min/m$

The furrows are on 30 inch centers with a trapezoidal channel having 1:1 side slopes, 5 inches maximum depth and 3 inches bottom width. Many irrigators use 12 hour sets for 1/4 mile runs. In this case the performance was significantly improved by using 8 hour sets. Thus, 8 hour application times were used for all the reported SIRMOD runs. It should be noted that more effective irrigations could be found by varying the application time as well as the flow rate, but again, this is not the common practice in production situations.

The graphs given in Figures 1 through 7 are consistent in notation. The labels GROSS, SMD and RUNOFF indicate in depth units the gross application, soil moisture deficit, and runoff, respectively, expressed as averages taken over the entire area of one furrow. The label INF indicates infiltration over the length of the furrow in depth units. The labels PERC and STORED indicate the bounds of the distribution of deep percolation and stored water over the length of the furrow. The label DEF indicates the extent of under-watering, ie. zones where infiltration is less than the soil moisture deficit, down the length of the furrow in depth units.

Blocked End Systems

Blocked end furrow irrigation systems are often used in the irrigated river valleys of the Central Plains on fields having little down-furrow slope. The furrow ends are diked because these valleys often have highly permeable soils with shallow groundwater tables, thus making runoff recovery pits impractical. Without the diked ends, there is often no exit route for runoff water.

The practical limits on stream size are those that will cause ponded water to overflow the dike at the downstream end of the field (too high) and those that are insufficient to advance water to the downstream end of the furrow (too low). The maximum non-erosive flow is usually not a factor in blocked end systems, because erosive flows are generally far greater than that which would cause the dike to be overtopped.

The graph of Figure 1 shows the ideal flow rate for the example problem using blocked ends. The soil moisture deficit has been replenished down the entire length of the furrow, with a small exception near the downstream end of the furrow. The small area labeled DEF is probably acceptable, given it's relative dimensions. The only loss in blocked end systems is deep percolation.

The graph of Figure 2 shows the effects of a stream size that is too small. Water advanced to the downstream end of the furrow, but was insufficient to adequately replace the deficit in the last 50 feet of furrow. The efficiency did not change significantly from the ideal case, because the gross application was lessened roughly proportionately with the amount of water infiltrated and stored in the root zone.

Figure 3 show the results of applying a stream size that is too large. Water advanced to the downstream end where surface storage is high. The water recedes upon cutoff, but the receding water is forced to infiltrate near the downstream end of the furrow instead of running off. This causes the extremely high infiltration depths in the last 100 feet of furrow.

Systems with Free Flowing Ends

Many graded furrow systems have free flowing ends. Water advances down the furrow and is allowed to run off the lower end until the soil moisture deficit is replenished throughout the length of the field.

The practical limits on stream size are those that cause excessive soil erosion (too high) and those that are insufficient to promote water advance down the entire length of the furrow (too low). The maximum non-erosive stream size is a function of soil characteristics and furrow slope (SCS, 1983):

$$\text{Maximum Flow Rate (gpm)} = \frac{K}{\text{furrow slope in (ft/100 ft)}}, \qquad (1)$$

where: K = 10 for erodible soils,
K = 15 for resistant soils, and
K = 12.5 for average soils.

Figure 4 shows the ideal flow rate for our example problem with free flowing ends and an 8 hour application time. Note that there is now a line representing the runoff volume distributed over the area of one furrow. The deficit has been replenished for the entire furrow without excessive deep percolation at the downstream end. The runoff volume is relatively small. Further changes in the furrow stream size while maintaining full replenishment of the root zone without changing the application time will not decrease the deep percolation at the upstream end of the field.

Figure 5 shows the results of a flow rate that is too high for our example problem with free flowing ends. Runoff has significantly increased, and excess deep percolation occurs at the downstream end of the field as well as the upstream end.

The graph of Figure 6 show the results of a stream size that is too low for our example problem. Water advanced to the downstream end in just enough time to produce a runoff volume that is too small to appear on the graph. This caused insufficient opportunity time at the downstream end of the field, resulting in a significant post-irrigation deficit in the last 50 feet of the furrow.

The graph of Figure 7 show the results of a stream size that is extremely low for our example problem. Water failed to advance the entire length of the furrow, causing a large area where the entire soil moisture deficit remains after irrigation.

Systems with Re-Use Facilities

For systems with runoff recovery facilities, many of the concepts of the free flowing end systems still hold. The difference is that with runoff recovery systems, runoff should only be counted against the system efficiency to the extent that losses in the recovery system occur. Thus, high flow rates that would cause undesirable runoff without a recovery system may be appropriate when a recovery system is present.

Stream Size, Furrows per Set, and Total Application Time

A relationship exists between the furrow flowrate, the number of furrows per set, and the total application time. In our example using free flowing ends, we have chosen a stream size of 24 gpm. An 80 acre, 1/4 mile run field with 30 inch furrows has a total of 1056 furrows. If the pump flow rate is 900 gpm and we want to use 24 gpm per furrow, we would have 37.5 gates per set, so we must use 38 gates per set. Using 38 gates per set, we would need 27.8 sets. We don't want a partial set left over, so we must use 8 sets with 37 gates open and 20 sets with 38 gates open. This will make the number of sets exactly 28 with no gates or partial set left over. See Appendix 1 for details of these calculations. Using 28 sets at 8 hours per set yields a total application time of 224 hours or 9.33 days. A 3.25 inch deficit divided by a maximum ET rate of 0.35 inches per day yields 9.28 days, indicating that this stream size decision is adequate to handle the maximum crop water demand.

It also stands to reason that the most efficient or effective flowrate may be prohibitive in terms of the total application time. For example, if the most effective flowrate was 45 gpm, then the set size would be 20 furrows, yielding 53 sets at 8 hours per set. This means the total application time would be roughly 20 days, which is not acceptable when compared to 9.28 days of storage capacity during peak consumptive use.

Field Techniques in Determining Effective Stream Sizes

While it is nearly impossible to determine the most effective furrow flow rate in a production situation, there are some simple observations that an irrigator may note to help lead to that end. These observations involve simple estimates of the soil moisture status before and after irrigating, and observations of water advance and runoff.

The pre-irrigation soil water status should be determined to estimate the amount of water that must be replaced in the root zone. This estimate, when combined with estimates of gross water applied, will indicate problems with the irrigation system. For example, if the pre-irrigation soil moisture deficit was 3.25 inches, we would anticipate gross applications of 4.25 to 6.5 inches. This would mean that the application efficiency would fall between 50% and 75%.

Another useful technique is to estimate the soil moisture status at the downstream end of the furrow after irrigating. If the profile has not been replenished, this indicates a stream size that is too small or an application time that is too short.

If it is suspected that the gross application is too large with respect to the soil moisture deficit, one could observe the runoff. If the time during which runoff occurs seems abnormally long, or if the runoff flow is abnormally high, the flowrate is probably too high.

Field observations like these will help irrigators zero in on more effective flowrates. These observations should be repeated for every irrigation because the infiltration characteristics of the soil change with each irrigation.

Discussion

Several things can be noted from the example we used. Blocked end systems may be more sensitive to furrow flow rates, that is, a smaller range of flow rates may be practical with blocked end systems. This is because water easily "piles" at the lower end, causing very undesirable infiltration patterns.

The application efficiency, due to the definition of the term, is not always a complete description of the effectiveness of the system. No consideration is given to incomplete infiltration (cases where the root zone is not completely filled over the length of the furrow) in the efficiency term. For example the graph of Figure 7 shows a relatively high application efficiency, but this is not by any means a desirable application.

Irrigation effectiveness is not the only consideration when choosing a furrow stream size. The total application time, relative to the time required for the crop to use 50% of the water stored in the root zone, must be considered. Any number of gates per set is conceivable using the procedure outlined in Appendix 1.

Total application time is the indicator of the gross amount of water applied in one irrigation. While it is desirable to minimize losses and apply an efficient irrigation, it may be more desirable to lose some water to runoff or deep percolation if energy costs or water quantity is the primary consideration. That is, with altering the set time, lower stream sizes result in less total application time and therefore lower energy use and gross water consumption. The willingness to alter both set times and number of furrows per set allows water quality and quantity goals to be met simultaneously. Stream size and set time combinations would be determined that maximize efficiency and minimize gross water application.

Some simple observations, such as probing the soil profile and observing advance and runoff, may help irrigators choose more effective furrow flow rates.

References

Eisenhauer, D. E. 1984. Selecting and using irrigation propeller meters. Nebraska Cooperative Extension NebGuide G78-392.

Eisenhauer, D. E., C. A. Borcher, and D. G. Watts. 1985. A portable flow metering device for furrow irrigation studies. Transactions of the ASAE. vol. 28(6):1986-1988.

Trout, T. J. 1986. Orifice plates for furrow flow measurement: part I - calibration. Transactions of the ASAE. vol. 29(1):103-106, 111.

Trout, T. J. 1986. Orifice plates for furrow flow measurement: part II - design and field use. Transactions of the ASAE. vol. 29(1):107-111.

Trout, T. J., and B. E. Mackey. 1988. Furrow inflow and infiltration variability. Transactions of the ASAE. vol. 31(2):531-537.

Regier, C. 1981. A device for rapid measurement of rate of flow from gated irrigation pipe. Agronomy Journal. vol. 73(March-April 1981):375-376.

SCS. 1983. USDA Soil Conservation Service, National Engineering Handbook. Sect. 15, Ch. 5. Furrow Irrigation.

Utah State University. 1989. SIRMOD: Surface Irrigation Simulation Software. Users guide. Irrigation Software Engineering Division, Dept. of Ag. and Irrig. Engr., Utah State University, Logan, UT 84322-4105.

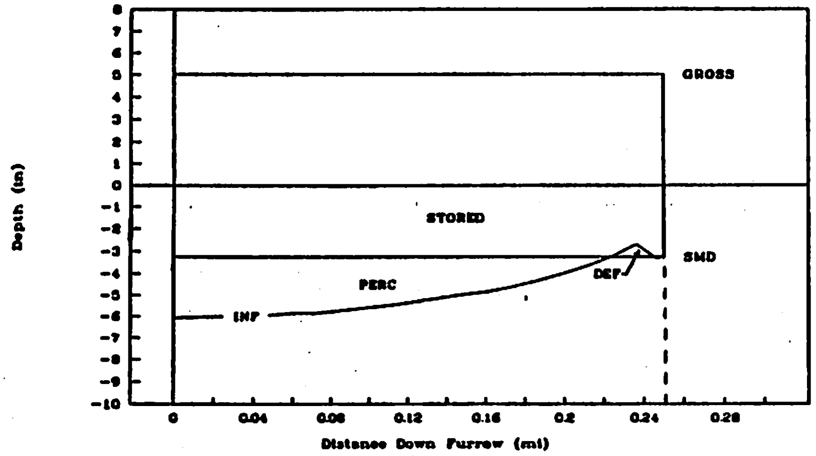


Figure 1. Blocked end example with the ideal flow rate. Stream size = 21.4 gpm, application efficiency = 65%, application time = 8 hours.

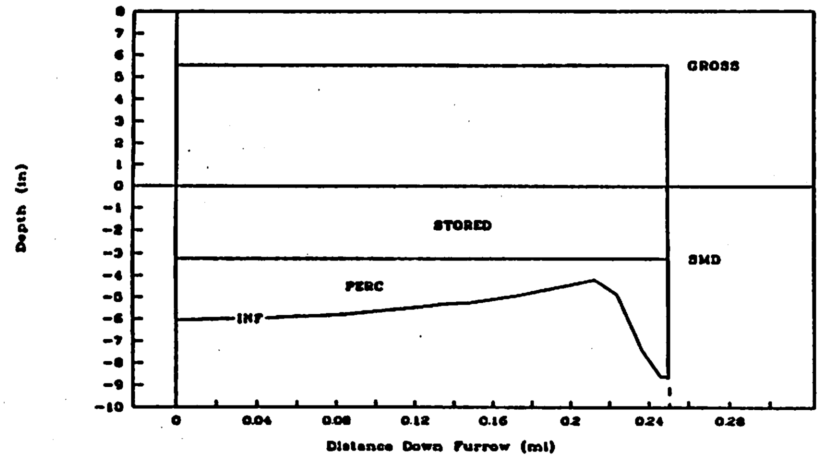


Figure 2. Blocked end example with a flow rate that is too high. Stream size = 24 gpm, application efficiency = 59%, application time = 8 hours.

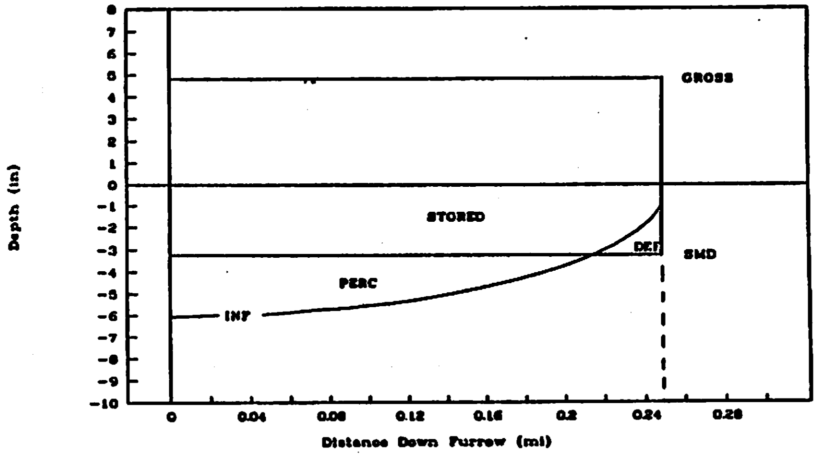


Figure 3. Blocked end example with a flow rate that is too low. Stream size = 20 gpm, application efficiency = 64% application time = 8 hours.

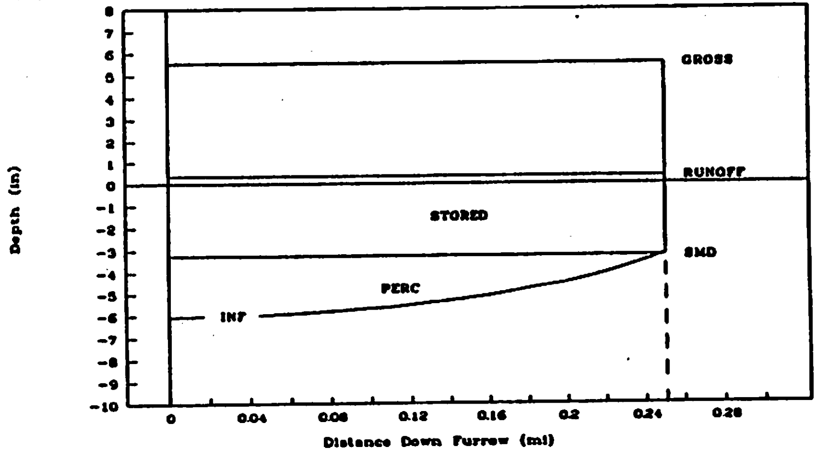


Figure 4. Free flowing end example with the ideal flow rate. Stream size = 24 gpm, application efficiency = 59%, application time = 8 hours.

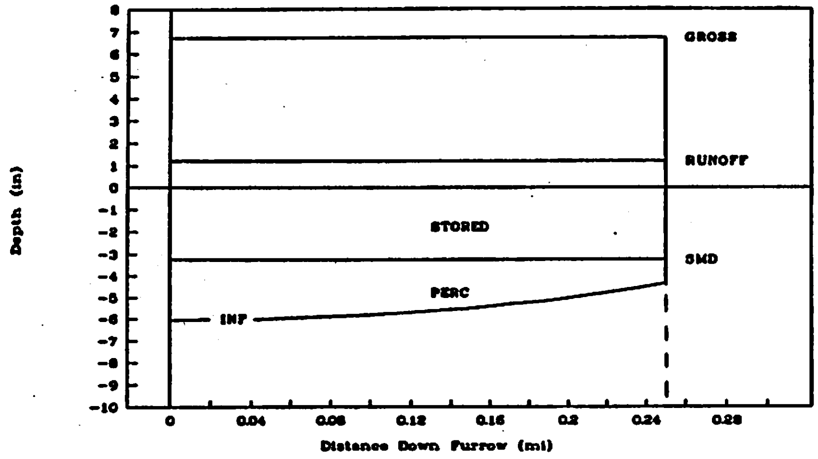


Figure 5. Free flowing end example with a flowrate that is too high. Stream size = 29 gpm, application efficiency = 48%, application time = 8 hours.

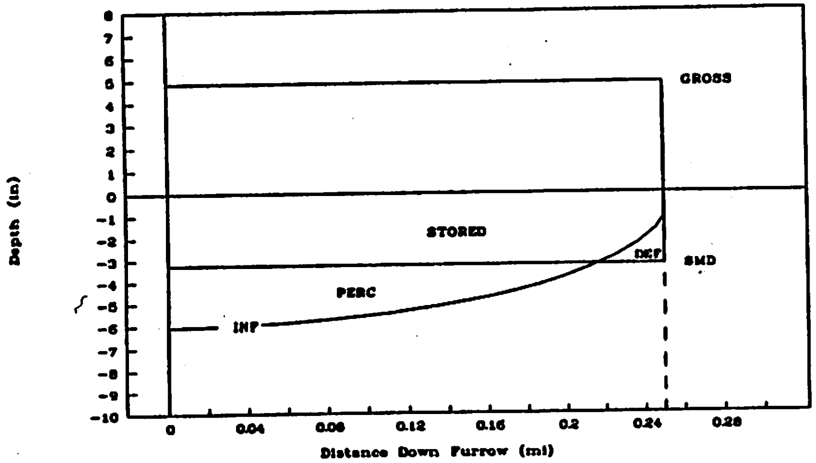


Figure 6. Free flowing end example with a flowrate that is too low. Stream size = 21 gpm, application efficiency = 65%, application time = 8 hours.

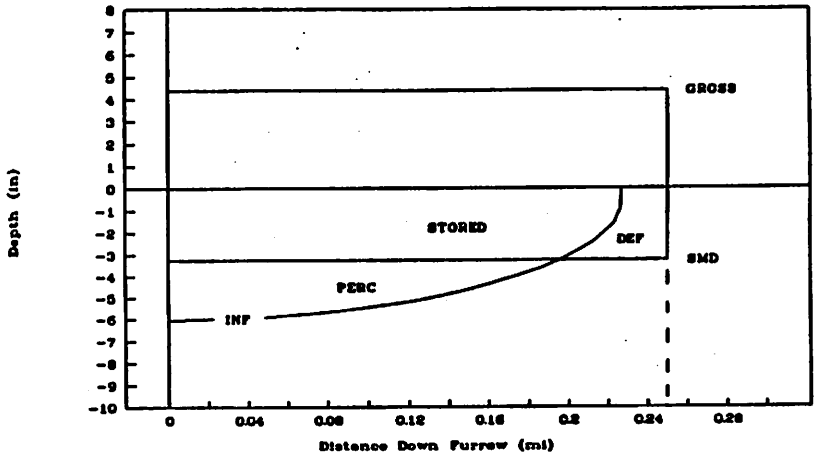


Figure 7. Free flowing end example with a flowrate that is extremely low. Stream size = 18.8 gpm, application efficiency = 64%, application time = 8 hours.

Appendix 1. Calculating an Integer Number of Sets

If you have problems making the number of sets you use with gated pipe furrow irrigation come out even, the following procedure should help. For example, an irrigator has a 55 acre block with 1/4 mile runs and 30" rows. This means he has 726 furrows to irrigate. He wants to use 31 gates per set. If he opens 31 gates on every set, he will have 23 sets plus one set left over that only has 13 gates open. To make it come out even, he can run different combinations of sets with 30, 31, or 32 gates per set. Here's how to determine the proper number:

Instruction	Our Example	Your Calculation
1. Write down total number of furrows	a. 726	a. ______
2. Write down the desired number of gates per set	b. 31	b. ______
3. (a.)÷(b.)	c. 23.42	c. ______
4. Round off (c.) to nearest whole number	d. 23	d. ______
5. (a.)÷(d.), using long division, the whole number & remainder are important		
$\begin{array}{r} 31 \\ 23\overline{)726} \\ \underline{690} \\ 36 \\ \underline{23} \\ 13 \end{array}$	e. 31 f. 13	e. ______ f. ______
6. (d.)-(f.)	g. 10	g. ______
7. If (d.) was rounded down then (b.)+1, else (b.)	h. 32	h. ______

Results

Our Example:

Run (g.) 10 sets with (e.) 31 gates open
and
run (f.) 13 sets with (h.) 32 gates open.

Your Calculations

Run (g.) _ sets with (e.) _ gates open
and
run (f.) _ sets with (h.) _ gates open.

SECTION D. EVERY OTHER ROW IRRIGATION[1]

Israel Broner[2]

Every other row or alternate furrow irrigation is not widely practiced, however some field experiments indicate that this practice can result in some benefits to the irrigators. In a recent study (Graterol et al. 1989) done in Clay Center, Nebraska every other furrow irrigation was compared to conventional furrow irrigation of soybeans. The results of the 1988 experiment showed that the same yields were obtained under both practices, however significantly less water (46%) was applied under every other row irrigation. The experiment was repeated in 1989 and similar results were obtained. Similar results were obtained in a field experiment conducted several years ago on corn (Fischbach and Mulliner, 1974). The same yields were obtained when irrigating every other row and every row, however, 40% more water was applied under every row irrigation. These results indicate the possibility of water conservation when irrigating every other row as compared to the traditional every row irrigation practice. In the study made in 1974 it was found that sufficient water moved laterally from the irrigated furrow to the dry furrow. In both studies it was concluded that irrigating every other row maintained yields with significantly less water input, less deep percolation and less runoff, thus leading to water conservation and reduced pumping costs.

A typical water distribution pattern under furrow irrigation is depicted in Figure D.1. The wetted pattern has a shape of a bulb and the width of the bulb depends primarily on the soil texture and structure and whether or not the soil is layered. It is recommended to monitor lateral water movement when first using every other row irrigation by probing the soil in the dry furrows.

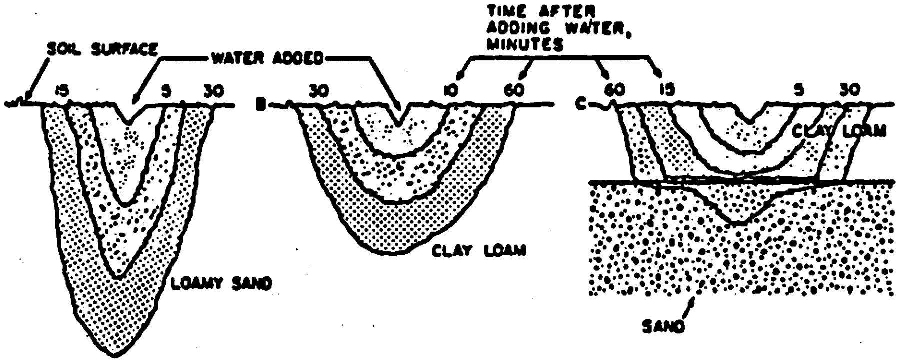


Figure D.1. Furrow irrigation lateral water distribution patterns.

---

[1] Prepared for presentation at the 1991 Central Plains Irrigation Short Course, North Platte, Nebraska.

[2] Extension Agricultural Engineer, Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins, Colorado, 80523.

Irrigating every other row has the following advantages over the traditional every row irrigation.

1. Conserves water by reducing water input which results in reduced deep percolation and reduced tail water.

2. Reduces evaporation because of reduced wetted soil surface.

3. Increases storage within the root zone for occasional rainfall.

4. When irrigating every row with saline water, salt will accumulate in the middle of the row (bed) near the plants root system. When every other row practice is used with saline water the salt will accumulate in the middle of the dry furrow and will stay there far from the plant's root system. This salt can be later leached below the root zone during heavy rain or by applying heavy irrigation to the dry furrows.

5. Less equipment or labor is needed. In gated pipe irrigation less gates are opened and in syphon tube irrigation less syphons are needed.

One potential problem when using every other row irrigation can be of obtaining adequate lateral water movement that will wet enough soil volume before significant deep percolation starts. Several factors can reduce lateral water movement.

1. Light homogeneous soils will have less lateral water movement than fine textured nonhomogeneous soils. The coarser the soils the faster water moves downward. In fine textured soils the attraction forces between the close soil particles are larger than the gravity force which increases lateral water movement. Layered soil changes the wetted bulb pattern under furrow irrigation. For example, a horizontal layer of coarse material or a layer of finer material causes the parabolic wetted bulb to flatten and actually increase the lateral water movement which is possible in homogeneous soil.

2. Obtaining adequate lateral water movement might be a problem. When irrigating shallow rooting system crops and applying light irrigations. In these cases lateral water movement may not be sufficient enough to wet enough volume of the root zone.

3. Steep furrow slopes limit the depth of flow in the furrow which affects the lateral water movement. Flat furrow slopes permit the use of larger stream size with deeper flow depth and greater wetted perimeter which increase the lateral water movement.

References

Fischbach P. E., and H. R. Mulliner (1974). Every-Other Furrow Irrigation of corn. Transaction ASAE 17(3)426-428

Graterol Y. E., R. W. Elmore and D. E. Eisenhauer (1989). The Use of Alternate-Irrigated Furrow Spacing For Soybean Production. UNL Clay Center NE.