PLANNING FOR DEFICIT IRRIGATION

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INTRODUCTION

The Great Plains depends almost exclusively on ground water to supply the water required to sustain irrigated agriculture. Throughout the Western Great Plains, irrigation has been developed to such an extent that withdrawals for irrigation exceed the annual recharge of the aquifer. The result has been declining water levels as irrigation continues. Throughout the region, several water use allocation systems have been developed. In some areas the annual or multi-year volume of water that may be used is limited by state regulation. In other locations the capacity of irrigation wells has declined with the falling water table. In such areas the annual pumpage is limited by the capacity not by a regulated amount of water. These factors, plus rising energy costs, are causing irrigators to ask; "How much water should I apply?"

When the available water supply is limited farmers are faced with different planning decisions than historically encountered. When ample water supplies are available in non-limiting flow rates, producers are primarily interested in irrigation scheduling to determine the depth and timing of water application needed to maintain crop water use rates near those required to produce the maximum yield. If water costs are quite high the annual application may be reduced slightly below the yield maximizing amount; however, the reduction is generally not to a great extent. When the water supply is limited, the decisions required are much different. In this paper we highlight some of the basic decisions that must be considered in planning for management of deficit irrigation.

CROP RESPONSE TO IRRIGATION

Irrigation management decisions depend on how the crop responds to irrigation. This relationship is usually called the crop production function. An example of a crop production function is shown in Fig. 1 for a hypothetical crop. The figure shows that if six inches of water were applied for the season, the yield would be approximately 90 bushels/acres. If two more inches of water were applied, the yield might increase to 120 bushels/acre, giving a 30 bushel yield increase. When ten inches are applied, the yield is about 147 bushels/acre, giving an increase of 27 bushels/acre above that for eight inches. Each time an additional two inches of water is applied the yield increases, but by a smaller margin than the previous irrigation depth. The yield increases until 16 inches are applied. At that point, enough water is available to produce the maximum yield (180 bushels/acre). If more than 16 inches of water are applied, the yield does not increase above the 180 bushel/acre maximum.

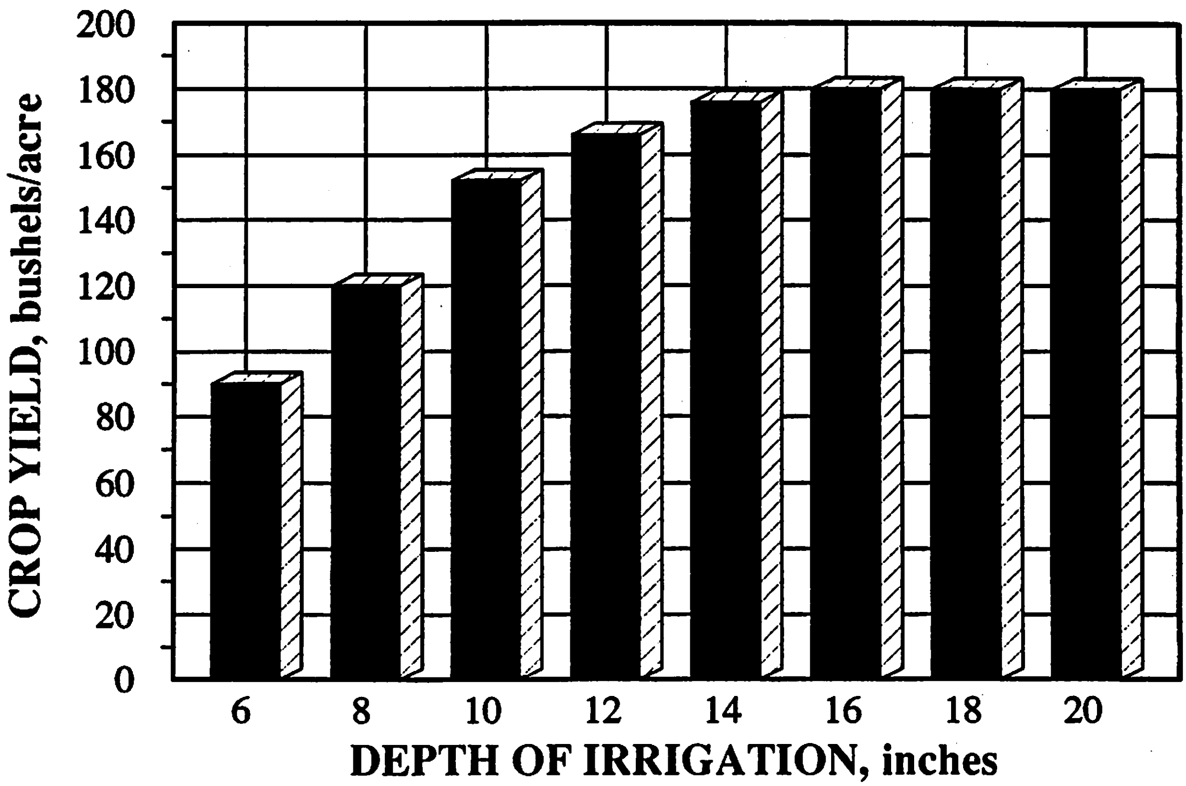

Fig. 1. Example crop production function relating yield to irrigation depth.

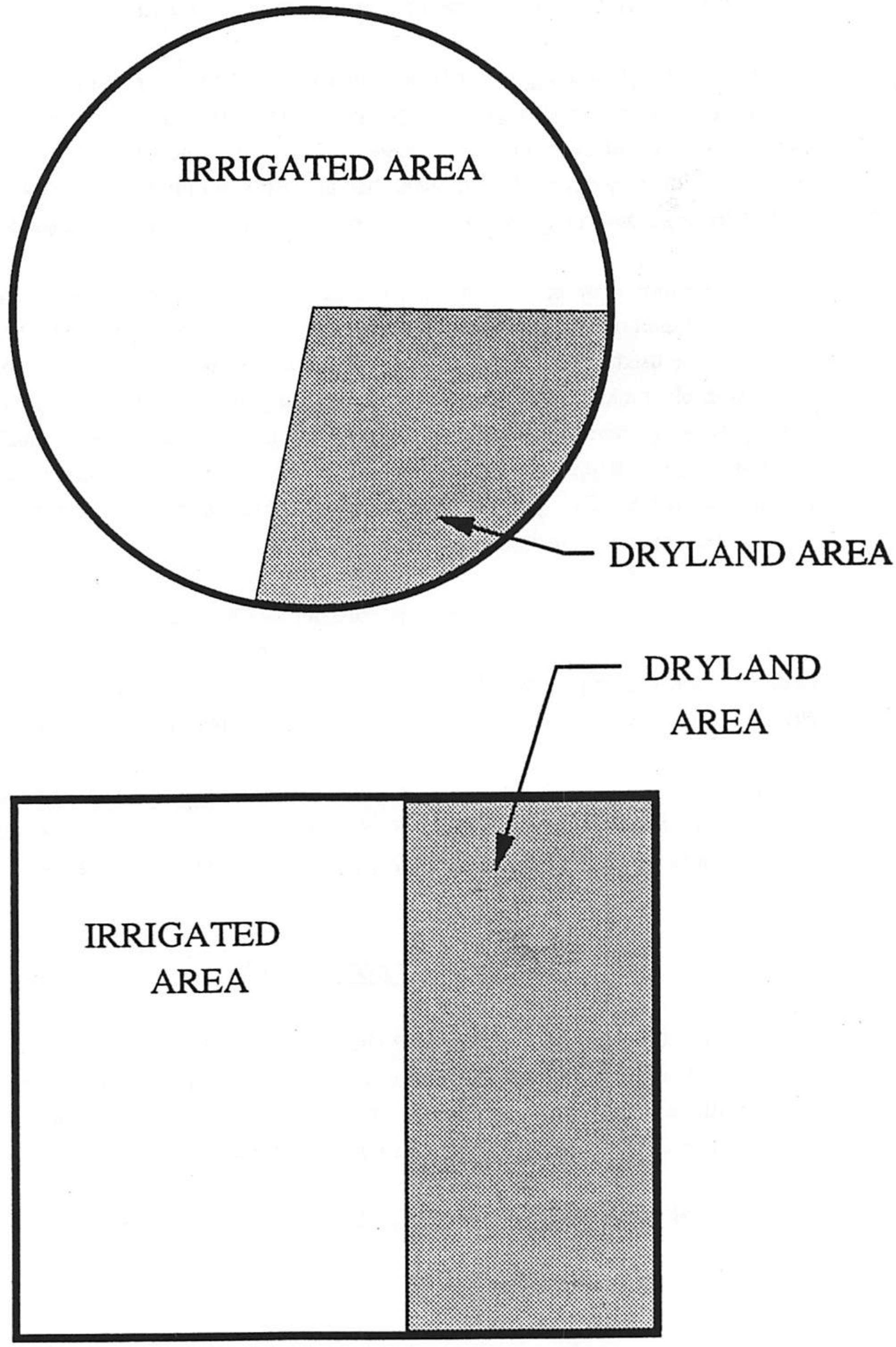

Fig. 2. Division of the irrigated field into the irrigated and dryland areas.

Although the production function shown in Fig. 1 is a hypothetical example, it illustrates that yield increases per inch of irrigation water are generally larger when small irrigation amounts are applied. The yield increase decreases to zero when the maximum yield is reached.

When water is unlimited, you only need to decide if the yield increase will pay for the cost of pumping or purchasing the water. For example, going from 14 to 16 inches produces an extra four bushels of crop. Suppose the price of the crop is $2.50/bushel. Then the income increases by $10/acre for using two inches of water. If the water costs $2/acre-inch, then the cost was only $4/acre. Since you received $10/acre and spent $4/acre, it pays to apply water up to the maximum yield for this example.

If you are limited on how much water you can apply for the season, the problem of how much water to apply to each unit of land area is more complicated. If irrigation is profitable then all of the available water supply will be used. The question is how to distribute the water supply over the area that can be irrigated. As an example, look at the increased income for going from six to eight inches in Fig. 1. Using the prices in the previous paragraph shows that the income will go up $75/acre (i.e., 30 bushels/acre x 2.50 $/ bushel), compared to only $10/acre for going from 14 to 16 inches. If you had an acre getting 16 inches and another getting six inches, you would be money ahead to reduce the irrigation on the one getting 16 inches and use that water to irrigate the one getting only six inches.

Another way to view the problem is to consider two options. Irrigate one acre with 16 inches or two acres with eight inches each. Which is most profitable? With 16 inches on one acre we produce 180 bushels, while with eight inches on two acres we produce 240 bushels. This is a yield increase of 60 bushels. Most likely it will be very profitable to irrigate two acres instead of one.

The major point is that with deficit irrigation you must consider and evaluate the amount of land area to irrigate and the amount to plant to a dryland crop (Fig. 2). It may not be optimal to plant and irrigate the entire field, or to plant a small area that produces the maximum yield per acre.

PRODUCTION COSTS

To determine how much area to irrigate you must consider how profitable the dryland crop is compared to the irrigated crop. To do this, we define a quantity called the net return from irrigation. The net return is not profit, as it only considers those costs directly associated with irrigation. If a cost does not change with irrigation depth or amount of irrigated area, then that cost will not affect how water is distributed.

For the land that is irrigated, we computed the net return using the following equation:

$$NR_{irr} = [\ V_{irr} \times Y_{irr} - PC_{irr} - C_w \times D\ ] \times A_{irr} \qquad [1]$$

where

NR_{irr} = net return for the irrigated area ($)
A_{irr} = area of land irrigated (acres)
V_{irr} = value of the irrigated crop ($/bushel)

Y_{irr} = yield of the irrigated crop (bushels/acre)
PC_{irr} = production cost per acre of irrigated land ($/acre)
C_w = cost to pump or buy a unit of water ($/acre-inch)
D = depth of irrigation water applied (inches).

The net return for dryland production is about the same as for the irrigated, except there is no cost for irrigation water. For dryland the net return is:

$$NR_{dry} = [\ V_{dry} \times Y_{dry} - PC_{dry}\ ] \times A_{dry} \qquad [2]$$

where
NR_{dry} = net return from the dryland area ($)
A_{dry} = area of dryland production (acres)
V_{dry} = value of dryland crop ($/bushel)
Y_{dry} = yield of the dryland crop (bushels/acre)
PC_{dry} = production cost of the dryland crop ($/acre).

The total net return for the field is the sum of the net return for the irrigated and dryland areas:

$$NR_{total} = NR_{irr} + NR_{dry} \qquad [3]$$

Some crop production costs are directly related to yield and are not a constant cost per acre. An example might be the cost of nitrogen fertilizer. The amount of nitrogen fertilizer needed per acre depends on the yield goal you establish. To account for input costs that are related to yield the value of the crop can be reduced from the selling price. For example, if you expect to need 1.3 pounds of nitrogen per bushel of crop produced, and if nitrogen costs 12¢/pound, then the value of the crop should be reduced by about 16¢/bushel.

WATER SUPPLY AND COST

The amount of water available for the year must be distributed over the area irrigated. Here we will assume that the water is evenly distributed so that each acre irrigated receives the same depth of water. Therefore, the area irrigated and the depth of water applied are related by:

$$A_{irr} = W_s / D \qquad [4]$$

where
A_{irr} = area irrigated (acres)
W_s = annual water supply (acre-inches)
D = depth of water applied (inches).

For example, if you have 1,000 acre-inches of water available, you could apply ten inches to 100 acres, or eight inches to 125 acres.

The cost of pumping water is approximately:

$$Cw = \frac{11.4 \times (Lift + 2.31 \times Psi) \times P_f}{K_f \times PR} \quad [5]$$

where

C_w	= cost to pump water ($/acre-inch)
Lift	= distance water is lifted to reach the pump base (feet)
Psi	= discharge pressure at the pump base (psi)
P_f	= cost of a unit of fuel or energy ($/unit)
K_f	= fuel conversion constant from Nebraska Standard
PR	= performance rating of the pump (%).

Several extension publications are available that more fully explain this calculation (see Klocke and Clark, 1988; Dorn et al., 1981; or Hay et al., 1984). For the purpose of this paper, the amount of fuel or electrical energy needed to pump the water can be estimated from Table 1.

For example, suppose the pumping information is as given in Table 2. The diesel fuel needed to pump at 100% of the Nebraska Standard is determined from the top part of Table 1. It takes about 1.97 gallons/acre-inch to lift water 100 feet and to develop a pressure of 50 psi at the pump. Since the pump operates at 85% of the Nebraska Standard, the multiplier is 1.18, so it takes about 2.33 gallons/acre-inch. If diesel costs $1.10/gallon, then the cost per acre-inch of water applied is $2.56/acre-inch. The amount of energy needed for electricity would be 27.8 kWh/acre-inch (= 1.97 gallons diesel/acre-inch x 14.12), 3.57 gallons of propane (1.97 x 1.814), etc., for the other energy sources.

ACREAGE CONSIDERATION

The area that can be irrigated with a given water supply and irrigation depth can be calculated using Equation 4. However, there are limits on using Equation 4. The first limit is the maximum area that can be irrigated. You cannot have more irrigated area than there is in the irrigated field. The second limit is not as severe as the maximum area limit, but it is unprofitable to apply more water than needed to produce the maximum yield. If you apply more water than needed, you would have to reduce the irrigated area to be sure to not use too much water. Since you don't produce more yield per acre, for this case it is very costly.

Once the irrigated area has been determined, the area of dryland production can be determined. The dryland area is:

Table 1. Energy required to lift and pressurize irrigation water.

Lift, feet	Gallons of Diesel Fuel Required to Pump an Acre-Inch of Water Assuming a 100% Pumping Plant Performance Rating — Pressure, psi: 0	5	10	15	20	30	40	50	60	70	80
0	0.00	0.11	0.21	0.32	0.42	0.63	0.84	1.05	1.26	1.47	1.69
25	0.23	0.33	0.44	0.54	0.65	0.86	1.07	1.28	1.49	1.70	1.91
50	0.46	0.56	0.67	0.77	0.88	1.09	1.30	1.51	1.72	1.93	2.14
75	0.68	0.79	0.89	1.00	1.11	1.32	1.53	1.74	1.95	2.16	2.37
100	0.91	1.02	1.12	1.23	1.33	1.54	1.75	1.97	2.18	2.39	2.60
125	1.14	1.25	1.35	1.46	1.56	1.77	1.98	2.19	2.40	2.61	2.83
150	1.37	1.47	1.58	1.68	1.79	2.00	2.21	2.42	2.63	2.84	3.05
175	1.60	1.70	1.81	1.91	2.02	2.23	2.44	2.65	2.86	3.07	3.28
200	1.82	1.93	2.03	2.14	2.25	2.46	2.67	2.88	3.09	3.30	3.51
250	2.28	2.39	2.49	2.60	2.70	2.91	3.12	3.33	3.54	3.75	3.97
300	2.74	2.84	2.95	3.05	3.16	3.37	3.58	3.79	4.00	4.21	4.42
350	3.19	3.30	3.40	3.51	3.61	3.82	4.03	4.25	4.46	4.67	4.88
400	3.65	3.75	3.86	3.96	4.07	4.28	4.49	4.70	4.91	5.12	5.33

Conversions For Other Energy Sources:

Energy Source	Fuel/Energy Unit	Multiply by
Electricity	kilowatt-hours	14.12
Propane	gallons	1.814
Gasoline	gallons	1.443
Natural Gas	1000 cubic feet	2.026

Multiplier for less than 100% pumping plant performance

Performance Rating, %	100	95	90	85	80	75	70	60	50
Multiplier	1.00	1.05	1.11	1.18	1.25	1.33	1.43	1.67	2.00

Example Calculation:

Lift = 100 feet — Pressure = 50 psi
Performance Rating = 85% — Energy Source = Electricity

Energy required for diesel at 100% performance rating is:
1.97 gallons of diesel/acre-inch.

Multiply by 14.12 for electricity:
1.97 x 14.12 = 27.8 kWh/acre-inch.

Adjust for 85% performance ratio by using the 1.18 multiplier:
Energy required = 1.18 x 27.8 = 32.8 kWh/acre-inch of water.

$$A_{dry} = A_{total} - A_{irr} \quad [6]$$

where

A_{total} = the total area that can be irrigated (acres).

EXAMPLE CALCULATION

An example of using the concepts presented in this paper are illustrated in Table 2. The top part of the table summarizes the given or available information, while the results are listed at the bottom of the Table. The example is based upon an annual supply of 1560 acre-inches of water which is equivalent to a depth of 12 inches if the entire field (130 acres) is irrigated. The crop production function used in Figure 1 is used for the crop response for this example. When less than 12 inches of water are applied the entire field can be irrigated. The yield of the irrigated crop increases as the depth of irrigation increases from 6 up to 12 inches. If more than 12 inches are applied then the amount of irrigated area must decrease because there is not enough water. The maximum yield is accomplished with an irrigation depth of 16 inches. Applying more than 16 inches would waste water since yields per acre stay the same and the area irrigated must decrease due to the limited amount of water available. So for the simplified example shown in Figure 2 there are really only three irrigation depths to consider (12, 14 and 16 inches).

The crop yield for a given irrigation depth is determined using the crop production function as shown in Fig. 1. If a depth of 12 inches was applied the crop yield is 166 bushels per acre. The area that can be irrigated with 1560 acre-inches when a depth of 12 inches is applied is 1560 acre-inches/12 inches = 130 acres. The net return from the irrigated area is computed using equation 1 which gives:

$$N_{irr} = (\, 2.25\ \$/\text{bu} \times 166\ \text{bu/acre} - 115\ \$/\text{acre} - 2.56\ \$/\text{ac-in} \times 12\ \text{inch}\,) \times 130\ \text{acres}$$

$$N_{irr} = \$29{,}611.$$

Since the entire field is irrigated when a depth of 12 inches is applied the net return from the dryland area is zero, and the total net return equals the net return from the irrigated area.

When a depth of 14 inches is applied the yield per acre increases to 176 bushels per acre. However, the area that can be irrigated decreases to 1560 acre-inches/14 inches = 111.4 acres due to the limited water supply. The net return for the irrigated area is then:

$$N_{irr} = (2.25\ \$/\text{bu} \times 176\ \text{bu/acre} - 115\ \$/\text{acre} - 2.56\ \$/\text{ac-in} \times 14\ \text{inches}) \times 111.4\ \text{acres} = \$27{,}311.$$

The dryland area will be the difference between the total area that could be irrigated and the area that is irrigated = 130 - 111.4 = 18.6 acres. The net return from the dryland area is

$$N_{dry} = (2.00\ \$/\text{bu} \times 90\ \text{bu/acre} - 38\ \$/\text{acre}\,) \times 18.6\ \text{acres} = \$2{,}641.$$

So the total net return for a depth of 14 inches is $27,311 + 2,641 = $29,952. From Table 2 the total net return for applying a depth of 16 inches to an irrigated area of 97.5 acres is $28,896.

Table 2. Data and results of deficit irrigation planning example.

PRODUCTION AND COST DATA	VALUE
Cost to Pump Irrigation Water:	
Pumping Lift, feet	100
Pressure at Pump, psi	50
Pumping Plant Performance, % of NEBR Standard	85
Cost of Diesel Fuel, $/gallon	1.10
Water Cost, $/acre-inch	2.56
Irrigated Crop:	
Crop Value Adjusted for Yield Related Costs, $/bushel	2.25
Crop Production Cost - Irrigated, $/acre	115
Dryland Crop:	
Value of Dryland Crop, $/bushel	2.00
Dryland Production Cost, $/acre	38
Dryland Yield, bushels/acre	90
Total Area That Can Be Irrigated, acres	130
Available Water Supply, acre-inches	1560

RESULTS

Irrig. Depth, inches	Irrig. Crop Yield bu/ac	Irrig. Area, acres	Irrig. Net Return $	Dryland Area, acres	Dryland Yield bu/acre	Dryland Net Return $	Total Net Return $
6	90	130.0	9,378	0.0	90	0	9,378
8	120	130.0	17,488	0.0	90	0	17,488
10	152	130.0	26,182	0.0	90	0	26,182
12	166	130.0	29,611	0.0	90	0	29,611
14	176	111.4	27,311	18.6	90	2,641	29,952
16	180	97.5	24,281	32.5	90	4,615	28,896
18	180	86.7	21,148	43.3	90	6,149	27,297
20	180	78.0	18,626	52.0	90	7,384	26,010

The total net return for applying the depths of irrigation listed in Table 2 are summarized in the graph shown in Figure 3. The results show that the net return is a maximum at an irrigation depth of 14 inches for the hypothetical crop production function shown in Figure 1. However there is little difference in total net return between a depth of 12 or 14 inches. Irrigating for maximum yield by applying 16 inches to an area of 97.5 acres results in $1000 less profit per year than if 14 inches were applied to 111 acres. The results shown in Figure 3 also illustrate that it is very costly to not use the available water supply by withholding too much irrigation. It is also costly to apply more water than is needed to produce the maximum crop yield.

It is not possible to predict the actual crop response function before the start of the growing season. The climate, especially rain, is quite variable causing projections to be off. However, the results shown in Figure 3 illustrate that it is generally better to not irrigate for maximum yield and to accept some stress over a relatively large portion of the area that can be irrigated. Planting an area that will produce the maximum yield (97.5 acres in Table 2) is perhaps the most risky policy. In dry years the decision may not be too bad. However, in wetter than normal years you will not use all of the water that has been allocated. The result is similar to applying an irrigation depth of 20 inches in Figure 3. It is not wise to irrigate the entire area in all cases either, but it is generally safer to error by planting a large area that to plant too little area.

INDIVIDUALIZED PLANNING

The results used to illustrate the concepts of planning for deficit irrigation are based on hypothetical data. Producers must estimate values that represent their own operation for meaningful results. Producers can develop reasonable estimates based upon personal experience in their area. The outline below summarizes the steps required to complete the analysis:

1. Estimate the crop response to varying depths of irrigation.

2. Determine the yield of the most profitable dryland crop.

3. Estimate the adjusted value and production costs for the irrigated and dryland crop.

4. Compute the cost to pump (or buy) irrigation water.

5. For a given water allocation compute the total net return for varying irrigation depths as illustrated in Table 2.
    a. compute the area that can be irrigated
    b. compute the net return for the irrigated area
    c. compute the area that is for dryland production
    d. compute net return for the dryland area
    e. compute the total net return.

These results can then be analyzed to determine the best area to plant and irrigate. The annual water supply should be used in the specified year unless you have a multi-year allocation, or unless smaller amounts of water produce the maximum yield per acre.

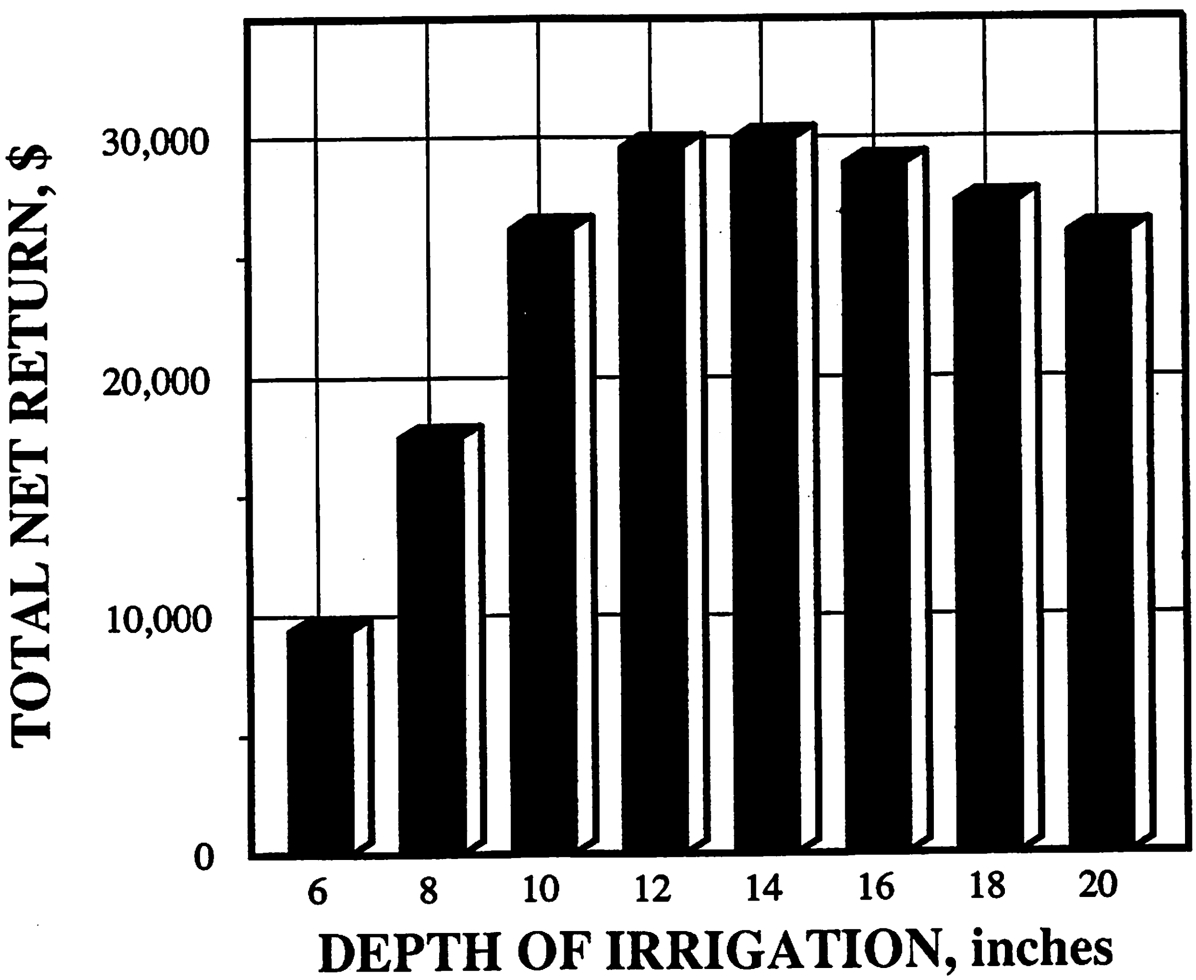

Fig. 3. Graph of total net return for the example analyzed in Table 2.

SUMMARY

When the annual supply of water is not adequate to produce the maximum yield for the entire field producers must adapt by either reducing the area irrigated or the depth of water applied to each acre, or both. The basic analysis required to plan for this type of irrigation management is summarized in this paper. A hypothetical example is included to illustrate the procedure. Results from the example will not represent general conditions in the Western Great Plains. Instead producers should develop their own estimates of yields, costs and crop values for planning. The procedure is fairly simple and very helpful in deciding on the area to irrigate when water is limiting.

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