Border Irrigation

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Border Irrigation

(Design and Evaluation)

1. Introduction

At first glance, borders seem very similar to basins. The land is divided into strips by small earth bunds to irrigate similar crops and soils (Figure 1). However, there are two important differences.

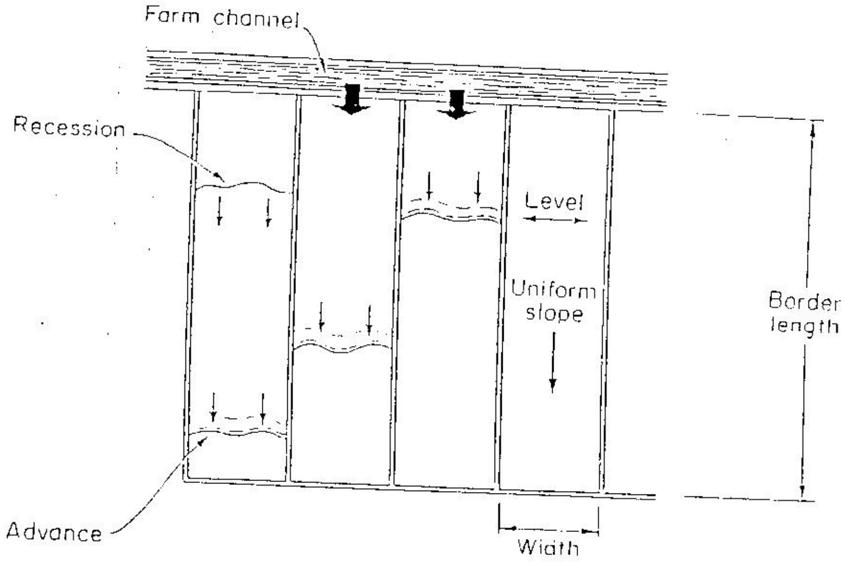


Figure 1 Border Irrigation

Borders usually slope uniformly away from the farm channel in the direction of water flow. They are not level like basins. Borders are irrigated in quite a different way to basins.

Borders are often recognized by their characteristic long, narrow shape, but this can be misleading because basins can also be shaped in this way. They are also called border strips, border checks or strip checks. The names are different but they all refer to the same method of irrigation.

Border irrigation can be adapted to suit many field and row crops, soils and farming practices. However, it is important to use the right size and shape of border and good water management for this method to work well.

2. Size and Shape

Borders are usually rectangular in shape, varying in size from 100-800 m long and 3-30 m wide. As a general rule borders should be as long as is practically possible. This means fewer farm channels and drains are needed, less land is taken up by channels and it is much easier to mechanise. Construction and maintenance costs for the channels and structures are also reduced.

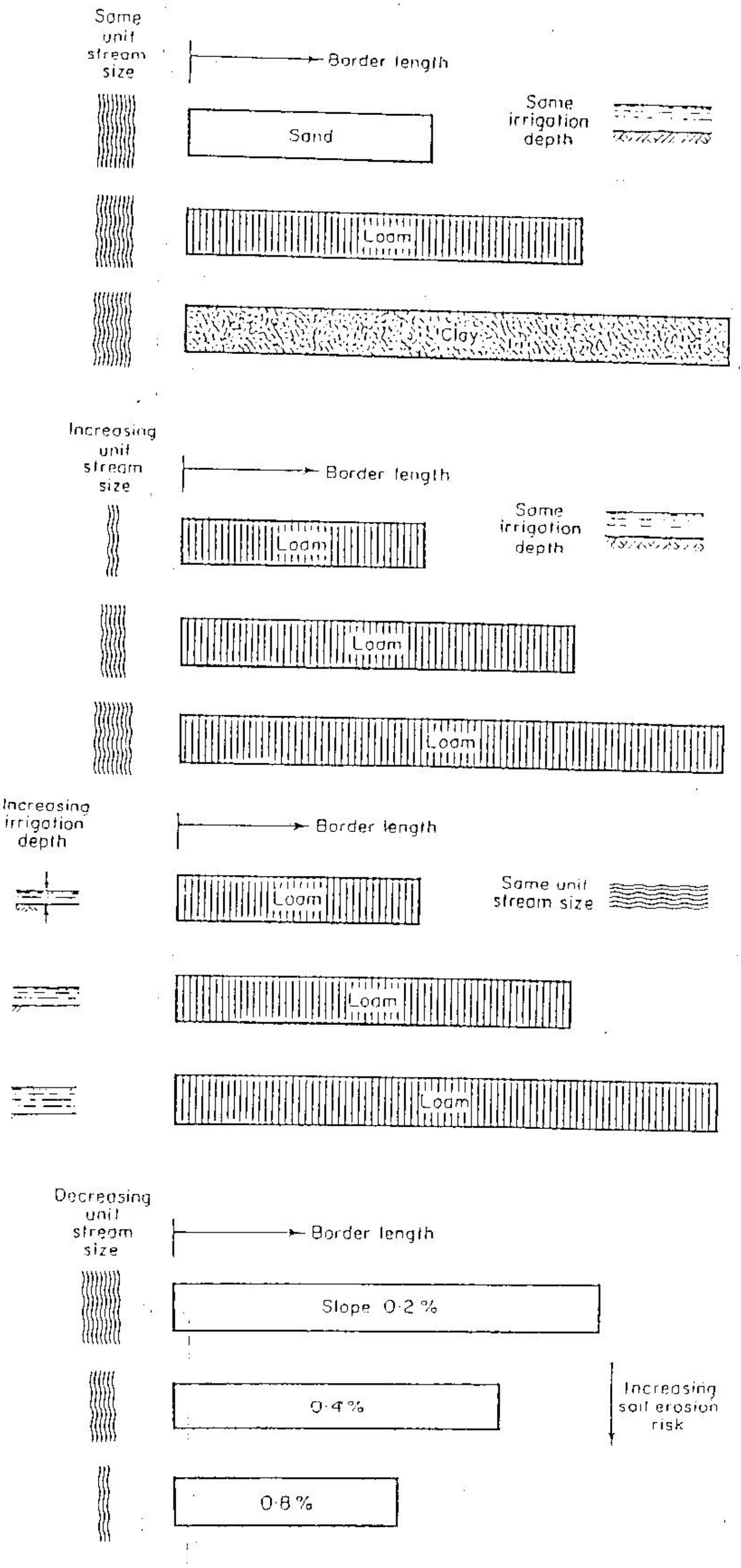
There are many factors which affect the choice of border size and shape. These include: soil type; unit stream size, irrigation depth, slope, field size and shape and farming practice.

2.1 Soil Type, Unit Stream Size, Irrigation Depth and Slope

These factors are the most important in determining the area of land that can be enclosed within each border (Figure 2).

When irrigating sandy soils water infiltrates rapidly. This means that borders must be short (100 m or less) for water to spread down the field even when quite large unit stream sizes are used (Figure 2 a). If the border was too long for the available stream size, too much water would be absorbed and lost near the farm channel before the flow had time to reach the far end of the border.

When irrigating clay soils water infiltrates much more slowly than in sands and so it can take a long time to fill the soil reservoir. Water cannot be ponded on the soil and left to infiltrate as



(a) Border can be longer on clay soils than on sands

(b) Borders can be longer when a larger stream size is used

(c) Borders can be longer when a larger irrigation depth is applied

(d) Borders are shorter on steeper land

Figure 2 Factors Effecting Border Size and Shape in basin irrigation and so long borders are needed even when the unit stream size is small. This allows sufficient time for water to infiltrate into the soil as it flows down the borders.

If the borders were too short for the stream size, the flow would reach the far end before sufficient water had infiltrated near the farm channel. This means that water must be left flowing to complete the irrigation and so some water would run-off the end of the border and be lost in the drainage system.

Borders can usually be much longer on the same soil when a larger unit steam size is available (Figure 2 b). This is because the water will spread more rapidly acrcss the soil surface when the flow is increased.

Applying a larger irrigation depth also means that borders can be increased in length (Figure 2 c). A larger depth of water needs a longer contact time and so there is more time available to spread water along the border. This may not be much of a problem on sandy soils, but on clays excessively long borders may be needed when large irrigation depths (100-200 mm) are applied. In such cases very low unit streams are used to slow down the advance and provide more time for infiltration.

On sloping land there is always the risk of soil erosion. On steep land slopes smaller unit stream sizes must be used to slow down the advance and so prevent erosion. This means that borders must be reduced in length as well if they are to be irrigated efficiently (Figure 2 d).

Border width largely depends on the length of border chosen and the available stream size. For example, if a 100 m. long border on a sandy soil needs a unit stream (q) of 10 l/s and the available stream size (Q) is 50 l/s, the border width (W) is calculated as follows.

$$W = \frac{Q}{q} \qquad \text{(1)}$$

$$= \frac{50}{10}$$

$$= 5 \text{ m}$$

Border width can also be affected by land slope. When there is across slope the land is usually levelled across each border and the "Staircase" effect is made in the same way that level areas are made for basins on sloping land as shown in Figure 3.

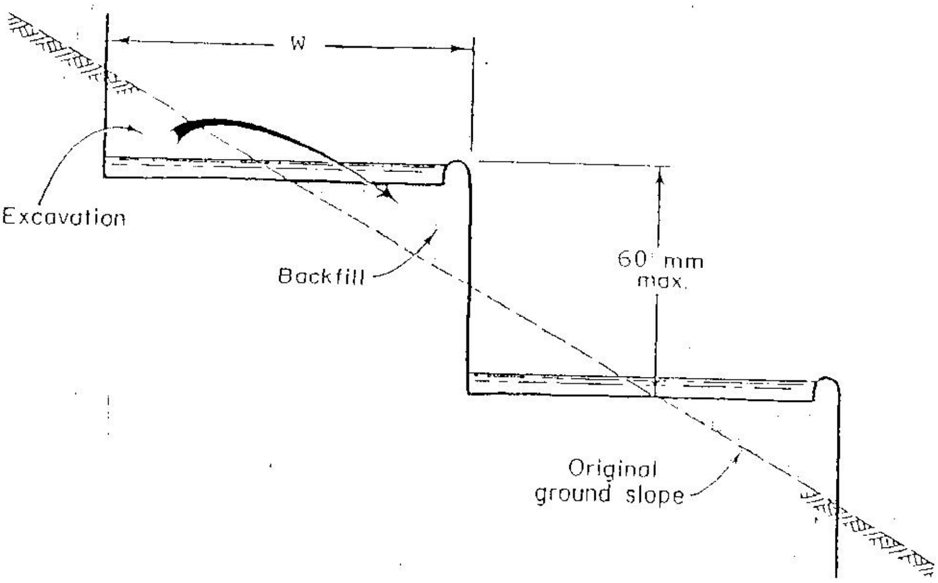


Figure 3 A Staircased Border.

The step between each border is usually limited to 60 mm to stop leakage through the earth bunds. This limits the width of the borders. The border width depends on a cross slope as shown in the following equation.

$$W = \frac{6}{S} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where W = Border width in m.

S = Border slope in %

For example, if there is a cross slope $S = 1$ %

$W = 6$ m.

As with basin irrigation, there are no simple calculations to help select the best dimensions for different soil types and unit stream sizes. It is usually rely on local experience or the experience of others (Table 1).

Table 1 Suggested Border Sizes

Soil type	Irrigation Depth (mm)	Slope (%)	Width (m)	Length (m)	Unit Stream (l/s/m)
Sand	100	0.2	12-30	60-100	10-15
		0.4	10-12	60-100	8-10
		0.8	5-10	75	5-7
Loam	150	0.2	15-30	90-300	4-6
		0.4	10-12	90-180	3-5
		0.8	5-10	90	2-4
Clay	200	0.2	15-30	350+	3-6
		0.4	10-12	180-300	2-4

For example using Table 1 when an irrigation depth of 100 mm is required on a sandy soil sloping at 0.2 %, a border of length 60-100 m is needed with a unit stream size of 10-15 l/s/m. On a clay soil the unit stream can be lower 3-6 l/s/m and the border needs to be much longer (350 m or more).

2.2 Field Shape and Size

This may be a practical limit to the size and shape of borders. In small fields borders may be as long as the field of different lengths if the field is an irregular shape (Figure 4). In large fields a common practice is to divide the land into two or more equal lengths. This makes it easier to deliver the same amount of water to each border.

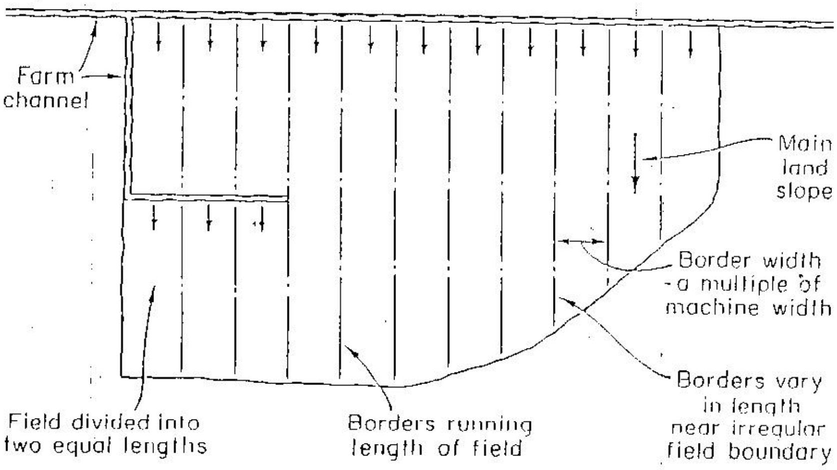


Figure 4 Effect of Field Size and Shape on Border Size

2.3 Farming Practice

Border irrigation tends to be used mainly on the larger farms because of the long lengths needed for good water distribution. For this reason they are also very suitable for mechanised agriculture. Border widths should be some multiple of the machine used as shown in Figure 5.

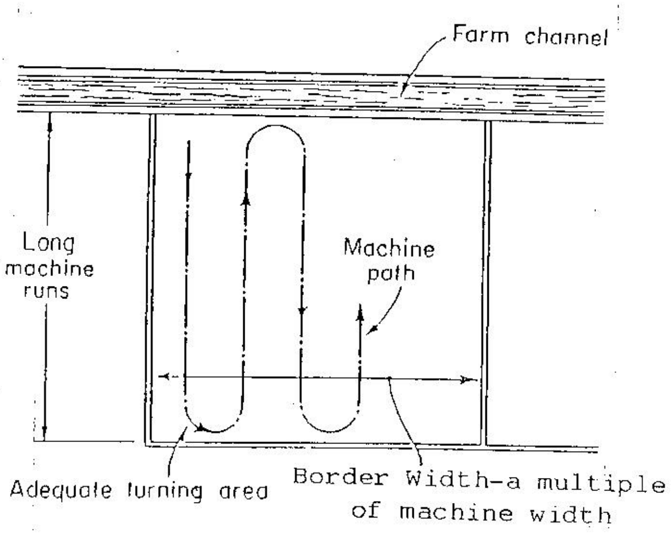
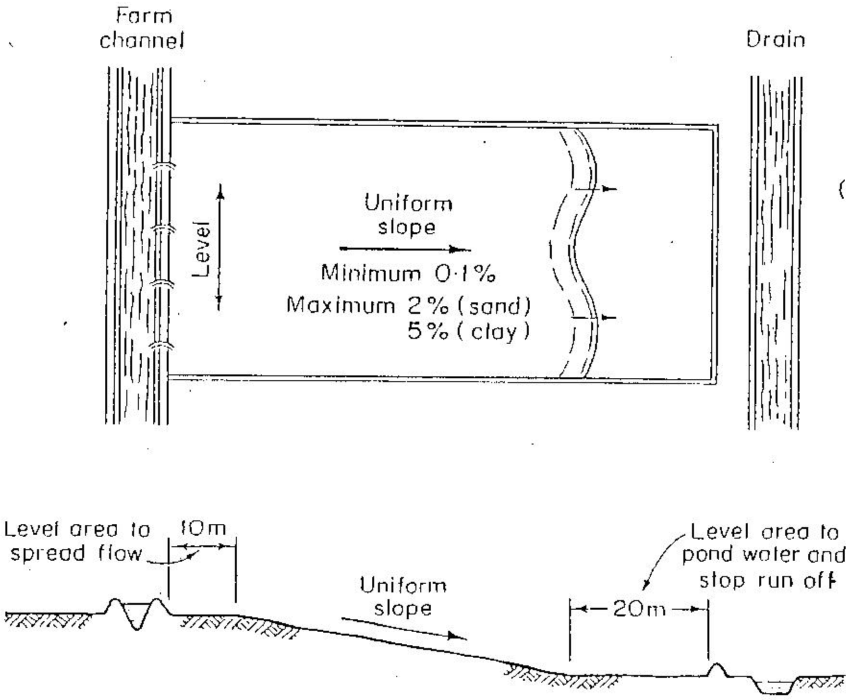


Figure 5 Border Width for Mechanized Farming

3. Slope

Ideally borders should have a uniform slope along the length and nc cross slope (Fugure 6).



(a) Typical border

(b) Section along border

Figure 6 Border Slope

The minimum slope is usually 0.1 %. This ensures that water will flow down the border and any excess water can be easily drained.

The maximum slope depends on the risk of soil erosion. This depends on rainfall, soil type and crop cover (Table 2). A good crop cover for reducing erosion is grass or lucerne.

Table 2 : Maximum Land Slopes for Borders (%)

	Humid areas		Arid areas	
Soil type	Bare soil	Good crop cover	Bare soil	Good crop cover
Sand	0.3	1.0	1.0	2.0
Clay	0.5	2.0	2.0	5.0

When it is practicable, borders should be straight and aligned down the main field slope to eliminate any cross slope. This ensures that water flows evenly across the entire width of the border. Land slopes can be changed in a field by careful preparation but this work can be difficult and costly.

Some irrigators prefer the first 10 m along the border to be level as this helps to spread the water evenly across the border width. The last 20 m or so can also be levelled so that water can be ponded, as in basin irrigation, and run-off avoided (Figure 6 b).

4. Irrigating Border

When irrigating borders it is important to use the right unit stream size for the soil and land slope and to stop the flow at the right time so that just enough water infiltrates to fill the soil reservoir.

Deciding when to stop the flow can be a problem. If the flow is stopped too soon water may not even reach the end of the border. If it is left flowing too long, water will run off the end of the border. Irrigators often rely on general guidelines to decide when to stop the flowe as follows:

Soil Type	Stop the flow when advance reaches the following portion of border length.
Clay	0.6
Loam	0.7 - 0.8
Sand	almost end of border

However, these are only guidelines. Only practice in the field will really help the irrigator to make the right decisions.

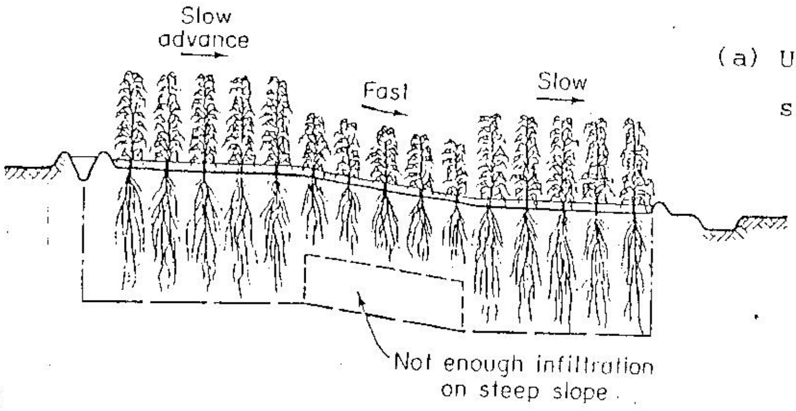
Generally, on well managed border irrigation there should be very little deep percolation loss. Some run-off can be expected but this should be no more than 10-15 % of the total amount of water applied. A small drain is needed at the end of each border (sometimes called a tail drain) to remove the excess surface water.

5. Common Faults

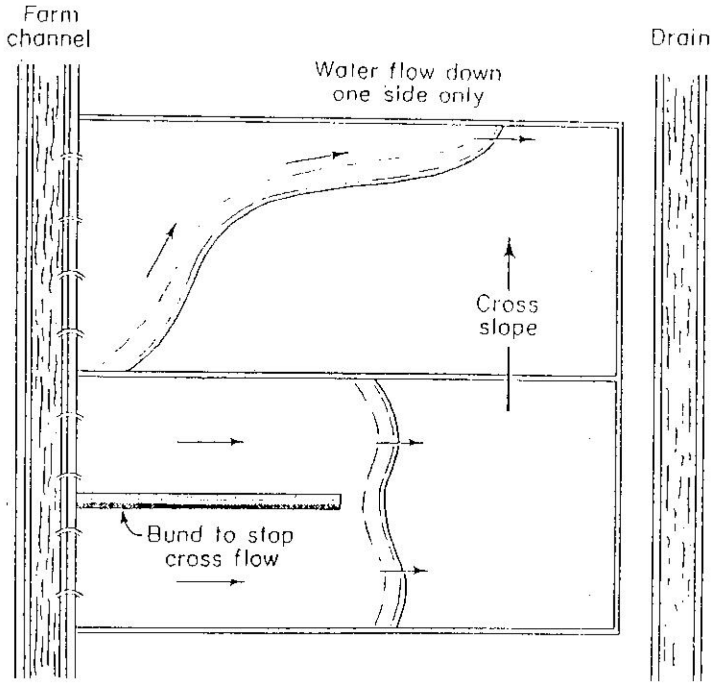
Although border irrigation can be very efficient there are many common irrigation practices which result in poor water distribution and low irrigation efficiency. Some of these are described below.

5.1 Poor Land Preparation

When a border slopes unevenly the flow down the border is also uneven (Figure 7). It flows slowly down the gentle slopes and faster down the steeper slopes. This affects the time available for infiltration and results in a poor distribution of water.



(a) Uneven border slopes



(b) Effect of cross slope

Figure 7 Common Fault - Poor Land Preparation

An uneven land surface having small depressions or high ground results in an uneven water distribution and water wastage in the same way as in basin irrigation.

A cross slope in a border also causes problems. Water tends to flow down one side resulting in poor distribution across the borders (Figure 7 b). This can sometimes be corrected temporarily by constructing a bund down the border to stop the cross-flow.

All these faults can be corrected by careful land preparation.

5.2 Different Soil Types along Border

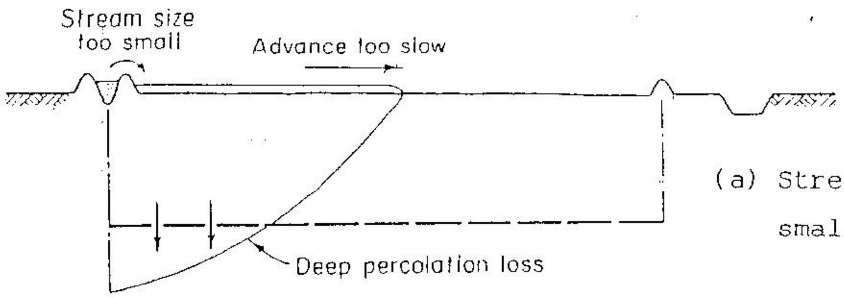
The effect of this is very similar to that in basins (section 9.2). Water distribution can be very uneven. The only solution is to realign the borders so that they contain only one soil type.

5.3 Using the Wrong Stream Size

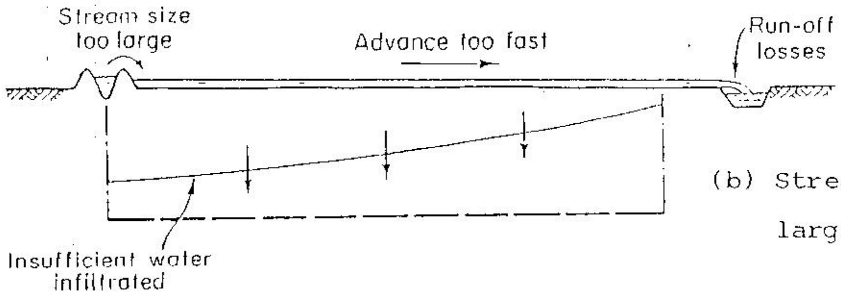
Once a border system has been installed the stream size is the only factor that can easily be changed.

Too much water applied usually means that the stream size is too small. The water takes a long time to flow down the border and reach some point when the inflow can be stopped. As a result too much water flows into the border and is lost as deep percolation (Figure 8 a).

A larger stream size would reduce these losses. The water would flow much faster and reach the point when the inflow can be stopped much sooner. As a result less water would flow into the border and the losses would be reduced. This problem usually occurs on sandy soils.



(a) Stream size too small



(b) Stream size too large

Figure 8 Common Falut-Using the Wrong Stream Size

It seems strange at first to think that using a larger flow will reduce water losses. However, the larger flow is used for a much shorter time. The discharge is higher but the volume of water required is much less.

Applying too little water usually means that the stream size is too large. The water flows too quickly down the border and reaches the point when the inflow should be stopped before sufficient water has time to infiltrate (Figure 8 b). If the water is left flowing to give more time for infiltration then some will run off the end of the border. A smaller stream size would reduce these losses. Water would flow more slowly down the border giving more time for infiltration and reducing runoff. This is usually a problem on clay soils. A level area at the end of the border would allow water to be ponded and stop any run-off occurring.

To summarise :

Large stream sizes apply small irrigation depths.

Small stream sizes apply large irrigation depths.

5.4 Fixed Irrigation Schedule

Although the right stream sizes are used, some irrigators choose the irrigation time to fit in with other farm work rather than on the irrigation needed. Irrigation times to a fixed schedule such as 12 or 24 hours are common when only 6-10 hours are really needed. A lot of water can be wasted by this practice and fertilizers can also be washed out of the soil.

6. Efficiency

On well managed borders the irrigation efficiency can be as high as 80 %. When borders are not used properly the efficiency can be much lower. The following are guidelines on the effects of poor practice on irrigation efficiency. The figures should be subtracted from 80 %.

Common faults	Subtract
Poor land preparation	10-20%
Different soil types along border	5-10%
Using wrong stream size	10-15%
Fixed irrigation schedule	10-20%

7. Border Irrigation Evaluation

After the border strip was designed and prepared based on the aformentioned procedure, the designed border should be evaluated under actual field conditions to check how well the border operates and to detect the problems and finally how to improved the existing border.

7.1 Required Data

In the border trial, the following data and information must be collected.

1. Stream size and water application time for each border. If the trial purpose is to determine a proper border size. The size should be selected from Table 1 , but should have a length a little bid longer. At least 3 border trials should be conducted. Each border should have the same slope and other properties but different stream sizes, namely larger, equal to and smaller than the recommended table values.

2. Advance and recession curves.
3. Infiltration characteristics of soil.
4. Width of flowing water if not completely flooded.
5. Depth of water applied to bring the soil moisture to field capacity.
6. Time and rate of runoff at the tail end.
7. Soil texture and profile.
8. Crop growth stage and its effect on flow retarding.

Analyze the effectiveness of irrigated border and determine the improved technique.

7.2 Required Equipments

1. A surveying tape
2. Stakes with hammer
3. A watch
4. Flow measuring flumes
5. A shovel
6. Soil core sampler
7. Infiltrometer with a hook gauge
8. Recording forms

7.3 Field Procedure

A border trial should be conducted when the soil moisture content is decreased to the level where irrigation should start. Before releasing water to the border, one must prepare the following things:

1. Select representative borders.
2. Measure the width of border.
3. Set stakes at 20-30 m. interval start from the upper end, at least 10 stakes.
4. Measure soil moisture deficiency.
5. Choose stream size.
6. Install double ring infiltrometer at 3 different location.

Start irrigating the borders by maintaining the constant application rate and record the following data:

1. Time when irrigation starts and application rate.
2. Advance time, use average water front.
3. Time when runoff starts and measure runoff rate periodically

4. Time when irrigation stops and recession times.

5. Check adequacy of irrigation 1-2 dats after irrigated using soil probe.

1.4 Analysis of Data

1. Cumulative infiltration curve.
2. Advance and recession curves.
3. Uniformity of water application.
4. Application efficiency.
5. Adequacy of irrigation.
6. Recommendations for improvement.

8. Example of Border Irrigation Evaluation

The following example shows how to determine uniformity, efficiency and adequacy of water application and how to improve border irrigation based on the field border trial. The trial uses only one border since the discharge of the ground water well is limited. Other data are given below :

- Distance from center to center of bunds is equal to 8 m, but the border width is 7 m.
- Total border length is 420 m but only the first 210 m is used for trial.
- Application rate 34 lps.
- Root zone depth 1.50 m.
- Soil texture is sandy loam.
- Soil moisture deficiency is 70 mm.
- Use 30 x 90 cm cut throat flumes.

The infiltration data are shown in Table 3. The cumulative infiltration are plotted in Figure 9 and lebelled a "typical" line.

The advance and recession data are shown in Table 4 and are plotted in Figure 10.

Table 3

Cylinder Infiltrometer Data

Location KU, KPS. Observer VARAWOOT Date 7 July 1992

Soil Texture Sandy Loam Soil Moisture 70 mm/m.

Crop Types Corn Remarks : High soil moisture content left.

Cylinder No. I					
Time - min.			Infiltration (mm.)		
Watch	Diff.	Cumu.	Depth	Diff.	Cumu.
11:03			31	0	0
04	1	1	35	4	4
08	4	5	42	7	11
18	10	15	54	12	23
28	10	25	63	9	32
48	20	45	78	15	47
12:13	25	70	95	17	64
48	35	105	117	22	86
13:28	40	145	133	16	102
14:08	40	185	148	15	117
38	30	215	158	10	127

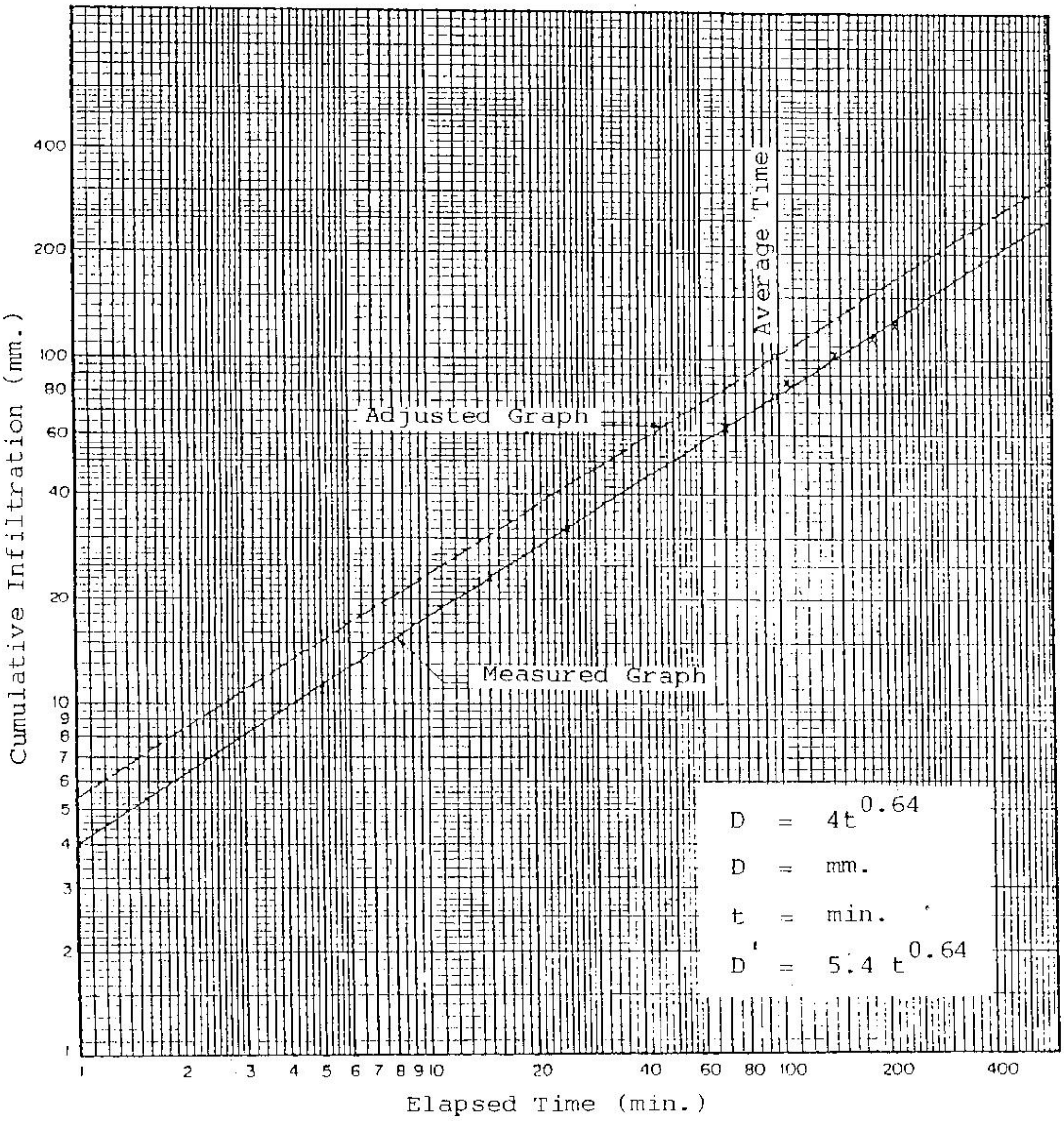


Figure 9 Cumulative Infiltration Curves

Table 4

Water Advance and Recession Data for Border Irrigation

1. Location KU, KPS., Observer VARAWCCT, Date 7 July 1992
2. Crop and Condition Corn, Border condition USED
3. Border: spacing 8 m, strip width 7 m, wetted width 7 m, slope 0.2 %
4. Irrigation: duration 7, frequency 7, water spread UNIFORM
5. A: Advance B: Recession C: Advance D: Recession
Stream Stream

Time _ min.			Station	Time _ min.			Station	Time _ min.			Station	Time _ min.			Station
Watch	Diff.	Cumu.		Watch	Diff.	Cumu.		Watch	Diff.	Cumu.		Watch	Diff.	Cumu.	
10.51		0	0	10.51		0	0								
59	8	8	1	12.19	88	88	0								
11.11	12	20	2	27	8	96	0								
26	15	35	3	59	32	128	1								
41	15	50	4	13.18	19	147	2								
58	17	67	5	29	11	158	3								
12.16	18	85	6	35	6	164	44								
36	20	105	7	38	3	167	5								
13.01	25	130	8	42	4	171	6								
32	31	161	8.5	44	2	173	7								
				44	0	173	8								
				13.41	3	170	8.5								

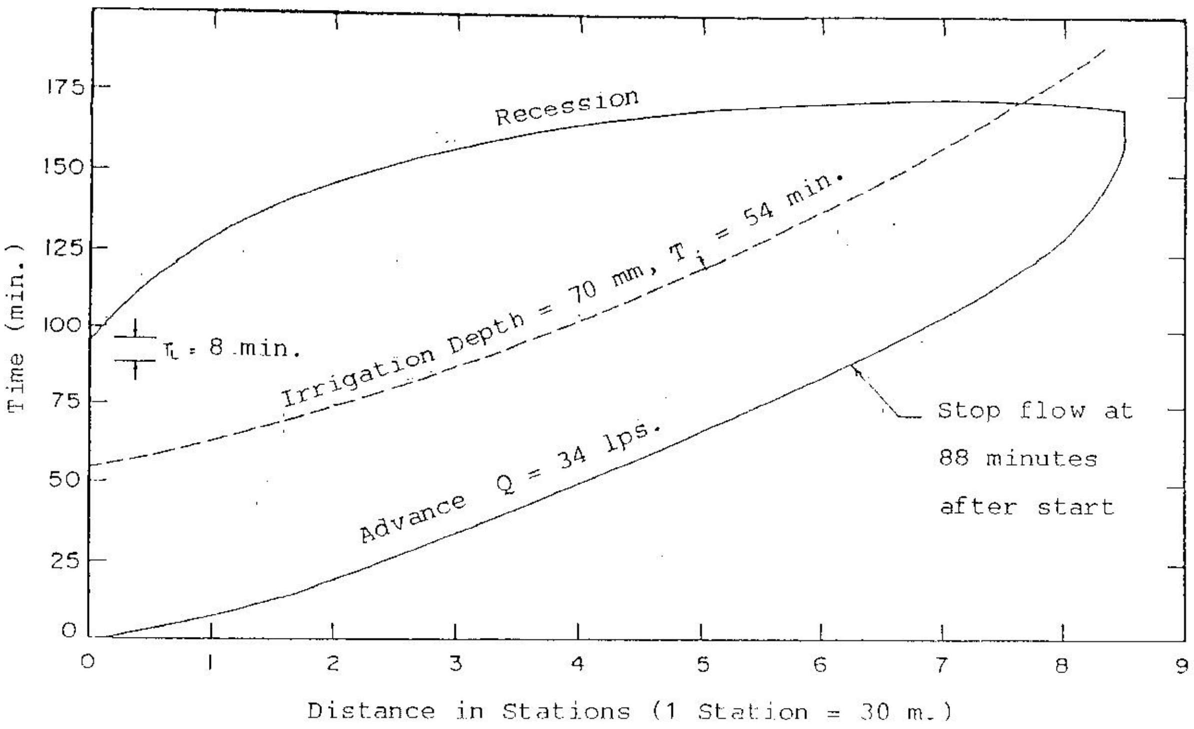


Figure 10 Advance-Recession Curves

8.1 Adjustment of Cumulative Infiltration Curve

From the advance and recession curves in Figure 10, the opportunity time at different stations can be obtained. Afterward the cumulative infiltration depths can be determined using the "typical" cumulative infiltration curve in Figure 9 as shown in Table 5.

Table 5 Calculation of Average Depth Infiltrated in Border

Station (i)	To_i (min.) (From Figure 10)	D_i (mm.) (Typical Curve)	D_i (mm.) (Adjusted Curve)
0	96	78	102
1	120	90	118
2	127	94	112
3	123	92	120
4	114	88	113
5	100	80	104
6	86	74	96
7	68	64	82
8	43	46	60
8.5	9	17	22

From the typical curve

$$\bar{D}_{8.5} = \frac{\frac{78}{2} + 90 + \ldots . \; 64 + \frac{46}{2} + (\frac{46}{2} + \frac{17}{2}) \times 0.5}{8.5} \text{ mm.}$$

$$= \frac{659.75}{8.5} = 77.6 \text{ mm.}$$

Total depth applied measuring by cut throat flume can be calculated by the following equation :

$$Q.T = A.D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$A = 7 \times 8.5 \times 30 \text{ m}^2.$$

$$D = \frac{34 \times 88 \times 60}{7 \times 8.5 \times 30} = 100.6 \text{ mm.}$$

The total depth applied (D = 100.6 mm.) is greater than the total depth infiltrated ($\bar{D}_{8.5}$ = 77.6 mm.), despite they should be equal. It is considered that the calculated infiltration depth may not be as accurate as the cut throat flume measured depth. The "typical" cumulative infiltration curve and formula should be adjusted. The adjustment can be done graphically by drawing an "adjusted" line parallel to the "typical" line through the depth of 100.6 mm. at 95 minutes, the time at which the "typical" line has average depth of 77.6 mm. The adjusted curve will be used for further analysis.

To check the correctness of the adjusted curve, the infiltrated depths are recalculated using the adjusted curve in Figure 9 as shown in the last column of Table 5. The average depth infiltrated can be calculated as follow :

$$\bar{D}_{8.5} = \frac{\frac{102}{2} + 118 + \ldots . + 82 + \frac{60}{2} + (\frac{60 + 22}{2}) \; 0.5}{8.5}$$

$$= \frac{856.5}{8.5} = 100.8 \text{ mm.}$$

$\bar{D}_{8.5}$(adjusted) is very close to the total depth applied (100.6 mm.), therefore the adjustment is accepted.

8.2 Uniformity of Water Application

Distribution Uniformity (DU) is used to calculate the uniformity of water application by border trial.

$$DU = \frac{\bar{D}_{LQ}}{\bar{D}} \times 100\ \%$$

where

DU = Distribution Uniformity (DU)

$\bar{D}_{LQ}$ = Average Low Quarter Depth (mm.)

$\bar{D}$ = Average Depth Infiltrated (mm.)

Plot D_i from Table 5 versus i to show the infiltrated depth pattern as in Figure 11.

Border length for trial = 210 m. or 7 stations

$\bar{D}_{LQ}$ = Average low quarter depth $(\frac{L}{4})$

$$\frac{L}{4} = \frac{7}{4} = 1.75 \text{ stations}$$

$$D_{5.25} = 104 - (104 - 96) \times 0.25$$

$$= 102 \text{ mm.}$$

$$\bar{D}_{LQ} = \frac{\frac{102 + 96}{2} \times 0.75 + \frac{96 + 82}{2}}{1.75}$$

$$= 93.3 \text{ mm.}$$

$$\bar{D}_7 = \frac{\frac{102}{2} + 118 + \dots + 96 + \frac{82}{2}}{7}$$

$$= \frac{765}{7} = 109.3 \text{ mm.}$$

$$DU = 100 \times \frac{93.3}{109.3} = 85.3\ \%$$

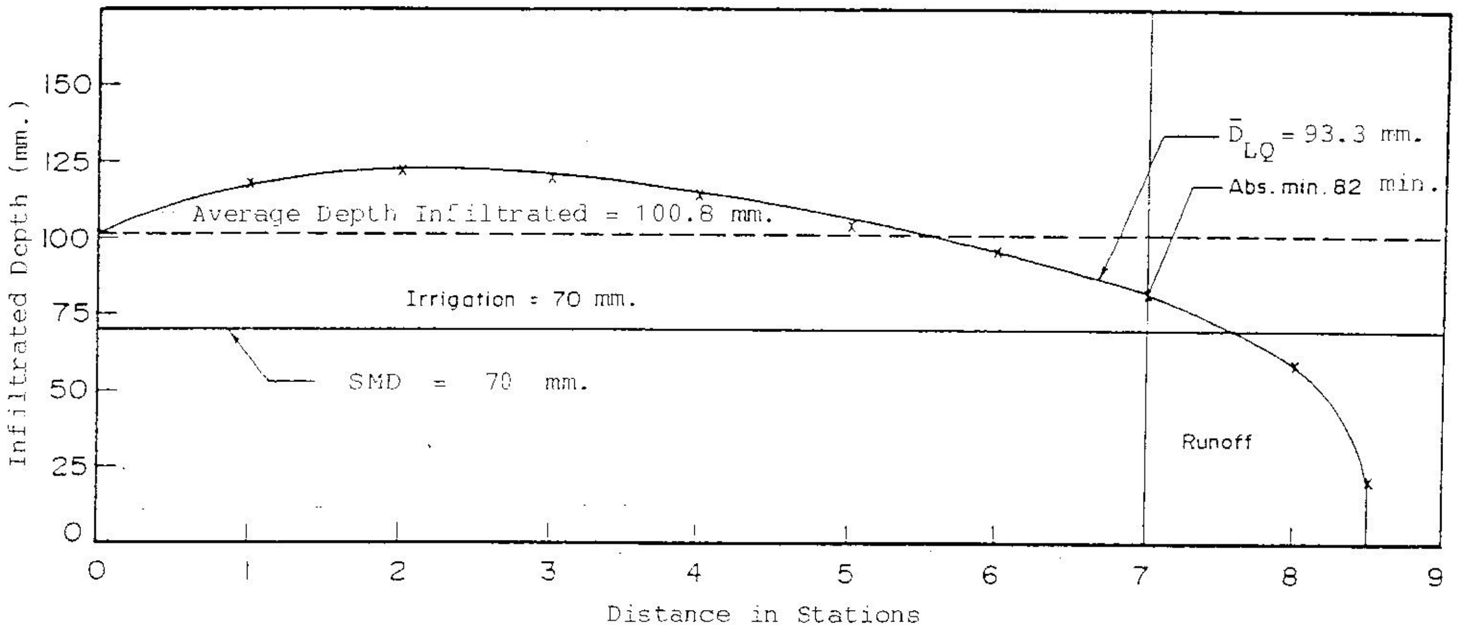


Figure 11 Infiltrated Depths at Different Stations

8.3 Application Efficiency and Storage Efficiency

Application Efficiency (Ea)

$$E_a = \frac{V_{RZ}}{V_T} \times 100 \%$$

where

V_{RZ} = Volume or Depth of Water Stored in the Root Zone

V_T = Total Volume or Depth Applied

Considering D_i from Table 5, it is over-irrigated for stations 0-7, $D_i > SMD$.

$$E_s = 100 \%$$

$$V_{RZ} = SMD = 70 \text{ mm.}$$

$$V_T = \frac{34 \times 88 \times 60}{7 \times 7 \times 30} = 122.1 \text{ mm.}$$

$$E_a = \frac{70}{122.1} \times 100 = 57.3 \%$$

8.4 Runoff and Deep Percolation Losses

The trial indicated over-irrigated and both runoff (RO) and deep percolation (DP) took place.

$$RO = V_T - \bar{D}_7$$

$$= 122.1 - 109.3 = 12.8 \text{ mm.}$$

or $$RO = \frac{12.8}{122.1} \times 100 = 10.5 \%$$

$$DP = \bar{D}_7 - V_{RZ}$$

$$= 109.3 - 70 = 39.3 \text{ mm.}$$

or $$DP = \frac{39.3}{122.1} \times 100 = 32.2 \%$$

8.5 Improved Techniques

The analysis of DU, E_a, E_s, RO and DP indicates that the actual water application trial has one important mistake. That is application time (T_a = 88 min.) too long. It results in D_i a lot greater than SMD. If the irrigation is delayed 2-3 days such that the SMD reaches 82 mm. (the minimum infiltrated depth at station 7 in Table 5). The deep percolation losses will be decreased and the E_a increases. For example,

If the irrigation is postponed until SMD = 82 mm.

$$E_a = \frac{82}{122.1} \times 100 = 67.2\ \%$$

and $$E_s = 100\ \%$$

However is the postponement of the irrigation schedule is impossible, and one wants to irrigate when SMD equal to 70 mm. The application time has to be reduced until D_7 equal to 70 mm. The suitable application time can be determined from the cumulative infiltration curve (Figure 9) and the advance curve (Figure 10).

In order to decide on the improved water application techniques which reduces the operating costs and is convenient in practices, one should know the following principles.

There are 3 factors to be considered for improving border irrigation.

(1) size of unit discharge which has effect on advance curve and application time.

(2) soil moisture depletion which effects opportunity time and irrigation frequency.

(3) length of border which can be varied using portable pipe line.

Other factors including the uniformity of soil and land slope are also important. However those factors usually remain unchange.

Conditions for just complete irrigation with high efficiency are :

(1) The opportunity time at the upper end of border must equal to the irrigation time (T_i) or the application time. (T_a) plus lag time.

$$T_o = T_i = T_a + T_l$$

(2) Every point on irrigation curve should be below the recession curve and .

(3) After the flow is stopped, the remaining water is still keeping on flowing and some water is infiltrated into the soil. According to this fact, the flow is usually closed when water flows to about 60 - 100 % of the border length. This depends on unit discharge, soil types and land slope.

(1) Choosing a Suitable Unit Discharge

From the analysis of border trial, the discharge is to small. It results in high deep percolation loss (about 30 %). Therefore the suitable discharge can be determined as shown in Figure 12.

To construct the curves in Figure 12, the following conditions are considered.

(1) Since the SMD is equal to 70 mm, a recession curve should begin at 54 minutes after the start of irrigation and the recession pattern should follow the actual trial recession curve as shown in Figure 10.

(2) At station 7, mark the advance curve at a point 54 minutes below the recession curve. This is to make sure at sufficient water is applied at the tail end of border.

(3) Draw a new advance curve similarly to the trial advance curve on Figure 10, but a little flatter because of a greater discharge.

(4) It is estimated that lag time (T_l) is equal to 10 minutes. This estimation is based on the fact that at discharge of 34 lps, the lag time is 8 minutes. If the discharge increases, T_l should be increased. Therefore the T_a is equal to 50 - 10 = 44 minutes. From the advance curve in Figure 12, it can be seen that when the flow is stopped, water advances to 4.93 stations or 148 m, or 70 % of the border length. This may be to early to stop the flow on sandy loam soil, however, this can be adjusted in actual water application.

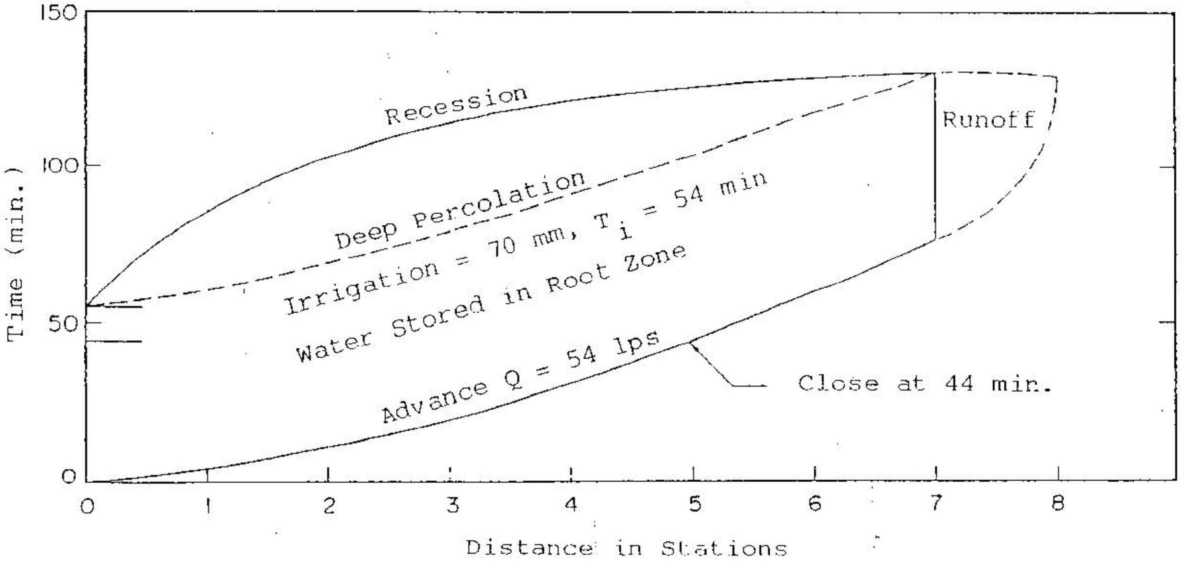


Figure 12 Adticipated Advance and Recession Curve when the Discharge Increases

Based on the new advance and recession curves on Figure 12, the average depth infiltrated can be determined as shown in Table 6.

Table 6 Calculation of the Infiltrated Depths to Determine a suitable Q

Stations	To_i (minutes)	D_i (mm.)
0	54	70
1	80	90
2	91	99
3	94	101
4	88	97
5	80	90
6	68	81
7	54	70
8	20	37

$$\bar{D}_8 = \frac{\frac{70}{2} + 90 + \ldots + 70 + \frac{37}{2}}{8}$$

$$= \frac{681.5}{8} = 85.2 \text{ mm.}$$

$$Q = \frac{7 \times 8 \times 30 \times 85.2}{44 \times 60} = 54 \text{ lps.}$$

$$q = \frac{54}{7} = 7.7 \text{ lps/m.}$$

Therefore, if the Q is fixed at 34 lps.

$$W = \frac{34}{7.7} = 4.4 \text{ m.}$$

Determine DU

$$D_{5.25} = 90 - (90 - 81) \times 0.25$$

$$= 87.75 \text{ mm.}$$

$$\bar{D}_{LQ} = \frac{\frac{87.75 + 81}{2} \times 0.75 + \frac{81 \times 70}{2}}{1.75}$$

$$= 79.3 \text{ mm.}$$

$$\bar{D}_7 = \frac{\frac{70}{2} + 90 + \ldots + 81 + \frac{70}{2}}{7}$$

$$= \frac{628}{7} = 89.7 \text{ mm.}$$

$$DU = \frac{79.3}{89.3} \times 100 = 88.4 \%$$

Determine E_a and E_s

$$V_T = \frac{54 \times 44 \times 60}{7 \times 7 \times 30} = 97 \text{ mm.}$$

$$E_a = \frac{70}{97} \times 100 = 72.2\ \%$$

The application efficiency increases 14.9 %

(2) Determine Management Allowed Deficiency

The management allowed deficiency (MAD) should vary according to the root zone depth. Since the root zone depth varies according to the stage of growth, the MAD should vary within a range suitable to the field practices, crop development stage and field application efficiency. In this border trial, water was applied when SMD is equal to 70 mm. On the sandy loam soil, the available moisture is 1.25 mm per cm depth of soil. The root zone depth is 1.50 m. If the depth of water applied is 70 mm, the MAD is equal to 37 % which is too low. If it is considered that the water should be applied when 60 % of available moisture is depleted. The MAD is equal to 0.6 x 1.25 x 150 = 112.5 mm. This MAD of 112.5 mm may be used instead of 70 mm.

The anticipated advance and recession curves when the depth applied increases to 112.5 mm are shown in Figure 13. From the cumulative infiltration curve in Figure 9, the irrigation time (T_i) is equal to 110 minutes. The new advance and recession curves are drawn exactly the same as the trial curves for the discharge of 34 lps. There is one important notice that since this case the soil moisture content before irrigation is a lot less than that of the trial. The initial infiltration rate is much larger which will result in a slower advance or the

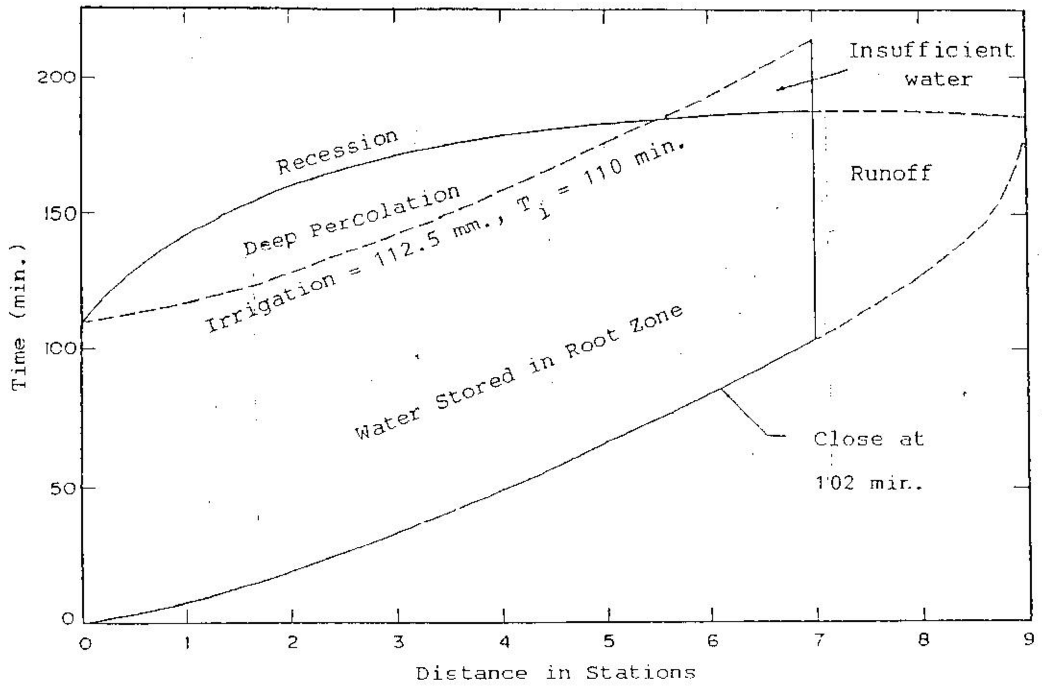


Figure 13 Anticipated Advance and Recession Curves when Increases MAD.

advance curve is steeper. Also because of longer application time, the lag time should be longer. By the same reason, the recession curve should be steeper because of longer application time resulting in smaller infiltration rate. Although the field trial curves may not be a correct one, they are accurate enough for the evaluation purposes.

Figure 13 indicates just enough irrigation on the head end, over irrigation on the upper 2/3 of the border but insufficient irrigation on the lower part of the border. A lot of runoff take place because the flow is closed when water reaches the tail and. Since the trial was conducted on the upper half of 420 m long border, the additional supply pipe at 210 m distance would increase the application efficiency. The runoff from the upper half could be utilized on the lower half and also the water supplied from the mid-field pipe would supply some water to reduce the under irrigation at the end of the first half.

Field Practice

Field Evaluation of Border Irrigation

1. Purpose

Graded border is one of the most efficient surface irrigation techniques if it is properly designed and managed. It is important that size, shape and slope of border strip must be carefully selected to suit the soil, application rate, depth of irrigation water applied, slope-shape and size of the field, cultivation practices, crops and rainfall conditions. Besides, the application rate and time must be properly chosen. As mentioned, there are so many factors effecting an irrigation efficiency of the graded border. Therefore field evaluation is necessary to determine the uniformity, adequacy and efficiency of the border irrigation system so that the evaluation results can be used to improve the effectiveness of border irrigation.

2. Required Equipments

1. A leveling surveying instrument
2. A surveying tape
3. A watch
4. 10 Stakes of 60 cm. long per border strip with a hammer
5. 2 cutthroat flumes of 30 x 90 cm. in size
6. A shovel
7. A bucket
8. A water leveling indicator
9. A soil core sampler with 5 sets of 1 + 3 + 1 - cm. Thick rings.
10. 3 sets of double ring infiltrometer

11. A 70 cm. diameter plastic sheet
12. 3 hook gauges
13. A water container of 20 lites
14. 20 of 2" diameter siphon tubes
15. A form for recording infiltration
16. A form for recording flow through cutthroat flume
17. A form for recording advance and recession.

3. Field Evaluation Procedure

1. Determine soil moisture content, bulk density, water contents at field capacity and permanent wilting point using a soil core sample. Take at least 3 samples.

2. Measure border slope.

3. Measure border width.

4. Set stakes starting from the upper end at 25 m. interval.

5. Install one cut-throat flume at the upper end and the other one at the lower end.

6. Measure infiltration characteristics using double ring infiltrometers.

7. Record time when flow was started and application rate. The application rate should be frequently checked.

8. Record time when water advances to each station. Use the average if water is unevenly spreaded.

9. Record time and runoff discharge at interval until no water flows out of the field.

10. Record time when flow is stopped and the time when water is receded at each station. Usually recession starts at the upper end first.

4. Analysis Procedure

4.1 Preliminary Analysis

1. Determine infiltration curves or formula.
2. Determine advance and recession curves.
3. Determine soil moisture depletion (SMD).
4. Adjust the infiltration curves.

4.2 Analysis of Effectiveness of Water Application

1. Uniformity
2. Irrigation Efficiency
3. Adequacy

4.3 Analysis for Improving Effectiveness

1. Changing Q
2. Changing L
3. Changing SMD

5. Recommendations

Cylinder Infiltrometer Data

Location .... Observer .... Date ....

Soil Texture .... Soil Moisture ....

Crop Types .... Remarks : ....

Cylinder No.					
Time - min.			Infiltration (mm.)		
Watch	Diff.	Cumu.	Depth	Diff.	Cumu.

Cut Throat Flume Data

Type of Flume .... Size ....

Location.. Recorder ....

D-M-Y	Time	Ha (cm.)	Hb (cm.)	Hb/Ha	Types of Flow	Discharge m^3/s

Ha - upstream head

Hb = downstream head

Water Advance and Recession Data for Border Irrigation

1. Location ________________, Observer ____________, Date ______________
2. Crop and Condition ____________________, Border condition ______________
3. Border: spacing ____ m, strip width ____ m, wetted width ____ m, slope ________ %
4. Irrigation: duration ____, frequency ______, water spread ______________
5. A: Advance B: Recession C: Advance D: Recession

Stream __________ __________ Stream __________ __________

Time _ min.			Station	Time _ min.			Station	Time _ min.			Station	Time _ min.			Station
Watch	Diff.	Cumu.		Watch	Diff.	Cumu.		Watch	Diff.	Cumu.		Watch	Diff.	Cumu.	