Economics of Irrigation Efficiency Improvements and System Conversions

Danny H. Rogers
Extension Agricultural Engineer
Kansas State University
Manhattan, Ks. 66506

Kevin C. Dhuyvetter
Extension Agricultural Economist, SW
Kansas State University
Garden City, Ks. 67846

Mark E. Nelson
Extension Agricultural Economist, NW
Kansas State University
Colby, Ks. 67701

Ron F. Meyers
Area Extension Agronomist
Colorado State University
Burlington, Co. 80807

This paper is intended to demonstrate a procedure for analyzing the economic feasibility of irrigation improvements and system conversions. Because the variables that affect these decisions vary from farm to farm, it is important for each producer to analyze their own operation using their own data.

Food production requires a large amount of water, even under the best of conditions. In Kansas, the largest permitted water use is irrigated agriculture and in western regions of Kansas, irrigated agriculture provides an important contribution to the economy. However, continued declines in the water resources have emphasized the need to minimize usage as much as possible, with due consideration on individual economic impact that dictate optimum yields. Improvement in irrigation water use efficiency, whether through better management techniques or system efficiency upgrades, may be able to accomplish partial conservation of water resources and preservation of returns to irrigation farmers.

Irrigation research has been conducted for a number of years on a variety of crops, at various locations throughout Kansas. Information presented in this paper summarizes some research conducted on corn at Colby and Garden City, Kansas. While the data presented represents multiple years of research, the summary is still preliminary as we hope to compile additional information in the future.

Figure 1 is a presentation of corn water use versus yield from western Kansas. Yield is shown as a percentage of maximum yield for the study. This was done to "normalize" yield data across years, variety, and so forth. While there is scatter of data, the general trend of Figure 1 is increasing yield with increasing water until the maximum yield is obtained at approximately 28 inches of water use. This yield versus water use curve is consistent with information from other sources. Figure 2 illustrates one reason for the need to normalize data, by showing the general increase in performance test yields at Colby, KS. Figure 3 illustrates that corn generally requires about 10 inches of water before obtaining any grain yield, and would have a linear response to additional water. The water use graph curves, due to inefficiencies as maximum yield is approached.

The corn water use from the various studies were plotted against applied irrigation in Figure 4 and used to estimate the irrigation requirement. A line was fit to the data using linear regression to obtain a given level of water use. This irrigation-water relationship is shown on the corn water use yield curve in Figures 5a and 5b. The yield axis shows the normalized yield and a scale assuming a yield of 210 bu/ac, based on the average 1990 performance test value from Figure 2. Yields, in excess of 200 bu/ac are not uncommon for well-managed, fully-irrigated corn in western Kansas. Figure 5 can be used to estimate yields for various levels of irrigation applications.

The major irrigation system types of western Kansas are surface (flood using gated pipe) and center pivot. Several hundred acres of drip irrigation have been recently installed in Kansas and research on this type of system is on-going at Colby and Garden City. Real world examples of farmer field data were sought for several of the different systems from records of various demonstration plots and are shown in the examples. It was found that for the lower range of water use, producers were applying much more water than what would be predicted by the research based yield/water use curve (figure 5).

Typical corn water use for the Central Plains ranges from 24 to 30 inches per season, and can have peak daily use of one half inch per day. Corn also has a very critical stage of growth during tasseling and silking. Irreversible yield losses are likely at this time, if crop stress occurs. It is very important that adequate irrigation capacity is available to allow timely application of irrigation water during the growth stage. An important conversion factor used to relate crop water usage and irrigation discharge rate is 450 gpm = 1 acre-in/hour. The table below shows the capacity needed to meet a crop water use rate of 0.25 in/day for various irrigation efficiencies.

Irrigation capacity to provide 0.25 in/day net water for various irrigation efficiencies.

Irrigation Efficiency	GPM required for 1 acre	GPM required for 130 acres
100%	4.69	610
90%	5.21	677
80%	5.86	762
70%	6.70	871
60%	7.82	1,016
50%	9.38	1,219

However, even a capacity of 0.25 in/day net is insufficient to meet peak crop water use periods, and the irrigator must depend on additional crop water use from soil water or rainfall. Figure 6 illustrates the need for sufficient capacity to provide timely irrigation water. A typical cumulative water use curve for corn is shown having a seasonal need of 28 inches. Also, plotted on Figure 6 are net-irrigation capacities of 0.1 in/day and 0.2 in/day, shown in this example, beginning on May 1. If pumped continuously for 120 days, these capacities could apply 12 and 24 inches net irrigation, respectively. Assuming no rainfall, the 0.1 in/day capacity would have soil water deficiencies developing by June. The 0.2 in/day capacity would not have deficit soil water conditions developing until August. However, if soil water levels are near field capacity in May, irrigation should not begin until available soil water storage has occurred through removal by the crop or by drainage. This might be illustrated by the second line shown for each irrigation capacity. As a result, the 0.2 in/day capacity system has soil water deficits beginning in early July. The application amount also effects the timeliness of the water as well. If it takes twelve days to complete an irrigation cycle the last set of the irrigation would not see water until then, illustrated by the dotted line for the 0.2 in/day capacity system. In this case, the 0.2 in/day capacity would not be sufficient to restore the soil water for this set and the yield potential would be different than the first set.

The decision to make irrigation improvements and/or to convert to a different system often will not affect all costs and income that is generated on the farm. Because of this, the economic analysis can be done using the partial budget approach as opposed to a whole farm analysis. When constructing a partial budget, only the income and costs that will be directly affected need to be included. The increased income and decreased costs resulting from the change are compared to income reductions and increased costs. Using this method of analysis allows the producer to see how much the new investment will either need to be subsidized or contribute to the rest of the farm operation.

Partial Budget

Increased income	Increased cost
+ Decreased cost	+ Decreased income
A. Total annual additional returns and reduced costs.	B. Total annual additional costs and reduced income.

Annual net change in income (A minus B)

Increased income will be the result of higher yields and/or more acres being irrigated. Decreased costs will be things such as reduced labor, reduced pumping costs, fewer tillage operations, etc. Increased costs will be the added investment, higher repairs and possibly increased tillage and/or labor etc. Decreased income would be the result of reduced yields and/or fewer acres being irrigated.

Once the income and cost changes (increases and decreases) have been identified the analysis can be done. The net present value approach is a method often used in investment analysis. This method takes into account the time value of money because it discounts costs and returns that are realized in future years. This method is very useful in cases where income and/or costs vary from year to year over the investment period and are predictable. However, if the income and costs are relatively stable or unpredictable, this method has very little effect on the analysis. For the purposes of this paper, it is assumed that most variables will be stable and that the corn price is relatively unpredictable. Therefore, the most simple approach is to add annual increased income and decreased costs and subtract from them the annual increased costs and decreased income.

Some investment analysis will calculate an after-tax return. The returns calculated in this paper are before-tax. The tax implications of improving or converting irrigation systems cannot be ignored; however, they will vary considerably between producers so they have not been included in this analysis.

The economic feasibility of improving and converting irrigation systems will depend on the approach used and/or the assumptions made. This analysis is making the assumption that the acreage does not change between systems, but does allows for yields to change as irrigation efficiency changes. The economics of acreage changing is addressed in another paper (see paper on Planning for Deficit Irrigation).

Economic examples of analyzing irrigation improvements and conversions

Example 1 - Improving Flood Irrigation (medium capacity well)

Yield data was collected from a 127 acre irrigated corn field that was watered by a well with an average seasonal capacity of 480 gpm. The irrigation amount applied was 10.5 in/acre. It would take 52 days of continuous pumping to apply this amount of water. The yield from this field was 144 bu/acre. Assuming the yield potential of this field is 210 bu/ac (based on previous discussion from Figure 2), and plotting the 144 bu/ac yield on figure 5a (F_1), the predicted irrigation need is approximately 1 inch. This indicates a very poor utilization of the applied irrigation water due to such factors as poor water distribution (irrigation efficiency) or scheduling timeliness. Part of the problem may also be beginning soil water conditions. The water use curve was developed using research data from plots where soil water levels were uniform, and generally high. While, in general, sufficient off-season rainfall occurs to restore dry fall soil water levels, part of the applied irrigation may have been required on this field to restore the soil water practice and this may account for some of the water need difference. Rainfall amount on this field is unknown.

Regardless of the reason, the 10 inches of water pumped is apparently giving only the effect of one net inch. If irrigation efficiency could be improved to increase net water available for crop production from 1 to 3 inches, yield could be improved 11 bu/ac, from 144 bu/ac to 155 bu/ac (increase from F_1 to F_1^I on water use curve). One possible management option that might make this increase possible could be the use of surge irrigation. (See Surface Irrigation Section of proceeding for additional information on surge irrigation.) The following is a partial budget for investing in a surge valve.

Assumptions:

Field size	130 acres
Yield increase due to surge	11 bu/ac
Long run planning price of corn	$2.25/bu
Investment	
Surge valve	$1,500
1,075' Surface pipe	$2,419
Investment life	10 years
Interest rate	10%

Partial Budget

Increased income	Increased costs
$3,128 (11 bu x $2.25 x 130)	$244 surge valve $394 surface pipe
Decreased costs	Decreased income
none	none
A. Total annual returns $3,218	B. Total annual costs $638

Net change in annual income (A minus B): $3,218 - 638 = $2,580

Notes: The net change in annual income of $2,580 is profit and return to additional labor and management.

Total investment could be paid off in two years.

Based on a 10 year payback and $2.25 corn, yield improvement to breakeven is three bushels per acre per year.

Another method to improve irrigation efficiency is cutting the length of run. Table 1 shows yield distribution from a flood irrigation field, along with soil water readings. It was fortunate for the producer that the lower part of the field yielded well, in spite of the apparent soil water deficiencies, or the overall yield would have been much worse. However, suppose the yield distribution from the top half of the field (ave 167.8 bu/ac) could have been obtained in the bottom half of the field (148.8 bu/ac) by cutting the length of run. A yield improvement averaging 9.5 bu/ac for the entire field would be available to pay for the additional investment of pipe and labor. However, additional improvement over the entire field would be likely due to improved efficiency in the upper part of the field and better scheduling (timeliness), if smaller application amounts were possible. The following is a partial budget for cutting the length of run in half.

Assumptions:

Field size	130 acres
Yield increase due to shortened runs	9.5 bu/ac
Long run planning price of corn	$2.25/bu
Investment	
Surge valve	$1,500
3,465' pipe	$7,800
Investment life	10 years
Interest rate	10%
Additional labor to shorten runs	0.35 hrs/ac
Labor charge	$8/hr

Partial Budget

Increased income	Increased costs
$2,779 (9.5 bu x $2.25 x 130)	$244 surge valve
	$1,270 pipe
	$364 labor
Decreased costs	Decreased income
none	none
A. Total annual returns $2,779	B. Total annual costs $1,878

Table 1: Farmer Corn Field Soil Water Readings and Yield Distribution from Southwest Kansas. 1991.

SOIL WATER READINGS*

Station+ Number	Depth of Reading Inches	Date of Evaluation										Yield
		6-11-91	6-26-91	7-03-91	7-11-91	7-17-91	7-24-91	7-31-91	8-07-91	8-15-91	8-21-91	Bu/Ac
1	18"	82.00	100.00	88.00	12.00	98.00	40.00	100.00	100.00	87.00	100.00	183.8
	36"	27.50	92.50	87.50	80.00	82.00	74.90	53.00	62.00	52.00	67.50	
	60"	55.00	77.50	78.00	77.50	78.00	77.50	75.00	74.00	73.00	74.00	
2	18"	100.00	100.00	79.90	4.90	95.00	13.50	6.00	79.90	57.00	100.00	161.8
	36"	20.00	97.50	90.00	64.90	66.00	45.00	18.00	31.00	30.00	47.00	
	60"	52.50	57.50	63.00	64.90	62.50	63.00	62.00	60.50	60.00	60.00	
3	18"	89.90	81.25	69.00	4.00	67.00	5.00	6.00	70.90	15.00	7.50	148.0
	36"	7.50	50.00	24.00	8.00	15.00	4.50	2.50	2.00	4.50	4.00	
	60"	45.00	45.00	47.00	47.50	48.00	48.00	52.50	52.80	53.00	53.00	
4	18"	43.00	76.25	15.00	5.00	2.30	2.50	48.00	81.00	13.00	86.00	137.3
	36"	4.90	11.25	7.50	4.00	5.00	4.00	2.60	2.40	4.90	6.00	
	60"	42.00	42.50	43.00	43.00	43.00	45.00	45.00	45.50	46.00	46.00	
5	18"	91.25	100.00	66.00	6.00	2.50	2.30	1.50	100.00	55.00	17.00	160.8
	36"	3.00	35.00	6.00	6.00	3.00	2.50	1.50	12.00	3.50	3.00	
	60"	20.00	20.00	21.00	21.00	22.00	22.50	20.00	22.50	23.00	22.50	

AVE 158.3

* Readings from gypsum resistance blocks 100 = wet; 0 = dry
+ Stations were equally spaced at 10%, 30%, 50%, 70% and 90% of the half mile length of run.

Net change in annual income (A minus B): $2,799 - 1,878 = $921

Notes: The net change in annual income of $921 is profit and return to management.
Total investment could be paid off in four years.
Based on a 10 year payback and $2.25 corn, yield improvement to breakeven is seven bushels per acre per year.

Example 2 - Converting Flood to Center Pivot (medium capacity well)

Another possible option a producer has would be to convert from flood irrigation to center pivot irrigation (move from F_1 to P on figure 5a). Yields are increased from 144 bu/ac with flood to 164 bu/ac with center pivot based on 10.5 inches of water being applied. In this case, replacing the flood system with a center pivot system can have potential yield advantages because of the ability to apply smaller irrigation applications with better uniformity; therefore, the irrigation efficiency is improved. This also allows earlier start up without exceeding soil water storage capabilities or earlier start up since furrowing of rows are not necessary. The folowing is a partial budget for converting to center pivot.

Assumptions:

Field size	130 acres
Yield increase from converting to pivot	20 bu/ac
Long run planning price of corn	$2.25/bu
Investment	
Center pivot installed	$40,000 (less $2,145 pipe salvage)
Investment life	15 years
Interest rate	10%
Labor savings	1.0 hrs/ac
Labor charge	$8/hr
Tillage savings (2 operations @ $4.50)	$9.00/ac
Estimated system repairs	$10.00/ac
Increase in energy cost (gas @ $2.50)	$3.60/ac

Partial Budget

Increased income	Increased costs
$5,850 (20 bu x $2.25 x 130)	$4,977 pivot system
	$1,300 repairs
	$468 energy cost
Decreased costs	Decreased income
$1,040 labor savings	none
$1,170 tillage savings	
A. Total annual returns $8,060	B. Total annual costs $6,745

Net change in annual income (A minus B): $8,060 - 6,745 = $1,315

Notes: The net change is annual income of $1,315 is profit and return to management.
Total investment could be paid off in six years.
Based on a 15 year payback and $2.25 corn, yield improvement to breakeven is sixteen bushels per acre per year.

Example 3 - Improving Center Pivot System (medium capacity well)

A field demonstration project, conducted in Northwest Kansas from 1978 to 1981, gathered yield and applied irrigation amount from volunteer farmers' fields. The average yield from these fields was 152 bu/ac. Several included medium capacity center pivot systems (550 GPM). Assuming the yield potential of this field is 210 bu/ac (based on previous discussion from Figure 2), and plotting the 152 bu/ac on figure 5b, the predicted irrigation need is approximately 2 inches. There may be a slight bias in this example, because of improved yield potential of newer varieties. Again, some of the irrigation timeliness factors and low beginning soil water levels could account, partially, for seemingly low irrigation efficiency. However, improvements in center pivot irrigation efficiency may be possible. Several things that could be done to improve irrigation efficiency are: A) replacing the conventional sprinkler package or B) investing in a LEPA package and including cultural practices to control run off. If an additional two inches of the applied water in this example were utilized by the crop, a predicted yield increase of 12 bu/acre to 164 bu/acre would occur (increase from P_1 to P_1^I on figure 5b). It is assumed that the improvement in yield would be the same for the new conventional package as it would be for the LEPA package. LEPA may have potential for greater benefits at much lower well capacities (See proceedings papers from the sprinkler workshops). The folowing are partial budgets for (A) new spray package and (B) LEPA package.

A. New Conventional Spray Package

Assumptions:

Field size	130 acres
Yield increase due to spray package	12 bu/ac
Long run planning price of corn	$2.25/bu
Investment	
New spray package	$2,000
Investment life	5 years
Interest rate	10%

Partial Budget

Increased income $3,510 (12 bu x $2.25 x 130)	Increased costs $528 new spray package
Decreased costs none	Decreased income none
A. Total annual returns $3,510	B. Total annual costs $528

Net change in annual income (A minus B): $3,510 - 528 = $2,982

Notes: The net change in annual income of $2,982 is profit and return to management.
Total investment could be paid off in one year with a corn price of $1.29 or higher.
Based on a 5 year payback and $2.25 corn, yield improvement to breakeven is two bushels per acre per year.

B. LEPA Spray Package

Assumptions:

Field size	130 acres
Yield increase due to LEPA package	12 bu/ac
Long run planning price of corn	$2.25/bu
Investment	
LEPA spray package	$10,000
Investment life	5 years
Interest rate	10%
Additional tillage operation	$7.00/ac

Partial Budget

Increased income $3,510 (12 bu x $2.25 x 130)	Increased costs $2,638 LEPA spray package $910 added tillage
Decreased costs none	Decreased income none
A. Total annual returns $3,510	B. Total annual costs $3,548

Net change in annual income (A minus B): $3,510 - 3,548 = ($38)

Notes: The net change in annual income of ($38) is profit and return to management.
Total investment could be paid off in four years.
Based on a 5 year payback and $2.25 corn, yield improvement to breakeven is thirteen bushels per acre per year.

Example 4 - Converting Flood to Center Pivot (high capacity well)

Yield distribution and soil water readings from a flood irrigated field are shown in Table 2. In this example with a well capacity of 1,000 GPM on 130 acres, maximum yields were obtained. Examination of the soil water readings indicate the field was kept well-watered throughout the growing season. However, deep percolation losses were likely since five foot readings indicated soil water values at field capacity throughout the growing season. A farmer in this instance may want to consider converting to a center pivot system in an effort to conserve water and reduce pumping costs. In this case, the farmer should be able to maintain high yields while reducing irrigation pumping costs due to improving irrigation efficiency.

Table 2: Farmer Corn Field Soil Water Readings and Yield Distribution from Southwest Kansas. 1991.

SOIL WATER READINGS*

Station+ Number	Depth of Reading Inches	Date of Evaluation									Yield Bu/Ac
		6-05-91	6-26-91	7-03-91	7-11-91	7-17-91	7-24-91	8-07-91	8-15-91	8-21-91	
1	18"	96.90	94.00	98.00	97.50	99.50	98.50	100.00	96.00	84.00	228.1
	36"	98.00	86.00	100.00	100.00	100.00	99.50	100.00	97.70	95.00	
	60"	94.90	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
2	18"	98.00	97.50	93.00	97.50	99.90	99.80	96.00	97.50	80.00	250.8
	36"	95.50	98.00	100.00	100.00	100.00	99.80	96.00	96.50	61.50	
	60"	78.00	83.00	99.00	92.50	95.00	97.90	93.00	90.00	86.00	
3	18"	96.25	86.00	93.50	57.50	97.50	93.00	94.00	42.90	23.00	233.6
	36"	95.00	97.50	95.00	90.00	88.00	92.50	92.50	84.00	60.00	
	60"	92.50	93.00	94.50	95.00	95.00	96.00	96.00	94.80	91.00	
4	18"	95.20	50.00	69.90	96.50	91.00	83.00	84.00	33.00	21.00	244.6
	36"	95.00	86.00	85.00	47.50	66.00	71.50	56.00	43.00	28.00	
	60"	91.25	90.00	92.50	92.50	76.00	81.00	77.00	71.50	64.90	
5	18"	95.00	67.50	85.00	91.00	95.00	89.90	86.00	57.00	39.90	230.8
	36"	97.50	98.00	97.50	100.00	97.50	98.00	97.50	95.00	70.00	
	60"	95.00	92.50	94.90	97.50	97.50	97.50	100.00	95.00	87.50	

AVE 237.6

* Readings from gypsum resistance blocks 100 = wet; 0 = dry

\+ Stations were equally spaced at 10%, 30%, 50%, 70% and 90% of the half mile length of run.

Assumptions:

Field size	130 acres
Yield increase from converting to pivot	0 bu/ac
Long run planning price of corn	$2.25/bu
Investment	
Center pivot installed	$40,000 (less $2,145 pipe salvage)
Investment life	15 years
Interest rate	10%
Labor savings	1.0 hrs/ac
Labor charge	$8/hr
Tillage savings (2 operations @ $4.50)	$9.00/ac
Estimated system repairs	$10.00/ac
Decrease in energy cost (gas @ $2.50) (10 inches less water applied)	$4.65/ac

Partial Budget

Increased income	Increased costs
none	$4,977 pivot system
	$1,300 repairs
Decreased costs	Decreased income
$1,040 labor savings	none
$1,170 tillage savings	
$605 energy savings	
A. Total annual returns $2,815	B. Total annual costs $6,277

Net change in annual income (A minus B): $2,815 - 6,277 = ($3,462)

Notes: Return of ($3,462) is profit and return to management.
Investment could be paid off in 25 years.
Based on 15 year payback and $2.25 corn, yield improvement to breakeven is twelve bushels per acre per year.
Improving efficiency may allow for additional acres to be irrigated from same well.

The feasibility of improving a current irrigation system or converting to a different system will vary considerably from farm to farm. While the economic approach--partial budgeting--is straight forward, identifying the particular changes in income and costs associated with an improvement or system conversion can be very difficult. Because of this, it is imperative that you do two things before implementing an improvement or conversion for a particular field:

1) Thoroughly troubleshoot your irrigated enterprise. Make certain that there are no other possible reasons for low yields. Surge irrigation, for example, will do no good, if the problem is field topography.

2) KNOW YOUR COSTS! You'll then be in a much better position to:
a) troubleshoot your irrigated enterprise and,
b) estimate changes in costs/income due to an improvement or system conversion. For example, if you have a solid handle on your present repair expenses, you can more knowledgeably estimate any changes in repair costs due to an additional investment.

Figure 1: Normalized Corn Yield (% of maximum of test plot) and Total Water Use for Western Kansas. 1979 - 1990.

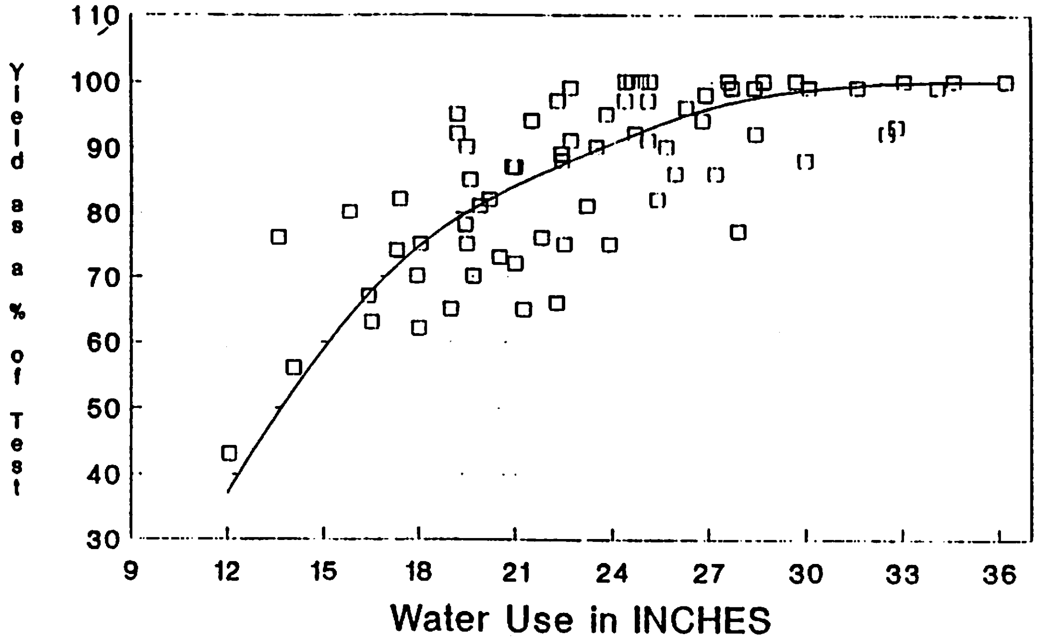
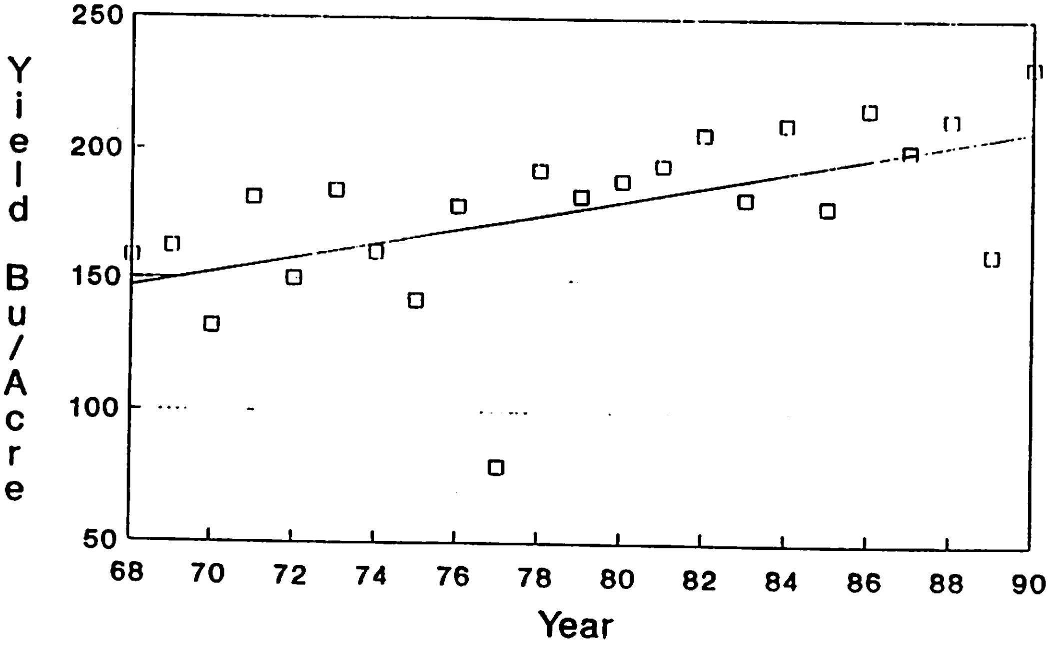


Figure 2: Corn Performance Test Average Yields. 1968 - 1990.



NW Res. Ext. Ctr., Colby, Ks.

Figure 3

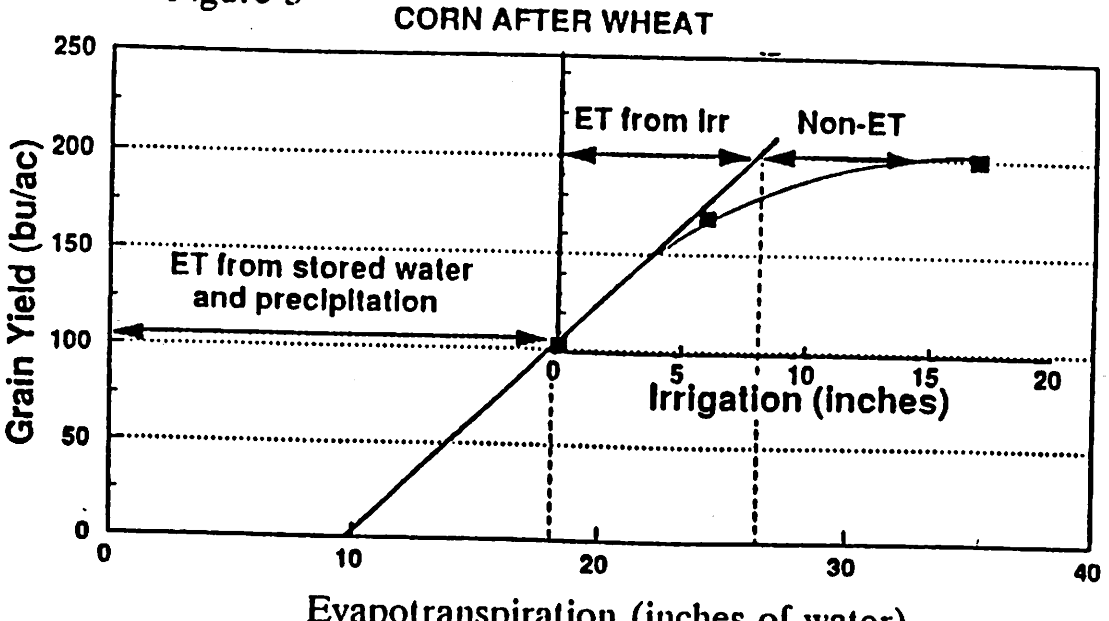
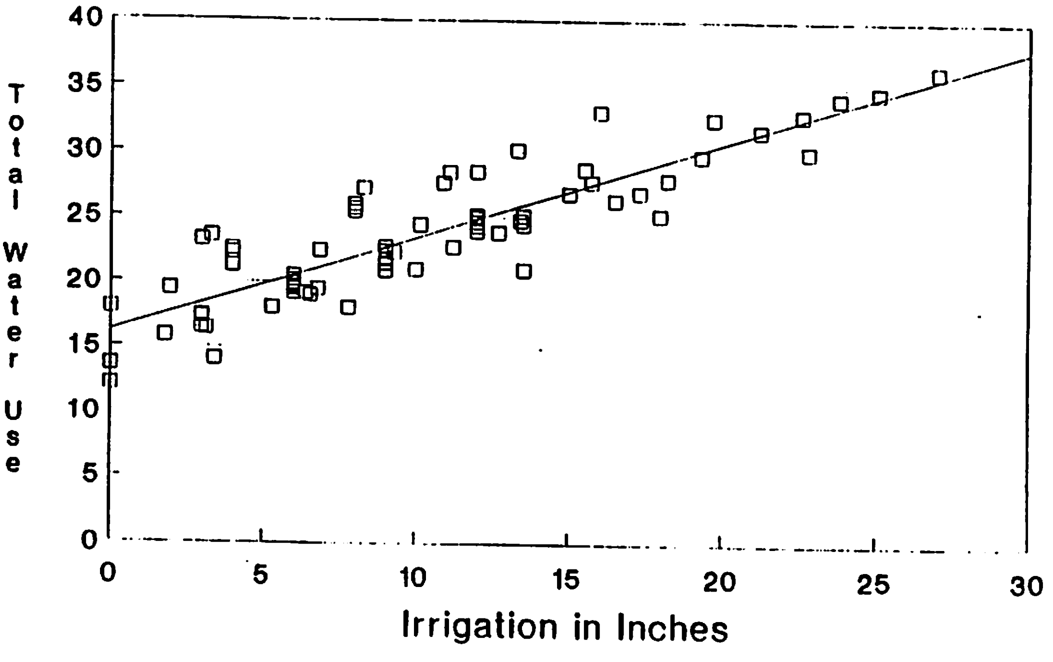


Figure 3. Generalized relationship between yield and evapotranspiration showing the contributions of stored soil water, growing season precipitation and irrigation to yield. Hergert, G.W., J.P. Schneekloth, and N.L. Klocke. 1991 Proceedings Centrals Irrigation Short Course, page 121).

Figure 4: Total Water Use and Applied Irrigation for Research Plots. 1979-1990.



(Data for Colby and Garden City)

Figure 5a: Corn Water Use and Irrigation vs. Yield from Western Ks. Researh Plots

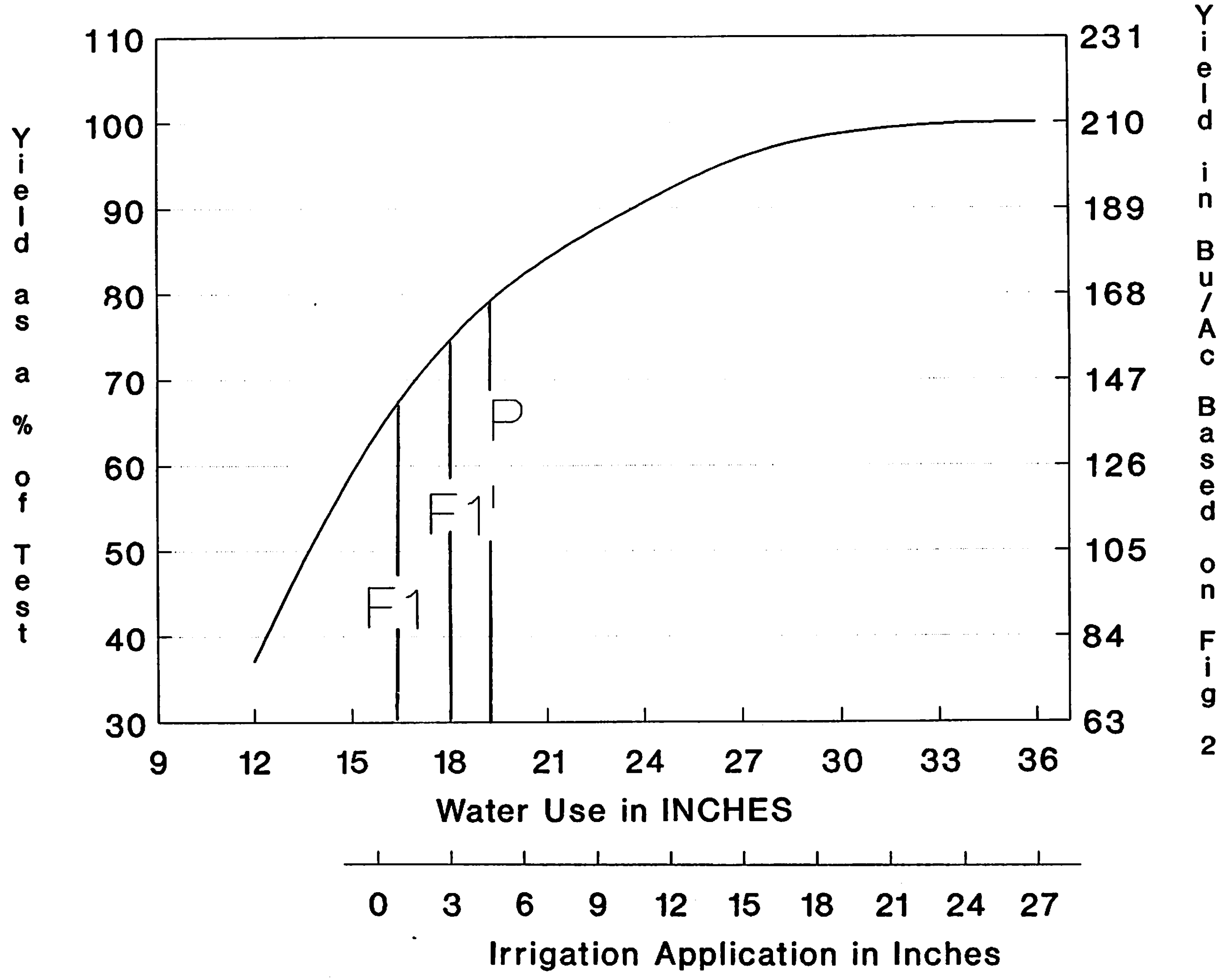


Figure 5b: Corn Water Use and Irrigation vs. Yield from Western Ks. Researh Plots

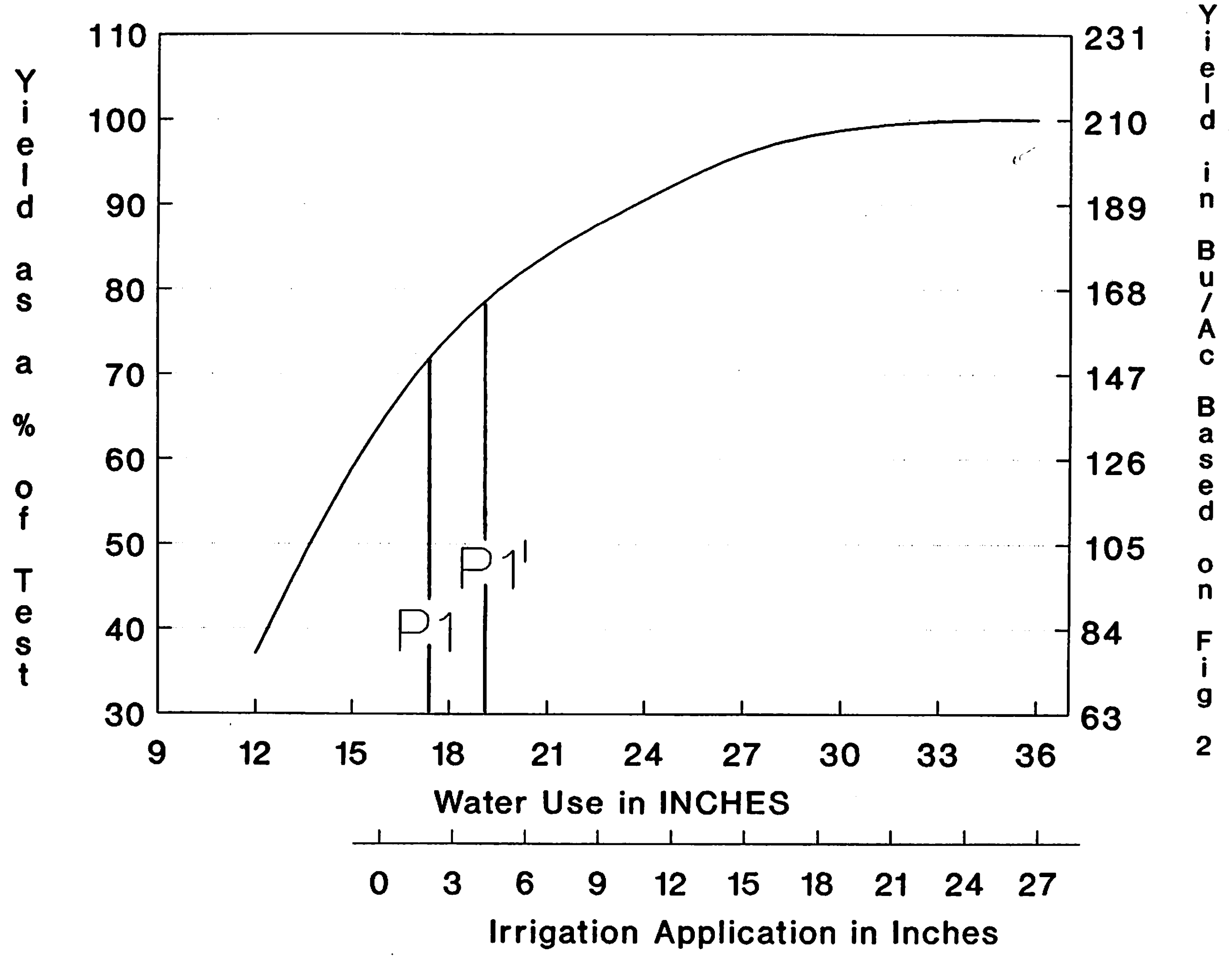
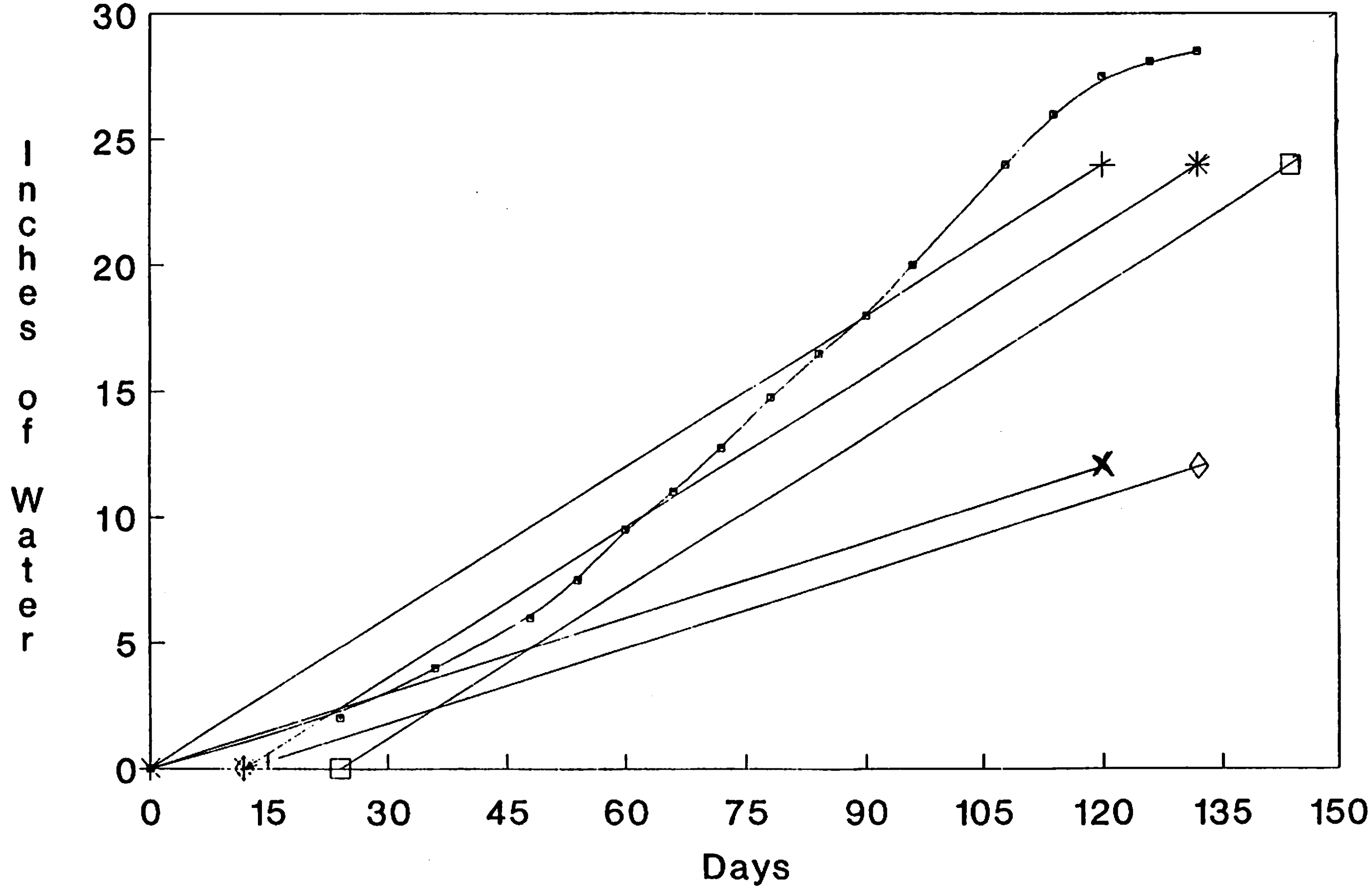


Figure 6: Typical Culmultive Corn Water Use Curve and Culmultive Irrigation for Two Irrigation System Capacities



A = 0.2 in/day net irrigation capacity
B = 0.2 in/day net irrigation capacity starting at day 12
C = 0.2 in/day net irrigation capacity starting at day 24
D = 0.1 in/day net irrigation capacity
E = 0.1 in/day net irrigation capacity starting at day 12