Does Irrigation Improve Soybean Yields?

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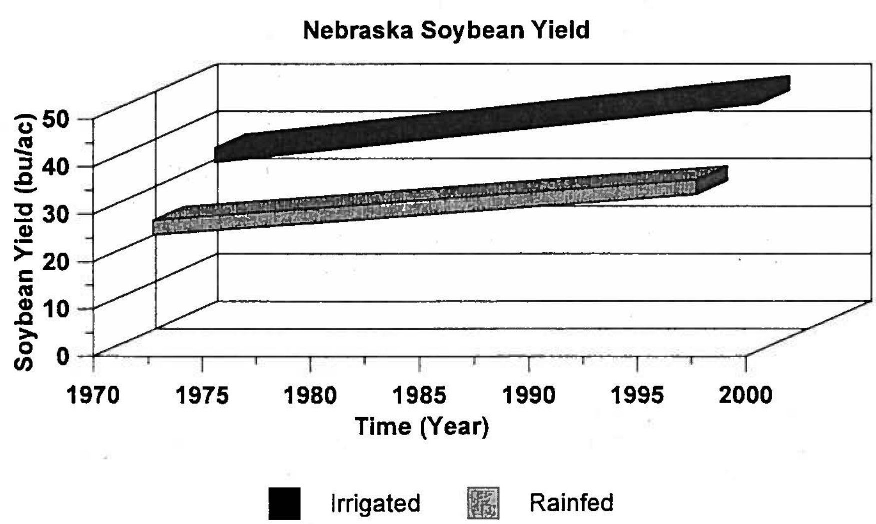
INTRODUCTION

In High Plains, areas once dominated by irrigated corn production are increasingly being replaced by corn-soybean rotations. As a result, soybeans now encompass a region with diverse soils and climate that require different irrigation management strategies.

To begin to answer the question posed by the title of this article, a bit of history may be useful. Research conducted by Specht et al., (2000) suggests an increasing trend in rainfed and irrigated soybean yield for the state of Nebraska (figure 1). Nebraska Ag Statistics data for average soybean yields were regressed for the period between 1972 and 1997.

Figure 1. Trend in Nebraska irrigated and rainfed soybean yields for 1972 -1997.



Note that the yield for irrigated soybeans is increasing at a rate faster than for rainfed conditions. The slope of the line is *0.52 bu/ac/yr* for irrigated soybeans and *0.37 bu/ac/yr* for rainfed conditions.

Though the yield data presented in Figure 1 concentrate on Nebraska results, similar trends have been experienced from Canada to Brazil. Specht et al. (2000) suggest that the increasing trend can be attributed to three factors: 1) an increase in CO_2 content of the atmosphere; 2) improvement in soybean genetics; and 3) improvement in the management of soybean production systems. Top yield claimed in the Nebraska irrigated category in 1997 was 99 bu/ac. They also present evidence that would place the maximum yield potential at about 120 bu/ac. Thus, the upward trend should continue for the foreseeable future.

SOYBEAN STAGE-OF-GROWTH & WATER USE RATES

With determinate varieties, vegetative growth ends at flowering. With indeterminate varieties, the later phases of vegetative growth overlap the early phases of reproductive growth. Though irrigation is usually required only during the mid- to late-reproductive stages, this overlap may mean some water will be applied during the later phases of vegetative growth. To help accurately identify soybean stage-of-growth during the most critical periods, soybean reproductive stages are described in Table I.

Table I. Reproductive stages of soybean plant development (Ritchie et al., 1994).

Stage		**Description**
Beginning Flower	R1	One flower at any node on the main stem.
Full Flower	R2	Open flower at one of the two uppermost nodes on the main stem with a fully developed leaf (nodes with fully developed leaves are those that are below a node with a leaflet unrolled to the extent that its edges are not touching).
Beginning Pod	R3	Pod is 3/16 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf. It is not uncommon to find developing pods, withering flowers, open flowers and flower buds on the same plant.
Pod Development	R4	A pod 3/4 inch long at one of the four uppermost nodes with completely unrolled leaves.
Beginning Seed Fill	R5	The presence of bean seeds (felt when pod is squeezed) in pods at one of the four uppermost nodes with completely unrolled leaves.
Seed Fill	R6	A pod with full-size green beans (bean is full size when it fills pod cavity) at one of the four uppermost nodes with completely unrolled leaves.
Beginning Maturity	R7	One normal pod on the main stem has reached its mature color, normally tan or brown.
Full Maturity	R8	Ninety-five percent of the pods have reached their mature pod color.

The total water use by a fully irrigated soybean crop (evaporation plus transpiration) ranges from 21 to 24 inches per year. About 65 percent of this water is used during the reproductive stages. The average peak crop water use rate, about 0.3 in/day, begins near the full flowering stage and continues through pod development. The average rate during the seed fill stage is about 0.25 in/day. However, daily crop water use rates can reach 0.35 to 0.40 inches under hot dry conditions. Figure 2 presents data that support the need for scheduling irrigation applications. The long-term average curve is smooth, climbing to about 0.3 in/day and then declines as the crop approaches maturity. Actual daily crop water use rates vary considerably from day to day based on the time of year and growth stage.

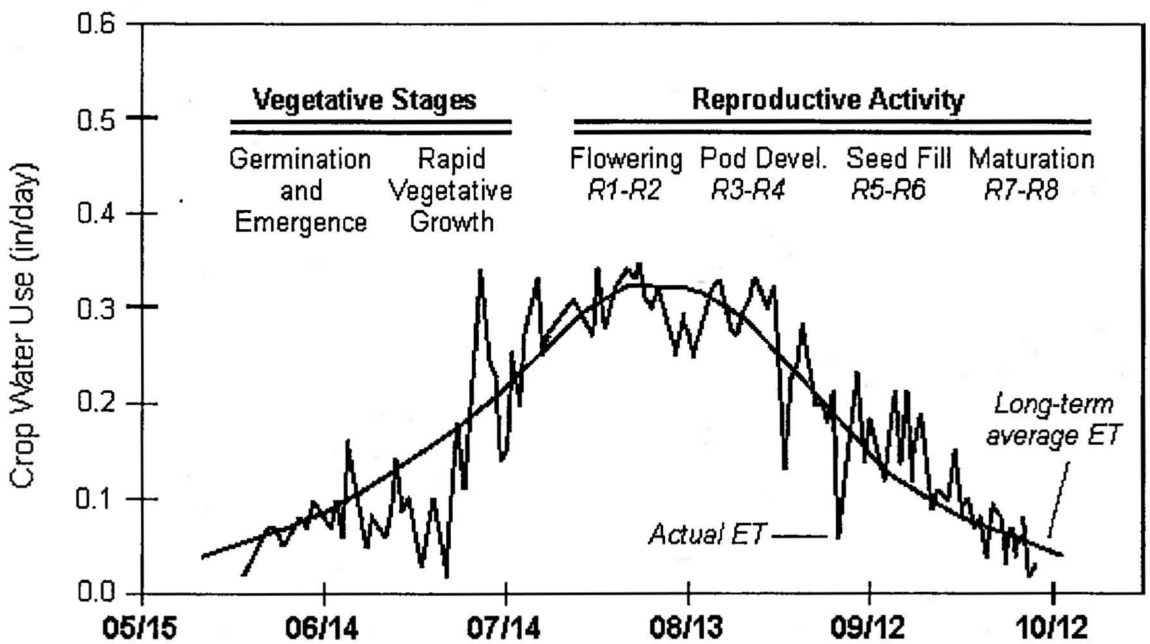


Figure 2. Long term average and actual soybean crop water use (ET) for one year based on day of the year and stage-of-growth.

Irrigation and/or high amounts of rainfall during vegetative growth are not normally beneficial except during periods when soil water levels are extremely low. Excessive water during the vegetative stage stimulates vegetative growth and increases the potential for lodging and fungal diseases with essentially no increase in yield. In some cases, excessive early season precipitation and/or irrigation can lead to yield reductions.

The most important times for soybean plants to have adequate available water are during pod development (R3-R4) and seed fill (R5-R6). Irrigation may also be required during the flowering stage on sandy soils or during very dry years on medium and fine-textured soils. However, if water is applied during flowering, it is important to follow with adequate water during seed fill. Otherwise, more but smaller seeds will develop, reducing yields.

Although soybean roots can reach depths of 5 to 6 feet, the largest concentration of roots and the majority of soil water extraction occur in the top 3 feet of the soil profile. Therefore, irrigation water management should concentrate on the top 3 feet of soil. Soybean produce highest yields on soils with good internal and surface drainage or a more common statement is '*soybeans do not like wet feet*'.

The most convenient way to time soybean irrigation is by using the crop stage-of-growth as an indicator. Stage-of-growth scheduling works well for crops like indeterminate soybean that respond well to water supplied during the later growth stages. However, stage-of-growth scheduling also depends on the capability of the irrigation system to supply sufficient water to the crop. Precipitation during the growing season, stored soil moisture prior to the growing season, and irrigation system capacity combine to furnish water to the crop.

RESEARCH RESULTS

1980's Nebraska Research

Research has shown that indeterminate soybean respond well to delayed irrigation. However, as rainfall and stored soil water decrease from east to west across the region, delayed irrigation can reduce yields when compared to full-season irrigation. To develop soybean irrigation best management practices (BMPs), research in Nebraska has focused on comparing full-season irrigation to stage-of-growth irrigation. In the early 1980's four irrigation treatments were evaluated across Nebraska at Tryon, North Platte, Clay Center, and Mead:

1. **Full-season (Full)**. If necessary, irrigation began prior to flowering to supply water according to the water use of the crop. Irrigations were scheduled in order to maintain the available soil water above the 50% depletion level in the active root zone.

2. **Full Flower (Flower)**. Irrigation began when a flower opened at a node immediately below the uppermost node on the main stem with a completely unrolled leaf *(R2)*.

3. **Pod Elongation (Pod)**. Irrigation began when a pod was 3/16 to 3/4 of an inch long at one of the four uppermost nodes on the main stem with a fully developed leaf *(R3-R4)*.

4. **Rainfed**. Water was applied only if needed for stand establishment.

Figure 3 illustrates the average relative yields compared to the Full-season irrigation treatment for Clay Center, North Platte, Tryon, and Mead based on the stage-of-growth when irrigation was initiated.

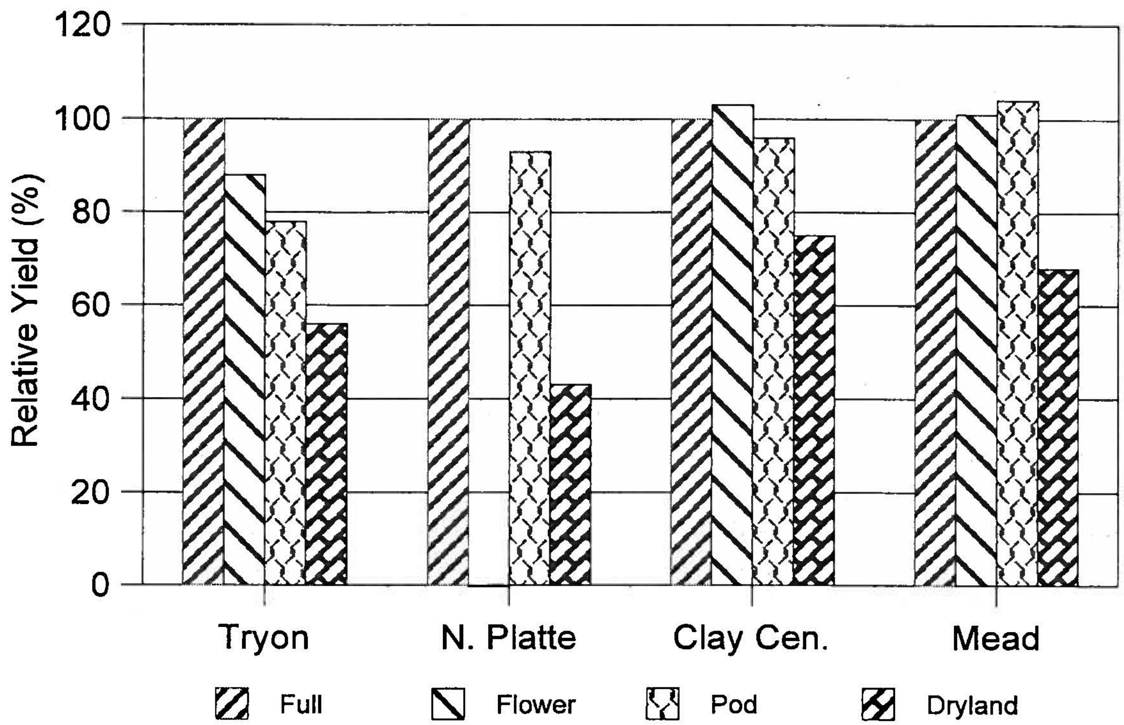


Figure 3. Relative yields for soybean irrigated at Flowering (R2), Pod development (R3-R4), and rainfed with respect to Full-season irrigation (*Full Flower treatment not tested at North Platte*).

Relative rainfed yields were greater at Mead and Clay Center than the two west-central locations. More precipitation before and during the growing season at the eastern locations increased the rainfed yields. Relative yields from the pod elongation treatments decreased from the eastern to the west-central locations. Soil water storage and rainfall were not enough to produce maximum yields from the pod-elongation treatment at the west-central locations; the pod-elongation treatment showed a positive yield response due to late-season water application at all locations. These data suggest that, for eastern Nebraska, a strategy of delaying irrigation until the pod-development stage will result in top yields. However, the data suggest that full season irrigation scheduling is necessary for soybeans grown in West and West Central Nebraska. Averaged across locations, the irrigation water use efficiency was 1.52, 1.35, and 0.95 bu/ac/in for irrigation treatments initiated at pod elongation, full flower, and full season irrigation, respectively.

1980's Kansas Research

Six irrigation treatments were evaluated at Colby,KS in the late 1980's. The approach taken was to replace a certain percentage of the estimated crop water use for the entire range of stage-of-growth. This allowed a range of available soil water contents to be evaluated. Two of the treatments had reduced irrigation during the vegetative stages and full irrigation during the reproductive stages.

The water budgets imposed between 1986 and 1988 for the six treatments were:

1. Full-season, 100% of ET
2. 75% of ET
3. 50% of ET
4. Rainfed
5. 75% of ET in vegetative stages and 100% of ET in reproductive stages
6. 50% of ET in vegetative stages and 100% of ET in reproductive stages

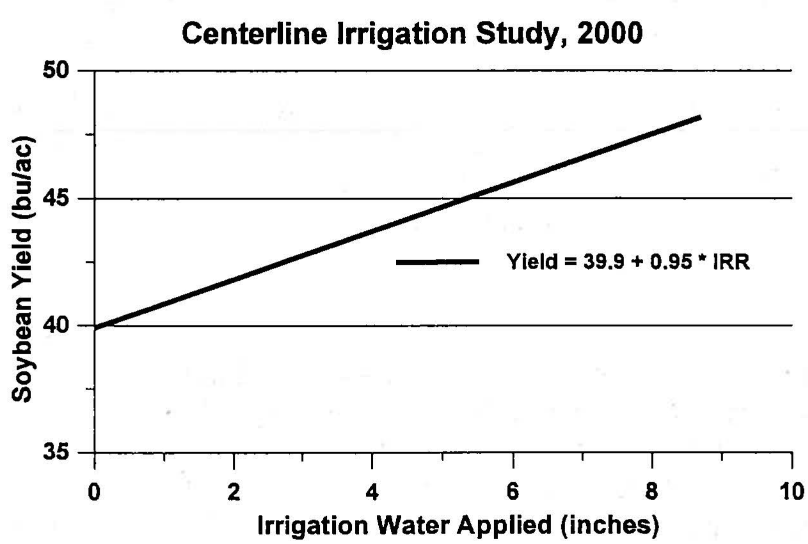
Yields for treatments receiving stress during the vegetative stages were equal or better than the 100% ET replacement treatment in 1986 and 1987 (Table 2). Significant savings in irrigation water pumped result from implementing Treatment 6 (50%/100%). However, in 1988 yields were depressed for both the Full-season and vegetative stage stress treatments. This is likely due to the severity of the stress that occurred in June of 1988. Accumulative ET for June of 1988 was the highest on record for the 17-year period in which estimates have been calculated. This coupled with less than 1.0 inches of rainfall resulted in severe stress.

This research shows that moderate stress during the vegetative stages can reduce irrigation pumping when compared to Full-season scheduling without a corresponding reduction in yield. However, managers must watch soil water contents during the vegetative stages to alleviate severe stress should it occur.

<u>2000 Concord Results</u>

In 2000, soybean irrigation tests were conducted at the Haskell Ag Laboratory near Concord, NE. The test delivered a range of irrigation application from rainfed to fully irrigated. A stationary towline like system was used to apply the water. The soils at the site were in the Nora-Crofton silt loams.

Figure 4. Soybean yield response to irrigation at Concord, NE in 2000.



Irrigation was initiated at the R3 stage of development. Irrigation was initiated to keep the soil water content in plots nearest the towline above the 50% available soil water content. Irrigation water application decreased with distance from the towline to cause water applications that ranged from rainfed to fully irrigated. These treatments would compare well with Treatment 5 of the Kansas research. Yield results are presented in Figure 4.

Yields ranged from 40 bu/ac for rainfed soybeans to 47 bu/ac in plots receiving an average of 8.7 inches of water. The slope of the line is 0.95 bu/ac/in of water. This number agrees well with the Full-season treatment discussed for research conducted in Nebraska in the early 1980's. Obtaining higher irrigation water use efficiencies is a function of the relative maturity of the variety and the growing season characteristics according to Specht et al., (2000). Thus, longer season varieties in the Group III or IV will have larger potential irrigation water use efficiencies than Group II or Group I. Consequently, yield boost expectations should be based on the relative maturity of the variety and how irrigation is managed during the growing season. And some seasons, Mother Nature has a lot to say about soybean yields.

Research Summary

Results of these and many other research efforts indicate that adequate water during the pod development and seed fill stages is critical to boosting irrigated soybean yields. Irrigation water use efficiencies are not as high as for corn and can be less than 1.0 bu/ac/in for shorter season varieties. Growing seasons that do not produce moderate to severe plant stress may not see much of a yield boost from irrigation. However, significant yield increases are possible if irrigation is used to alleviate severe plant stress during the reproductive stages.

RECOMMENDATIONS FOR COARSE-TEXTURED SOILS

Water management for coarse textured soils is more difficult than for medium-textured soils since there is less room for error in timing irrigations. Soils in this classification include fine sands, loamy sands and fine sandy loams. Generally, these soils have a low (less than 1.5 in/ft) available water-holding capacity, and some have root-restricting layers at shallow depths. The combination of low available water-holding capacity and shallow rooting results in a small soil water reservoir. The available water-holding capacity in a 3-foot active root zone will be 2.3 to 4.5 inches (Table 1). This low available water-holding capacity, coupled with the fact that sprinkler systems will likely be the irrigation used, means light, (0.5 to 1.0 inches), frequent water applications are necessary to recharge the limited soil water reservoir.

The general recommendation for water management on coarse-textured soil is to allow no more than 50 percent depletion of the available soil water in the top 2 feet during flowering (R1-R2) and no more than 50 percent depletion in the top 3

Table 2. Summary of soybean response to irrigation water studies from the KSU Northwest Research-Extension Center, 1986-1988.

	Soybean	**Yield**	**(bu/ac)**		
	1986	1987	1988	Mean	IWUE
Full-season	57.7	49.7	64.4	57.3	2.41
0.75 * ET	56.4	48.2	54.3	53.0	3.00
0.50 * ET	39.9	40.3	32.2	37.5	3.41
Rainfed	26.3	29.0	21.7	25.7	------
0.75V - 1.0R	59.7	48.5	55.6	54.6	2.49
0.50V - 1.0R	59.5	51.7	42.9	51.4	2.51
LSD (0.05)	10.7	5.3	9.9		
	Net	**Irrigation**	**(inches)**		
Full-season	15.5	11.1	12.7	13.1	
0.75 * ET	10.2	7.2	9.8	9.1	
0.50 * ET	3.6	3.5	3.2	3.4	
Rainfed	-----	-----	-----	-----	
0.75V - 1.0R	10.8	11.4	12.5	11.6	
0.50V - 1.0R	10.4	9.9	10.3	10.2	

feet during pod elongation (R3-R4) and seed fill (R5-R6). Soil water levels can be determined by combining the appearance and feel method with soil water-balance calculations using reliable evapotranspiration estimates.

RECOMMENDATIONS FOR DEEP FINE-TEXTURED SOILS

These soils (silt loams, silty clay loams, silty clay) generally have an available water capacity of more than 1.5 inches per foot. The available soil water at field capacity is between 4.5 and 6.0 inches in the top 3 feet. Applying irrigation water when the available soil water is depleted to 50 percent in the top three feet of the root zone after the full flower stage (R2) will generally result in maximum yields. The same methods mentioned for the sandy soils can be used to estimate soil water in these soils.

An alternative scheduling approach on deep- and fine-textured soils is stage-of-growth scheduling. This method works if the soil water reservoir is at or near field capacity to 5 feet at planting time. In the eastern half of Nebraska, this usually occurs if the soils were irrigated during the previous season and there was sufficient off-season precipitation to refill the profile.

For soybeans, between 10 and 11 inches of water are required from full flower (R2) to beginning maturity (R7). Therefore, effective irrigation plus rainfall should equal about 3 inches during full flower (R2), 3 inches during pod development (R3-R4) and 4.5 inches during seed fill (R5-R6). With adequate rainfall, optimum yields will be obtained with two, 3-inch net or effective furrow irrigations (typically at full flower or pod development and beginning seed fill). With systems such as center pivots applying smaller amounts of water per irrigation, it will be necessary to make two to four revolutions to apply the desired 3 inches during a particular growth stage. In dry years, an additional 3 to 5 inches of effective irrigation may be required.

If irrigation is started or unusually significant rainfall occurs during the beginning flower stage (R1), it is especially important adequate soil water (50 percent available soil water or greater) be maintained during the remainder of the growing season. If you are limited in the amount of irrigation water you can apply during the season, you will get the maximum benefit of this water if it is applied during the pod development (R3-R4) and seed fill (R5-R6) growth stages. However, when the rainfall is below normal during the vegetative and flower stages, a yield reduction may occur.

With furrow irrigation systems, it is generally not advisable to wait until pod development (R4) before applying the first irrigation, as this will probably cause extremely dry furrow conditions, making it difficult to get water through the field. An earlier irrigation date, perhaps beginning during the full flower stage, is advised. Individual effective irrigation applications should not exceed 3 inches.

Because precipitation decreases from east to west across Nebraska, a full soil water reservoir may not exist at planting time in the western half of the state. In this region, delaying irrigation until pod development may result in yield reductions when compared with full-season irrigation.

SUMMARY

When irrigating soybean in Nebraska:

1. Stage-of-growth irrigation scheduling for soybean should be limited to deep medium- to fine-textured soils. If soil water is at field capacity at planting, irrigation can be delayed until full flower (R2) and perhaps as late as beginning pod (R3).

2. If one or more of the following exists, irrigation should be scheduled according to soil water depletion and depletions should not exceed 50 percent:
   a. Soil texture is sandy loam or coarser
   b. The root depth is impeded (shallow, limits available soil water)
   c. Irrigation system capacity is 1.5 inches per week or less

3. Yield boost to irrigation will range from less than 1.0 bu/ac/in to 3.5 bu/ac/in depending on the relative maturity of the variety and the growing season characteristics.

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