DEFICIT IRRIGATION PLANNING

by

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Irrigation is one of the most productive and expensive agricultural practices. The current slim margins in agriculture require that irrigation alternatives be carefully analyzed. An especially important planning decision is the amount of the area to irrigate and the depth of water to apply. The loss from selecting the wrong irrigated area or depth can be quite large. If a poor decision is made at the start of the growing season the irrigator may not be able to recover during the season since the crops are already planted and a large portion of the earning potential has already been determined. Water allocation systems are beginning to be used in some regions. These programs require producers to manage a limited water supply which is not large enough to produce the maximum yield on all of the irrigable area. Limited irrigation is more risky than when the water supply is unlimited, and includes questions which most irrigators have not previously faced. A framework to determine the area of land to irrigate and the depth of water to apply will be developed in this paper. Results will be presented for conditions when either land or water is limiting. These relationships are amongst the most fundamental for deciding how to manage an irrigation system. Results of this paper may help producers understand the fundamental planning decisions.

Evaluation of planning alternatives requires a method of quantifying the economics of irrigation. The term net return will be used and is defined as the total income from a tract of land minus the irrigation related costs. The net return does not include fixed costs of irrigation, such as the cost of the land or irrigation system, and ignores any costs that are unrelated to irrigation, such as the cost of seed. It does include costs related to the decision to irrigate for a single season, and the variable cost per acre irrigated. The net return from a tract of land can be described by three factors:

Total Net Return = Net return from the irrigated area
+ Net return from the dryland area
- Startup cost of the irrigation system.

This expression shows that the irrigator may choose to only irrigate a portion of the area that the irrigation system could irrigate. It is also possible that the irrigated and dryland crop will be different.

The net return from the irrigated area can be described by:

$$\left[\begin{pmatrix}\text{Crop}\\\text{Value}\end{pmatrix} \bullet \begin{pmatrix}\text{Crop}\\\text{Yield}\end{pmatrix} - \begin{pmatrix}\text{Water}\\\text{Cost}\end{pmatrix} \bullet \begin{pmatrix}\text{Depth}\\\text{Applied}\end{pmatrix} - \begin{matrix}\text{Production}\\\text{Cost/Area}\end{matrix}\right] \bullet \begin{pmatrix}\text{Area}\\\text{Irrigated}\end{pmatrix}$$

The net return from the dryland area is:

$$\left[\begin{pmatrix}\text{Dryland}\\\text{Crop}\\\text{Value}\end{pmatrix} \bullet \begin{pmatrix}\text{Dryland}\\\text{Yield}\end{pmatrix} - \begin{matrix}\text{Production}\\\text{Cost/Area}\end{matrix}\right] \bullet \begin{pmatrix}\text{Dryland}\\\text{Area}\end{pmatrix}$$

The production cost per unit area for the irrigated crop and the dryland can be quite different, not only because the crops are different, but also because the anticipated yield from the dryland crop is less than expected from the irrigated tract. Thus, there may be differences in the cost per unit area for fertilizer, pesticides and tillage. The annual cost per acre to install and maintain an irrigation system should also be included into the production cost for the irrigated area. For example, the cost to ditch and install gated pipe depends on how many acres are to be furrow irrigated.

The startup cost of the irrigation system is due to factors that must be paid annually if the irrigation system is used. If no irrigation were applied these costs could be avoided that year. Note that these costs are not based upon the area irrigated but the decision to irrigate. An example of such a cost would be the connect charge for an electrically powered irrigation pump. In some cases, it is possible to avoid this cost if a field is not irrigated that season. However, if only 10 acres of the field are to be irrigated the same connect charge, startup cost, must be paid as if the entire 130 acres of a pivot were irrigated. Other examples would be the cost of rebuilding engines, or re-nozzling pivots since these expenditures probably would not be made in a year when you did not plan to use the irrigation system.

An example may help clarify the method used to compute the net return from irrigation. Suppose the data in Table 1 are available for a pivot irrigated field of 130 acres. Then the net return would be

= [2.5 $/bu · 160 bu/ac - 1.4 $/ac-in · 16 in - 115 $/acre] · 100 ac

+ [2.0 $/bu · 50 bu/ac - 38 $/ac] · 30 acres - 1800 $/year

= $26,320

The value of the net return is a large number since it does not include other, non-irrigated related, costs. However, the net return contains the relevant terms to describe the influence of irrigation alone upon profit.

Table 1. Example data used to calculated the net return for a 130 acre center pivot irrigated field.

QUANTITY	VALUE
value of irrigated crop	2.5 $/bushel
irrigated crop yield	160 bushels/acre
cost of irrigation water	1.4 $/acre-inch
depth of irrigation	16 inches
production cost of irrigated crop	115 $/acre
irrigated area	100 acres
value of dryland crop	2.0 $/bushel
yield of dryland crop	50 bushels/acre
production cost of dryland crop	38 $/acre
dryland area	30 acres
connect charge for pivot and pump	1800 $/year

Evaluation of irrigation alternatives also requires a relationship of crop yield to the amount of irrigation applied. This relationship changes from year to year and varies with the soil type. In general a diminishing return relationship exists as illustrated in Figure 1 for an example corn crop. For this example the yield that results for two inch increments of irrigation is shown. The first two inches of water applied produced 62 bushels of grain. The second two inch increment, from 2 to 4 inches, gave an additional 26 bushels/acre for a total yield of 88 bushels/acre. The final two inch increment, from 14 to 16 inches, only increased the yield from 158 to 160 bushels/acre. When the yield and net return expressions are combined the net return from a specific amount of irrigation can be estimated.

MANAGEMENT WHEN LAND IS LIMITING

Traditionally seasonal water availability has not limited irrigation management and producers have learned to manage what is called the land limiting case. With the land limiting case the objective is to maximize the net return produced per unit of land. This can be explained by considering the situation described in Figure 2. Consider an irrigable tract of land that is planned for production. Part of the land could be irrigated and part could be left for dryland, but the irrigation system is available to irrigate the entire area.

The first consideration is to determine the net return produced if the entire area were left to dryland production. Using data from Table 1 the net return if the entire area were dryland would be

$$= [\ 2.0\ \$/\text{bu} \cdot 50\ \text{bu/a} - 38\ \$/\text{acre}\ ]\ 130\ \text{acres} = \$\ 8060.$$

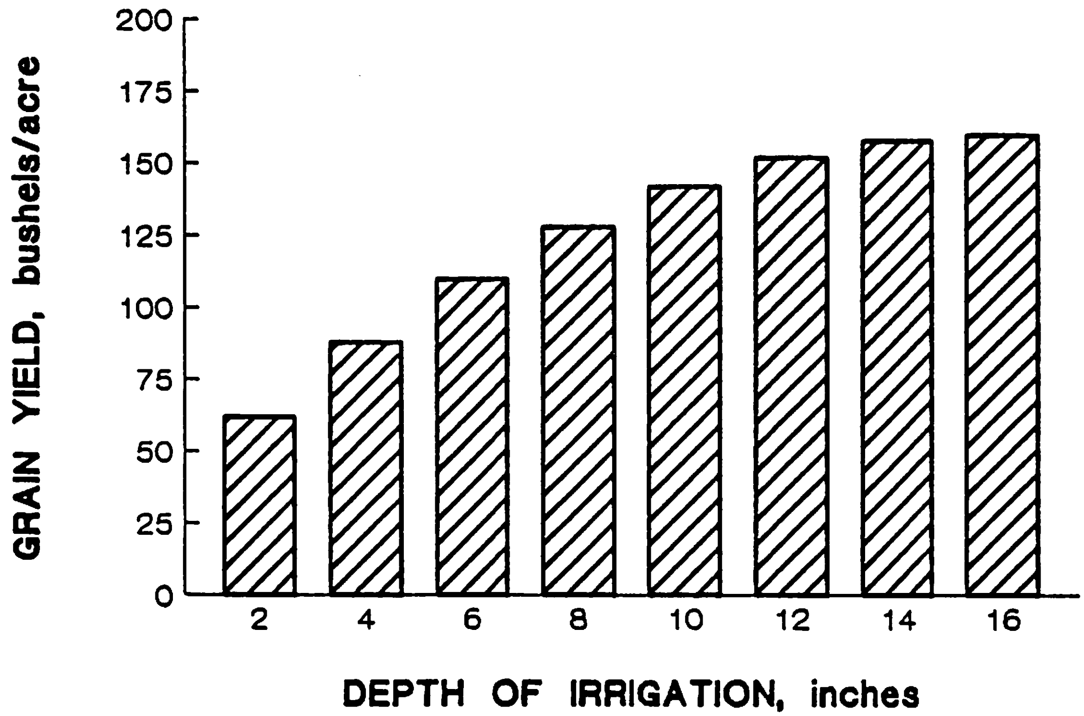


Figure 1. An example of the yield response of corn to irrigation.

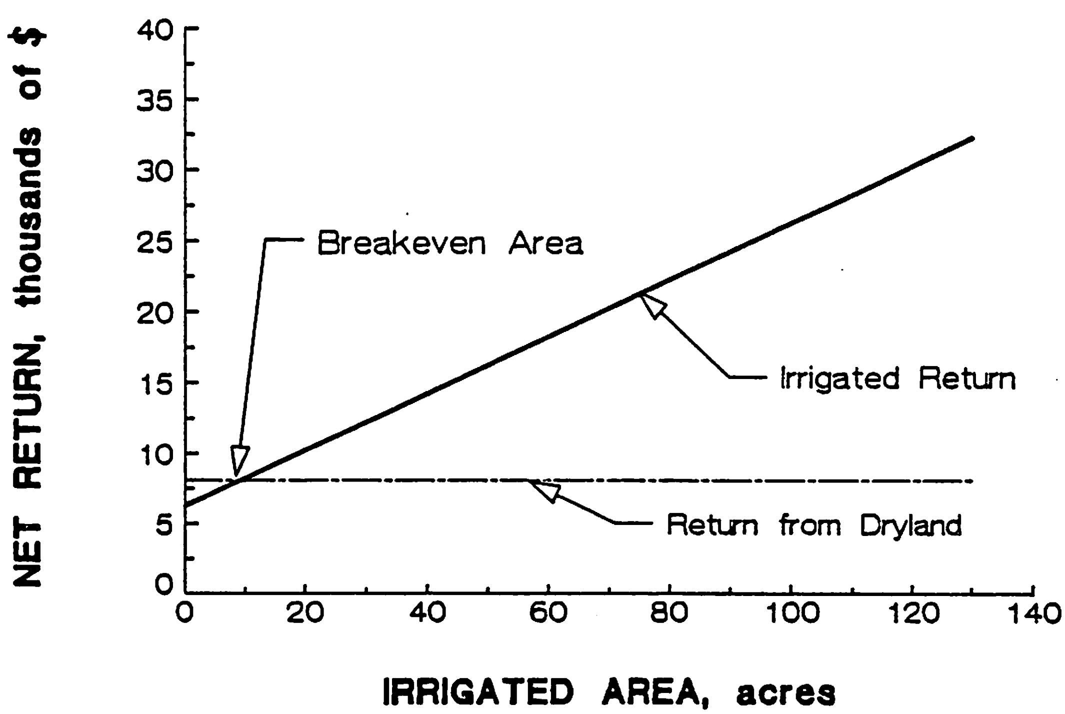


Figure 2. Net return as a function of the irrigated area and when the entire area is dryland when water is unlimited.

Irrigation alternatives that produce less net return than dryland should not be considered. Suppose that the irrigator planned to irrigate 5 acres with enough water to produce the optimal yield (i.e. using 16 inches) and that the rest (125 acres) will be dryland. The net return would be

= [2.5 \$/bu · 160 bu/ac - 1.4 \$/ac-in · 16 in - 115 \$/ac] · 5 ac

+ [2.0 \$/bu · 50 bu/ac - 38 \$/acre] · 125 ac - 1800 \$/year

= \$ 7263.

Thus, irrigating only 5 of the 130 acres results in less income than the producer would have realized for dryland production on the entire area.

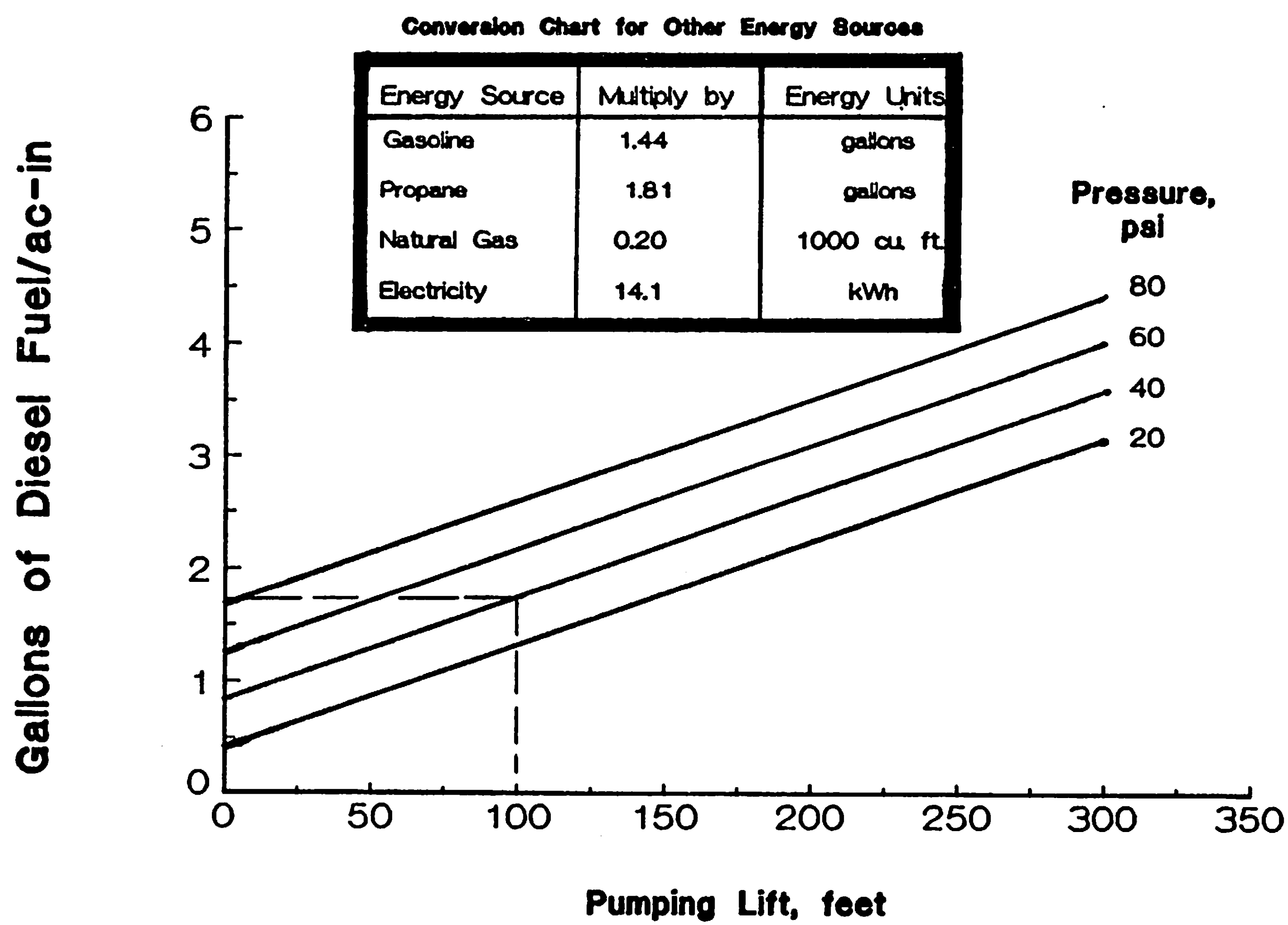
This example shows that when watered for the maximum yield the return from the irrigated area is \$262.60/acre and \$62/acre for the dryland. Enough area has to be irrigated to overcome the initial startup cost of \$1800 before irrigation is feasible. The breakeven irrigated area would be \$1800 / (262.60 - 62 \$/ac) or approximately 9 acres as shown in Figure 2. The breakeven area is small for this example and would not be considered by many irrigators. The breakeven area may be more important for other systems, or different costs and prices.

The irrigated net return shown in Figure 2 increases constantly as more acres are irrigated. In other words, there is a positive return of about \$200, above that for dryland, for each acre irrigated. Thus, it is advantageous to irrigate the entire irrigable area, in this case 130 acres, since that is where the total net return is the largest.

The other remaining question involves the appropriate depth of irrigation to produce the maximum net return. When water is readily available each increment of irrigation applied should produce enough product to at least pay for the water. If the water costs more than it produces in grain value it would obviously not be reasonable to apply that much water. However, if the water more than paid for its cost then it should be applied.

We can generally assume that the cost of an acre-inch of water is constant for irrigation systems. The primary component of the cost of water is the energy to lift and pressurize the water. The amount of energy required to pump an acre-inch of irrigation water, when using a pumping plant that meets the Nebraska Standard, can be determined from Figure 3. If other costs such as repair and maintenance, labor, etc. are to be included, or if the pumping plant is less efficient than the Nebraska Standard, the water cost per acre-inch would increase. Be sure that the annual cost of the irrigation system, land, etc. are NOT included in the water cost.

Consider, for example, a system where the cost of diesel fuel is \$0.80/gallon and a center pivot operates at 40 psi with a pumping lift, from the groundwater to the soil surface, of 100 feet. The cost of pumping one acre-inch of water for this system would be:



Conversion Chart for Other Energy Sources

Energy Source	Multiply by	Energy Units
Gasoline	1.44	gallons
Propane	1.81	gallons
Natural Gas	0.20	1000 cu. ft.
Electricity	14.1	kWh

Figure 3. Energy required to pump irrigation water. To convert to other energy sources, multiply by the given factor.

= (0.8 \$/gal) · [1.75 gallons of diesel/acre-inch]

= 1.40 \$/acre-inch.

If propane were used instead the fuel requirement would be 1.75 gallons of diesel fuel/acre-inch · 1.81 = 3.17 gallons of propane/acre-inch.

In Figure 1, the last two inch increment of water (i.e. going from 14 to 16 inches) produced about 2 bushels of corn. If the value of the corn is 2.5 \$/bushel, then the two inches of water would have generated \$5.00 of income while only costing an additional \$2.8. It would obviously be advantageous to apply the final two inches of water. In fact, the value of the crop would have to drop below 1.40 \$/bushel before the water would cost more than it generates in income.

Even though this example is only one representative case, it illustrates what is generally found when analyzing land limiting conditions. Three factors can be summarized from the analysis:

1) the optimal irrigation depth is very near the depth required to produce the maximum crop yield,

2) the entire area should be irrigated as long as it is above the breakeven acreage.

3) irrigation should not be considered if the net return from dryland is greater than that for irrigation, i.e. the irrigated area should be larger than the breakeven area, and

WATER LIMITING CASE

The most dynamic and difficult water management decisions deal with maximizing the net return for deficit irrigation. Planning the area to irrigate and the depth of water to apply are much more difficult because of the variability from year to year. If one plans anticipating an average year, but more than average amounts of precipitation occur, then the farmer will have realized less profit because a larger than average amount of land could have been irrigated. On the other hand, if too large of area is planted the available water may not be adequate to produce profitable yields on the larger area. Within the season, management of deficit irrigation is more difficult than when water is readily available. When water is unlimited the objective of irrigation scheduling is to determine the amount of water and appropriate timing of the next irrigation. However, with deficit irrigation, it is necessary to decide when is the best time to use the remaining water supply during the season. The proper timing of the irrigation contains a great deal of uncertainty also because the distribution of rainfall during the season may differ from what was anticipated before the irrigation season started. The main purpose of this paper is to discuss the planning considerations for deficit irrigation, namely the appropriate irrigated area and the depth of water to apply, as contrasted to that when unlimited water is available.

The net return from irrigation for limited water supplies is calculated the same as for the land limiting case. The difference is that the objective for water limiting cases is to maximize the net return per unit of water available. Water limiting irrigation is more difficult because the area that can be irrigated and the depth of water to apply are now directly related. For example, if 800 acre-inches of water were available, then either 100 acres (each receiving 8 inches), or 80 acres (receiving 10 inches) could be irrigated. The problem is to determine which combination of area and depth is the best. The problem is further complicated because the yields produced are not equal. Analysis of the data in Table 1 and Figure 1 for an annual allocation of 800 acre-inches of water is presented in Table 2.

Table 2. Irrigated area, yield and net return per acre for an allocation of 800 acre-inches and the data from Table 1 and Figure 1.

Depth, inches	Irrigated Area, acres	Yield, bu/ac	Irrigated Net Return, $/acre
2	130.	62.	34.
4	130.	88.	93.
6	130.	110.	142.
8	100.	128.	181.
10	80.	142.	210.
12	67.	152.	229.
14	57.	158.	238.
16	50.	160.	237.

The data in Table 2 show that the entire 130 acre pivot could be irrigated when less than 6 inches is applied. Once the depth of irrigation is greater than 6 inches the area irrigated must decline because of the water limitation. Also as the depth of irrigation increases the yield per acre increases. All of these factors work together to produce the pattern of net return per acre shown in the fourth column of Table 2. The total net return from the entire 130 acre field is the primary concern to the irrigator and is shown in Figure 4 as a function of the area irrigated.

The total net return from the field reaches a maximum when the area irrigated is about 90 acres (Figure 4). Notice that the total net return is nearly constant over a range of acres from 70 to 100 acres. There are two points that can be emphasized that apply to limited irrigation. First, the net return from limited irrigation appears to reach a plateau and remains relatively constant over a range of irrigated acreages. The advantage of the plateau is that the irrigated area may be different from the absolute optimum and still not drastically affect the net return. Second, the optimal range of the irrigated area is near the middle of the possible ranges of acres. The recommendation for limited irrigation is not as simple as either planting the

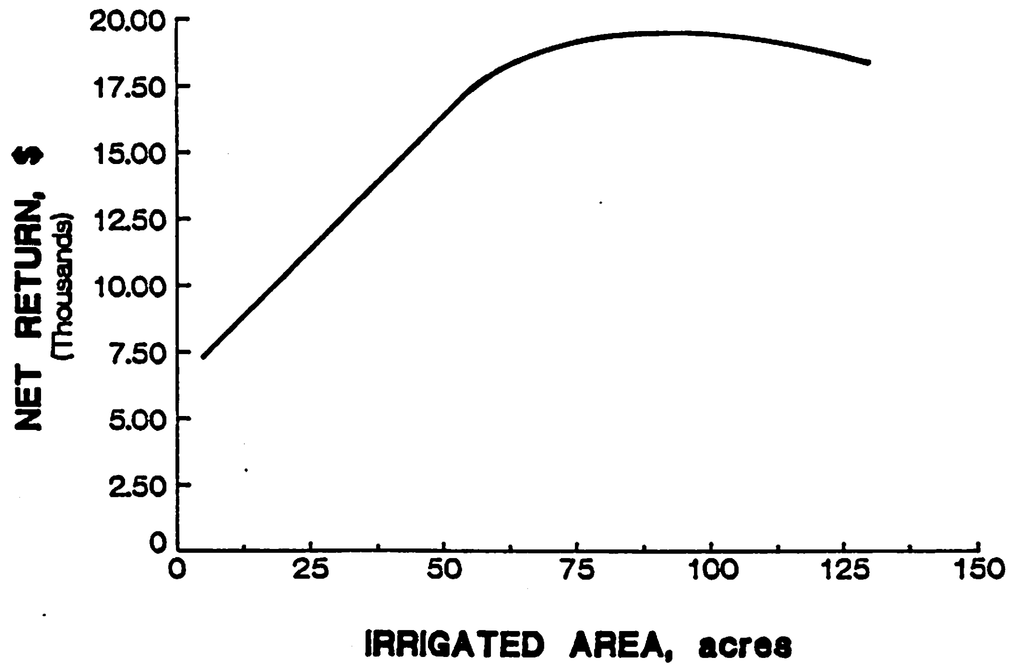


Figure 4. Net return for the data listed in Table 1 resulting from a limited water supply of 800 acre-inches.

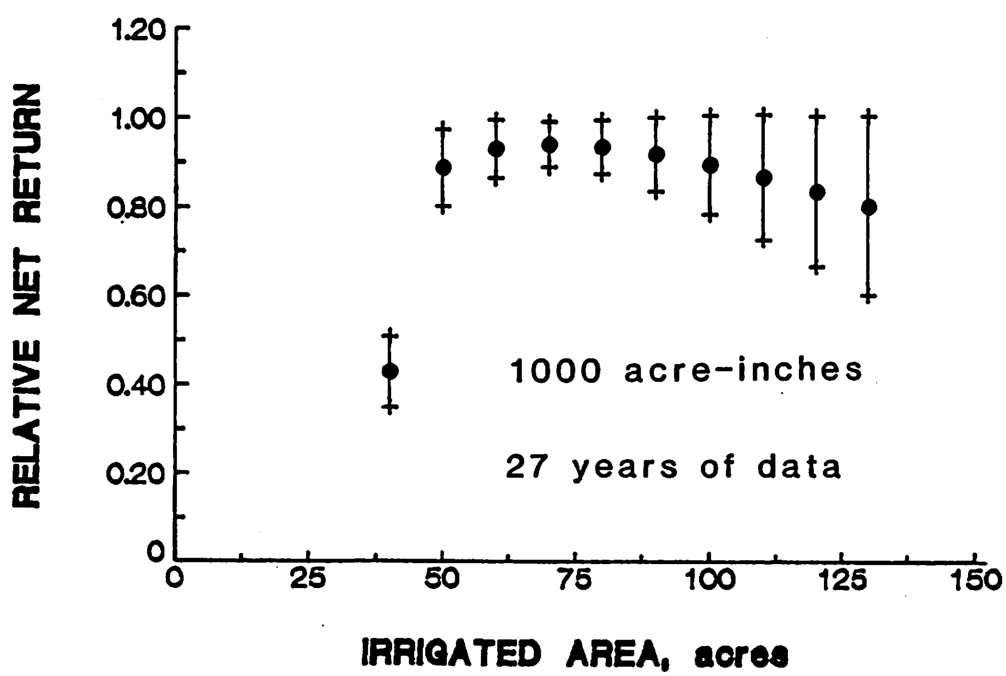


Figure 5. Average net return (•) and the variation (± one standard deviation) for center pivot irrigated corn and dryland grain sorghum on sandy loam soil in Southwest Nebraska.

entire area to the irrigated crop, or to produce the maximum yield on a reduced irrigated area. The optimal irrigated area will also change depending upon the volume of water allocated and financial parameters.

Weather data were used in a computer program to simulate the effect of climatic variation upon crop yields for a center pivot irrigated field and dryland conditions in Southwest, Nebraska for a sandy loam soil. Corn was used for the irrigated crop and grain sorghum for the dryland crop. Representative values were used for the prices and costs for each crop. Results from the analysis are shown in Figure 5.

The dot in the center of the vertical bar represents the average net return for a irrigated area relative to the net return for the area that was optimal for that year. The vertical bars show the range of the relative return for the specific area for the 27 years. The results show that the plateau of the net return is relatively wide for acreages between about 50 and 100 acres of irrigation. The variation of the net return is less for the acreages in the plateau than for acreages at either extreme of the irrigated area. The data show that small acreages, less than 50 acres, should not be considered. The average irrigation requirement for maximum yield was 18.7 inches for these years, and the water allocation was for 1000 acre-inches. The area that could have been irrigated for maximum yield would have averaged about 54 acres. These data suggest that the irrigated area should never be reduced below the area that on the average would have produced the maximum yield. Planting the entire area to irrigated crops and spreading the available water over that area is also more risky than maintaining the irrigated area within the range of the net return plateau.

The primary problem is that the range of irrigated areas that define the net return plateau varies for the crops grown, the costs and prices, the type of irrigation system, and the volume of water allocated. Thus the results shown here are only intended to illustrate the types of decisions necessary in evaluating irrigation when planning, and to illustrate the expected types of results.

Several methods that build on the concepts of this paper have been developed for deficit irrigation planning. Reprints of research articles describing those techniques are available on request.

SUMMARY

Results show that for unlimited water supplies the entire irrigable area should be irrigated and that enough water should be applied to produce near to the maximum yield. When water is limited it appears that the irrigated area should be reduced from the maximum irrigable area, and that the irrigation depth should be reduced from that required to produce maximum yields. Limited irrigation contains much more uncertainty than traditional irrigation practices. Producers will need to carefully analyze management options if faced with limited irrigation.