MISSISSIPPI SOYBEAN PROMOTION BOARD

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SOYBEAN IRRIGATION AND WATER RELATIONS

All plants require water for growth and reproduction. Crop plants require water in an amount that will allow them to produce an economical yield of grain, forage, or fiber.

Drought is an extended period of dryness and heat that results in stress to crop plants, which is manifested in irreversible yield loss. In the Midsouthern U.S., moderate to severe drought stress in soybeans is common during the summer growing season. For verification, look at the long-term summer weather records for locations in Mississippi and adjacent states.

The water required to produce an economical yield is significantly greater than that for survival. Hence, the effect of drought stress on soybeans and their ability to cope with it has been, and always will be, a major hurdle for Midsouth soybean producers. The following information can be used to successfully manage irrigation of soybeans to obtain the maximum yield. This information is a compilation derived from numerous sources. Estimates of plant stages and water use are representations based on best available information, and may need modifications for a specific location.

Soybean Irrigation Facts

Summer weather patterns [high temperatures and low rainfall] in the midsouthern U.S. dictate that irrigation is required for maximum soybean yields. Properly timed and applied irrigation will increase soybean yield significantly in most years, which in turn will increase profits.

There is a difference between irrigating soybeans and "watering" soybeans. Irrigating the crop results in increased yields and profits. "Watering" the crop may be a waste of time and money, and can actually reduce yield. When flood irrigation was a significant practice, many fields had levees thrown up late in the season to "water" beans after a long drought period. Such desperate measures are a waste of time and money.

Irrigation is the single most important agronomic input for realizing maximum yield potential of an established crop. It is especially important when both input and commodity prices are high. Producers cannot afford to grow poor soybeans with expensive inputs, nor can they afford to lose yield to improper irrigation when prices are high.

Properly managed irrigation of soybeans should result in a yield increase of 20 or more bu/acre in years with normal Midsouth weather. Even in years with above-normal rainfall, irrigated yields will increase profits because some degree of drought stress always occurs in the Midsouth.

Crop coefficients are being developed for soybeans grown in the Midsouth. Thus, the crop coefficients used in this writing are modifications of those developed elsewhere coupled with years of irrigation water measurements and weather patterns at the irrigated locations. They will be supplanted when coefficients for the Midsouth are developed.

Starting Points

There are items and terms pertaining to soybeans that will apply throughout this guide. They are presented here so that their meaning or description will be consistent when they are encountered later.

Soybean reproductive growth stages
R1–Beginning bloom [top of plant]
R2–Full bloom
R3–Beginning pod
R4–Full seed
R5–Beginning seed
R6–Full seed [seeds butted and squared]
R7–Beginning maturity
R8–Full maturity

Soybean reproductive growth stages. See the short descriptions in the attached box. More defined descriptions and pictures can be accessed here. These growth stage designations will be used throughout the paper, and understanding the relationship between the stages and irrigation timing as discussed later is critical for success.

Abbreviations
CSPS–Conventional Soybean Prod. System
DTM–days to maturity
ESPS–Early Soybean Prod. System
ET–Evapotranspiration
MG–Maturity Group
PE–Pan evaporation
SCN–Soybean Cyst Nematode

Abbreviations. Some terms and phrases are used throughout the text, and are shortened according to abbreviations given in the attached box.

Soil-Plant-Water Relations. **The moisture status of plants is a function of soil water supply, evaporative demand of the atmosphere, and the capacity of the soil to release water**. In the field, significant water deficits develop on hot sunny days even in well-watered plants. As water evaporates [transpires] from the leaves, the moisture tensions that develop increase the rate of water uptake from the soil. If roots cannot absorb water rapidly enough, plant water tension increases. These tensions become growth-limiting under these conditions. Click here for more details.

It is often thought that crops such as soybeans adapt to drought stress and become capable of withstanding drought. There is no evidence to support this view, when it is considered on the basis of producing an economic yield. The limited adaptation that does occur only increases the plant's ability to survive during drought. This may be a valuable mechanism for a desert shrub, but it is of little value where production of a profitable seed yield is important for a crop such as soybeans.

Each time drought stress occurs, yield reductions in some amount will occur. The intent of irrigation is to alleviate as many of these drought periods as possible, especially during reproductive development. Irrigation is best used in conjunction with a knowledge of factors highlighted below.

Soil texture and available water. Soil water that is available to plants is mainly governed by two traits: the amount of water that remains after cessation of gravitational drainage through the soil profile, and the ease of availability of that remaining water to plants. Texture is the major soil component governing available water to plants during the growing season.

Textural classes range from coarse sand [coarsest] to clay [finest]. Coarse-textured soils [sands] contain many large pores that lose water quickly due to gravity. Little plant-available water remains after gravitational water loss because of relatively little surface area of the large sand particles. Medium-textured soils [loams] contain intermediate-sized particles and pores that are only moderately affected by gravitational water loss. These soils have the most water available to plants. Fine-textured soils [clays] contain many small pores that lose water slowly due to gravity. The extensive surface area of the small clay particles holds water tightly against plant forces to extract water. Clay soils contain the most total water, but only an intermediate amount of plant-available water.

Available water holding capacity of soil categorized by textural class.

Soil textural class	In. available water/ft. (avg.)
Coarse sand	0.6 — 0.8 (0.7)
Fine sand	0.8 — 1.0 (0.9)
Loamy sand	1.1 — 1.2 (1.15)
Sandy loam	1.3 — 1.4 (1.35)
Fine sandy loam	1.5 — 2.0 (1.75)
Very fine sandy loam, silt loam	2.0 — 2.5 (2.25)
Silty clay	1.5 — 1.7 (1.6)
Clay	1.3 — 1.5 (1.4)

Available soil water in coarse- and medium-textured soils is more readily extractable by plants than is water in fine-textured soils. Data in the above box provide a general categorization of plant available water related to soil texture.

Available water per foot of soil ranges from an average of 0.70 inch in coarse sand to an average of 2.25 inches in very fine sandy loam and silt loam. Multiplying these numbers by the effective rooting depth [say 2 ft. although roots go much deeper] gives a fair representation of soil water that is available to plants. An online calculator can be used to determine soil texture class when soil texture components [% sand, silt, and clay] for an individual field or site are known.

Soybeans growing on coarse-textured soils generally will grow faster than soybeans growing on clayey soils. However, without frequent rain to replenish depleted soil water, crops growing on coarse-textured soils will show visible drought stress quicker that will plants growing on finer-textured soils. Crops growing on sandy soils may actually die from unremedied drought stress, while those growing on clay soils may wilt progressively over a long period of time, but still recover with the addition of water.

***Vegetative soybean-water relations*.** Leaf growth is very sensitive to water deficits, and nearly all vegetative growth occurs at night when water conditions in the plant are favorable. Daytime leaf growth in soybeans is greatly reduced even in well-watered soils. If plants are exposed to reasonably good soil water conditions, they will recover overnight and growth will resume during the nighttime hours.

In general, water deficits in the vegetative phase slow the overall crop growth rate and result in shorter plants with less canopy leaf area resulting from fewer and/or smaller leaves. Water deficits in the vegetative phase that are severe enough to delay or prevent full canopy development may reduce seed yield potential.

If prolonged drought stress occurs during the vegetative period, the leaves at the top of the main stem and branch stems will essentially stop growing and turn dark green. If and when the stress is relieved, these leaves may restart growth, but they will not reach the size of leaves that developed during non-stress periods. Internode length is affected in essentially the same manner. Therefore, both leaf area and plant height will be reduced by unrelieved drought stress during vegetative development.

Aside from effects on canopy development, vegetative water-deficit stress can reduce the maximum potential seed number in soybeans. Seeds are produced in pods that develop from flowers on branch and main stem nodes. Stress severe enough to restrict plant size or branching reduces the number of nodes and therefore reduces the number of pod sites. This in turn will impact the number of seeds that can be formed in the reproductive stage.

Soybeans grown on coarse-textured sandy soils, such as those in the southeastern U.S., are more prone to yield-reducing effects of drought before flowering than soybeans grown on finer-textured clay soils. Thus, crops growing on sandy soils should especially be monitored for pre-flowering drought stress that may limit vegetative growth. Severe water deficits in these soils prior to flowering can render crops unable to realize maximum yield potential because of too little vegetative growth to support maximum reproductive development. Also, plants affected by severe drought stress are slow to recover upon the addition of water.

Deciding to irrigate soybeans before reproductive development is a critical management decision. Oftentimes, subjective evaluations of soil and plant factors can be used to determine its need. These evaluations should be based on the following factors.

- Soil water status at planting should be determined. Soil profiles where plantings are made in March, April, and early May in the Midsouth and where weeds or cover crops were killed with a burndown application of herbicides in late winter/early spring normally should be fully charged with water. Average rainfall after planting in the Midsouth will usually be sufficient to support adequate vegetative growth and development until reproductive development begins. In fact, results from research conducted in the Midsouth indicate that soybeans grown in the ESPS will rarely suffer adverse effects from drought stress during the vegetative period [between planting and R1]–i.e. water use does not exceed rainfall in an average year. Soil profiles where soybean plantings are made in June following wheat probably will be less than fully charged.
- The assumption that irrigation of vegetative soybeans will promote more rapid vegetative growth and taller plants across all soil texture classes is not valid. In fact, soybean growth during the first 30 days of development is relatively slow. Irrigating will not change this on medium and fine-textured soils. Soybean plants just need time for nitrogen N] fixation to reach high levels, and time for enough leaf area to develop to support future rapid growth.
- In doublecrop plantings that are planted in early June and later, irrigation may be necessary just to achieve a stand. Also, irrigation of doublecrop soybeans during vegetative development may promote more rapid canopy development in the shorter season with hotter days, warmer nights, higher atmospheric water demand, and less time each day for plant growth and development.
- A frequent assessment of vegetative development can be used to determine if vegetative plants are stressed from lack of water. A new trifoliolate leaf normally appears in the soybean stem terminal about every 3 days, and these new leaves should be light green in color and remain so until they are fully expanded in 5 to 6 days. If these new leaves turn dark green after their emergence and do not increase in size, then drought stress is occurring. Persistence of this condition will result in inadequate vegetative growth prior to flowering, and should be alleviated by irrigation if rain does not occur.
- Soil moisture sensors can be used to determine the need to irrigate during vegetative and reproductive development. It is generally accepted that sensors placed in the 0-24-in. soil depth should average 80-90 centibars [cb] to trigger irrigation application at any time during the growing season. This will rarely occur before reproductive development in early soybean plantings.

  The most critical factor when using soil moisture sensors to schedule irrigation is ensuring they are placed in the most representative area or areas of each field to be irrigated. If only one sensor site is used, it should represent the soil texture that is the majority of the field. However, multiple sensor sites may be needed or preferred in fields with variable soil textures. This will be the norm in a majority of soybean fields.

Reproductive soybean-water relations. Growth of pods and seeds, like that of leaves, is sensitive to plant water deficits. However, since these stages occur later in the season when soil moisture and rainfall are at their lowest seasonal levels, the potential for significant reductions in their growth and development caused by drought is great. The extent of this reduction depends on the longevity of drought.

The effect of drought on soybeans is most critical during the beginning bloom to mid-seedfill period [R1 to 5.5]. Even within this sensitive period, the exact effect of water deficits is dependent on timing and duration. For example, water deficits at R3 may result in a low number of pods being set, while water deficits after R5 may result in a high percentage of small seeds.

If water is readily available during early reproductive development [R1 to R3] but is deficient thereafter, the yield potential of the pod load established during that time cannot be maintained by the plant. Therefore, number of seeds per pod and/or seed size will be reduced. On the other hand, if irrigation is delayed until later stages of reproductive development R4 to R5.5], the potential pod load may not be realized. In this case, seeds per pod and seed size may be near or at maximum, but yield will be reduced because of the reduced number of pods. The largest seeds for a particular variety are often found when nonirrigated soybeans were severely stressed through R5, and then received water [irrigation and/or rain] afterwards.

Initiating Irrigation

Early plantings of MG 4 varieties. Much has been written about when to start irrigating soybeans in relation to reproductive stage. Much of this discussion stems from early research with scheduling irrigation for May [full-season and not doublecrop] plantings of MG's 5 through 7 varieties [CSPS]. This research was conducted during the 1980's throughout the southeastern U.S. The vast majority of the results proved that irrigating soybeans before beginning bloom did not increase yields above the level achieved from starting irrigation at beginning bloom.

The majority of soybeans in the Midsouth are now planted from late March through late April [ESPS], and the varieties are predominantly MG 4. The reproductive period for these plantings begins in early to mid-May vs. early July and later in the CSPS. Thus, the decision about when to start soybean irrigation should be based on this early development in ESPS plantings. The following can serve as a guide for making this decision.

Four planting dates from early April through early May for MG IV soybeans are shown in **Table 1**. For each of these planting dates, estimated dates for R1, R3, and R6 are shown, along with average rain and PE between the indicated stages at Stoneville, Miss. Estimated water use was derived from PE multiplied by a crop coefficient for the period.

Between planting and R1 for every planting date, water use does not exceed rainfall in an average year. Thus, irrigation in an average year will not be needed before R1 for MG IV varieties planted early.

Water deficit [water use minus rainfall] between R1 and R3 for all plantings is less than the 2-inch deficit normally used to trigger irrigation. Thus, irrigation will not be needed prior to R3 in an average year because the soil can supply the deficit amount of water.

The R3 to R6 period of all planting dates in an average year experiences water deficits that range from 5.9 to 7.3 in. When added to the R1 to R3 deficits, the R1 to R6 water deficits range from 7.4 to 8.1 inches. Thus, in an average year, plantings of MG IV varieties made from early April to early May will need 7.4 to 8.1 inches of irrigation water to realize maximum yield potential. Irrigation should be initiated no later than R3 for these plantings.

Of course, no year has weather exactly like that for an average year. Some years will have conditions that result in larger deficits than those shown here for the various periods. This means that irrigation should be initiated before R3 in some years, and/or more water should be applied during the season to realize maximum yield potential. The information presented here can be used as a benchmark for irrigation planning of ESPS plantings of MG 4 varieties in a given year at a given location. Actual rainfall amount received on a given field can be compared to that shown in the table to determine when irrigation should begin and how much irrigation water should be applied to supplement rainfall during the growing season.

Soil moisture sensor readings can be used to trigger irrigation of soybeans. Results from MSPB-funded research indicate that soybean grain yield, net returns above irrigation costs, and IWUE are optimized using a season-long, static 85 cb threshold. Moreover, research conducted at the farm scale encompassing approximately 23,000 km^2 showed that 85 to 100 cb thresholds utilized season-long did not adversely affect irrigated soybean grain yield or net returns above irrigation costs on soil textures ranging from silt loam to clay.

Table 1. Date of Planting [DOP], average rain and pan evaporation [PE] from planting to R1*, R1 to R3, and R3 to R6 at Stoneville, MS, and estimated soybean water use at R1, R3, and R6 dates. Assumes mid-MG IV variety. Rain, PE, and water use in inches.**

		DOP to R1*			R1 to R3*			R3 to R6*	
DOP	**Estimated R1 date**	**Rain/PE**	**Water use**	**Estimated R3 date**	**Rain/PE**	**Water use**	**Estimated R6 date**	**Rain/PE**	**Water use**
Apr. 5	May 15-19	8.0/9.9	5.0	June 2-5	2.4/4.5	3.2	July 23-26	6.1/14.1	13.4
Apr. 15	May 20-24	7.1/9.2	4.6	June 11-14	2.7/5.8	4.1	July 29-Aug. 1	5.7/12.9	12.3
Apr. 25	June 1-5	6.7/10.4	5.2	June 20-23	2.3/5.2	3.6	Aug. 8-11	5.4/12.8	12.2
May 5	June 10-14	6.1/10.7	5.4	July 2-5	2.7/6.0	4.2	Aug. 13-16	4.2/10.6	10.1

*R1 = beginning bloom; R3 = beginning seed; R6 = full seed.
**PE x crop coefficient of 0.5, 0.7, and 0.95 for the periods DOP to R1, R1 to R3, and R3 to R6, respectively.

May and later plantings. Irrigation of all MG's planted after early May should be started at or just before R1 in most years. Of course, there have been a few years in the past when drought stress was perceived to justify pre-R1 irrigation, especially with late plantings.

The process used in the table above can be used for help with the decision about whether or not to irrigate pre-R1 soybeans. Crop coefficients for Midsouth soybean water use are lacking, so only rough estimates using numbers from other regions and regional irrigation research experience can be made about how water use relates to pan evaporation during the vegetative period of these plantings. The Arkansas Soybean Production Handbook–Chapter 8 contains general water use numbers that can serve as a guide.

Those numbers and calculations from 25 years of irrigation research at Stoneville Miss. agree that the average water use for soybeans before R1 is about 0.16 in/day regardless of planting date after early May. Use this value coupled with rainfall and pan evaporation numbers and days from planting to R1 in the above box to determine the water deficit during the planting to R1 period. Again, soil moisture sensor readings can be used to confirm this.

There are three important points to consider when debating pre-R1 irrigation. 1) Not watering before R1 is not nearly as critical a mistake as not watering when needed during reproductive development. 2) Agronomically, starting proper irrigation too early will not damage soybeans. Economically, it may slightly decrease net returns if it does not increase yield. 3) Unnecessary irrigation that is applied too early will contribute to depletion of water in the main water source, the Mississippi River Valley Alluvial Aquifer [MRVAA].

Delayed Irrigation Initiation

The decline in the MRVAA due to withdrawal for crop irrigation in the Delta is documented [Czarnecki et al., USGS 2003]. Thus, there may be cases where a limited amount of irrigation water is available, and it is not enough for full reproductive phase [R1-R6] irrigation. It can be allocated for use during early reproductive development to establish maximum number of seeds, or to the latter stages of reproductive development to maximize weight of seeds. However, neither of these practices is likely to produce the maximum yield that may be required to maximize net returns unless adequate rain is received during periods of no irrigation.

An Oct. 2018 report by Francis et al. [CFTM] provides results from research that show the effect of delayed irrigation initiation on soybean yield and net returns in the Midsouth when soybeans were planted from late May through early June on both silt loam and clay soils. In their studies, they used the Arkansas Irrigation Scheduler program to determine irrigation events. The program recommends a 2.5-inch deficit for silt loam soils and a 2.0-inch deficit for clayey soils. The initiation delays in these studies were defined as the number of rainfree days [0, 5, 10, and 15] past the first target threshold, and rainfall during the delay period was factored into the deficit balance.

On the silt loam soil, 10- and 15-day delays in irrigation initiation reduced yields and net returns from MG 3 varieties in one of three seasons, and from MG 4 varieties in two of three seasons. For MG 5 varieties, none of the delays in irrigation initiation affected yields and net returns in any of the three seasons, but did result in a reduction of 2 or more irrigation events. Delays of 5 days did not negatively affect yields and net returns from any MG variety, but did result in one less irrigation event for all varieties in all years. The results from the silt loam soil indicate that a 5- to 10-day delay in irrigation initiation can potentially save at least one irrigation without sacrificing yield or net return from most varieties in most years.

On the clay soil, a 15-day delay in irrigation initiation reduced yield of MG 4 and/or MG 5 varieties in 2 of 3 seasons, but it reduced net returns in only 1 of the 3 seasons. A 10-day delay reduced yields and net returns in 1 of 3 seasons, and reduced irrigation by 2 events. The 5-day delay did not reduce either yields or net returns, but did reduce irrigation by 1 event. The results from the clay soil indicate that a 10-day delay in irrigation initiation can potentially save two irrigations without sacrificing yield or net return in a majority of years.

Scheduling Irrigation Between Initiation and Termination

Once irrigation is started, it must be continued on a regular basis to provide the maximum benefit. An initial irrigation that recharges the soil profile will essentially kill deep roots on clay soil, and the plant is therefore dependent on a shallow root system from that point on. Thus, continued irrigation will be necessary to ensure adequate water for the remainder of the season. Irrigation that is reapplied to soybeans growing on clay soil when soil water deficit is no more than 2 in. will result in the greatest yield increase.

Weather station data show that PE during the June through August period in the midsouthern U.S. is generally between 0.25 and 0.30 in. per day. During the irrigation period for soybeans, which encompasses these months, ET by the crop will be 0.8 to 1.0 of PE. If an average of 0.25 in. PE/day is used as a baseline, and it is assumed that ET will be 0.95 of PE, then a 2 in. deficit will be reached 8 to 9 days after an irrigation. This has been confirmed by many years' data collected from soil water measuring devices, and by measuring irrigation water applied to soybean research plots. Thus, in the absence of rain, surface irrigation of soybeans on clay soils should be scheduled every 8 days to achieve maximum yield. If rain occurs between irrigations, the amount for each event can be added to the 2 in. deficit. For example, a 0.5 in. rain will equal 2 days of water, so irrigation can be scheduled 10 days from the previous irrigation event.

For soybeans growing on soil texture classes other than clay, scheduling surface irrigations to recharge the soil profile should be governed by how much water a particular soil textural class will provide between irrigations. Therefore, sustaining production potential in a crop that uses 0.25 inch of water per day from an effective rooting zone of 18 inches requires surface irrigation of a fine sand every 5 to 6 days, of fine sandy and silty clay loams every 9 to 12 days, and of very fine sandy and silt loams every 12 to 15 days.

Re-irrigation with overhead systems is typically timed to system capabilities rather than to available soil water. Thus, regardless of soil texture, an overhead system designed to apply a net 1 in./acre should be scheduled to irrigate every 4 days in the absence of rain when estimated crop water use is 0.25 in/day. Obviously, getting behind with an overhead system is much more critical than with surface application methods.

The University of Arkansas College of Agriculture has developed the Arkansas Irrigation Scheduler. It is a computerized version of their Checkbook Irrigation Scheduling program.

Terminating Irrigation

***Timing of Termination*.** Deciding when to end irrigation of soybeans in a season is a simple matter. When beans have completely filled the pod cavity, R6 has been reached. This is later than the "pods touching" criterion that is often used, and is more closely associated with the R6.5 stage that is now being used as the stage beyond which irrigation is no longer needed. Having wet soil or applying a last irrigation to dry soil at or just before R6 will ensure that enough soil moisture is available to completely fill the many seeds that result from a well-watered environment. This will likely ensure maximum yield.

Stopping irrigation too soon will not result in fewer seed, but will result in smaller seed. A properly irrigated crop with a 70 bu/acre yield potential will have 12.5 million [3000 seed/lb] to 14.5 million [3500 seed/lb] seeds/acre. Thus, even very small reductions in seed size can translate to large reductions in maximum yield.

Here is an example using the 3000 seed/lb variety. Suppose you skip the last needed irrigation and suffer a 10% reduction in the seed size that would have been achieved with the last irrigation. This will translate to a nearly 6 bu/acre loss in yield. Compare this to the cost of the last irrigation, and it is obvious that considerable net income is lost, especially when bean prices are above $10/bu. This is especially pertinent considering that the full seed stage of ESPS soybeans occurs from mid-July through mid-August when drought stress is usually greatest and lack of optimum soil moisture will have the greatest negative effect on yield. [Remember that a missed irrigation this late will have little if any effect on number of seeds that were set as a result of earlier optimum water availability].

Soybeans growing on clay soil should receive a last surface irrigation [in the absence of rain] 12 to 14 days before R7, which coincides with R6. Assuming a water use rate of 0.12 to 0.15 inch per day from R6 to R7, this last irrigation will provide enough available water in an 18-inch rooting zone to carry the soybean crop to beginning maturity or R7. The following calculations illustrate this.

R6 to R7 is 12 to 14 days. Pan evaporation from Aug. 1 (0.24 in) to Sept. 30 (0.18 in.) averages 0.21 *in./day at Stoneville, MS. Multiply 0.21 x 0.55 [crop coefficient] to get 0.12 in. average water use per day during the period. Multiply the 12 to 14 days of the period by 0.12 in. water use per day to get 1.4 to 1.7 in. water used from R6 to R7. A last surface irrigation at or just before R6 will carry the crop to R7.*

***Soil texture and termination*.** The coarser the soil texture, the later the last irrigation should be. The shortest and longest times between the last irrigation and maturity should be in the order of coarse- to medium- to fine-textured soils, respectively.

Soybeans growing on soils with a low infiltration capacity or on coarse-textured soils with a low available water holding capacity may need a last irrigation after R6. This decision about a last irrigation is more critical for early plantings because they are in the R6 to R7 period during the hottest and driest part of the growing season [see Table 3].

Irrigation Period

Knowing when reproductive stages start and how long they last will result in the most efficient scheduling of soybean irrigation. **Table 2** contains estimates of R1, R3, and R6 dates for MG 4, 5, and 6 varieties that are planted during April, May, and June in central Mississippi. These dates should be amended somewhat for plantings made at more northerly latitudes.

For MG 4 varieties planted in early to mid-April, initiation at R1 should be planned for mid to late May, while R3 initiation should be planned for early June. Initiation at R1 will occur progressively later with later plantings. Termination at R6 ranges from late July through early September depending on planting date.

For MG 5 varieties planted in April, initiation at R1 should be scheduled for early to mid-June. Initiation of irrigation of May and June plantings will occur from late June through late July. R6 termination will occur from mid-August through mid-September, again depending on planting date.

For MG 6 varieties planted in May and later, R1 initiation should be planned for early July through early August depending on planting date. R6 termination for these varieties will be after mid-September. The lateness of properly timed irrigation termination for these plantings will likely interfere with harvesting of other crops.

Note that the R1 to R6 and R3 to R6 irrigation periods for MG's 4 and 5 become shorter for May and later plantings. However, the irrigation period for these plantings is during the hottest and driest time of year, so irrigation may be needed more frequently. Note also the nearly 3-week later date when irrigation is initiated at R3 vs. R1 in April and early May plantings of MG 4 varieties. If irrigation of these plantings is not needed until R3 as discussed above, the savings in time, water, and money will be significant. This is a strong consideration for planting early as an irrigation water conservation measure.

Table 2. Estimated range of dates for occurrence of R1, R3, and R6 of MG 4, 5, and 6 soybean varieties planted in central Mississippi during indicated periods of April, May, and June.

		Date range of stage occurrence			Irrigation days	
MG	**Planting period**	**R1**	**R3**	**R6**	**R1-R6**	**R3-R6**
4	Early April	May 15-19	June 2-5	July 23-26	69	51
	Mid-April	May 20-24	June 11-14	July 29-Aug. 1	70	48
	Late April	June 1-5	June 20-23	Aug. 8-11	68	49
	Early May	June 10-14	July 2-5	Aug. 13-16	64	42
	Mid-May	June 20-24	July 12-15	Aug. 21-24	62	40
	Late May	July 1-5	July 20-23	Aug. 30–Sept. 2	60	41
	Early June	July 10-14	July 27-30	Sept. 1-4	53	36
5	Early April	June 1-5	June 24-27	Aug. 16-19	76	53
	Mid-April	June 7-11	July 1-4	Aug. 21-24	75	51
	Late April	June 15-19	July 9-12	Aug. 27-30	72	49
	Early May	June 26-30	July 18-21	Sept. 1-4	67	45
	Mid-May	July 4-8	July 25-28	Sept. 5-8	63	42
	Late May	July 12-16	July 30–Aug. 2	Sept. 10-13	60	42
	Early June	July 20-24	Aug. 3-6	Sept. 12-15	53	40
6	Early May	July 5-9	Aug. 4-7	Sept. 14-17	71	41
	Mid-May	July 14-18	Aug. 11-14	Sept. 19-22	67	39
	Late May	July 20-24	Aug. 15-18	Sept. 20-23	62	36
	Early June	July 30–Aug. 3	Aug. 20-23	Sept. 23-26	55	34

Irrigation Methods and Their Management

The method of applying irrigation to soybeans is not a factor in the response of the crop to water. Rather, the timing of irrigation, as discussed above, is the most important consideration.

Soybean grown on the flat alluvial flood plain of the lower Mississippi River Valley in the midsouthern U.S. is irrigated primarily using surface methods. Furrow irrigation accounts for the major area of irrigated soybean, but flood irrigation is used to irrigate a large area, especially that rotated with rice.

A more detailed description of requirements and specifications for each method described below is given in Irrigation Methods published by the Univ. of Arkansas.

Surface irrigation–Flood. Flood irrigation results in inundation of a field area that is contained within a set of levees. Usually, the entire soil profile is completely recharged during flood irrigation. This method requires levees that take away land area for production, take time to survey and construct, and take time to knock down after the irrigation. Generally, levees are surveyed on elevations of no more than 0.4 foot. Flood irrigation is typically 50 to 60 percent efficient.

Soybean in the irrigated area is exposed to varying depths of standing water for varying periods of time. The flow rate of the water source and the size of the enclosed area being irrigated determine the time required to complete the flood. During the flooding period, an increasingly larger area is covered with water until the entire area within the levees or borders is finally inundated.

The process should be managed so that the entire area that is enclosed by levees or borders is flooded and drained within 2 days. Longer flood irrigation periods result in a yield increase compared to no irrigation, but the increase is less due to prolonged soil oxygen deprivation. The damaging effect of prolonged flooding [more than 2 days] is more severe for soybean grown on clay vs. silt loam soils.

Properly timed and managed flood irrigation results in soybean yields that are comparable to those resulting from proper furrow irrigation.

Surface irrigation–Furrow. This is the prevalent system of irrigation in the Delta. It requires grading the land to a slope of 0.05 to 0.5 foot per 100 feet of row. The best row grades are 0.15 to 0.3 percent.

Rollout vinyl pipe is most often used because of its ease of handling and its amenability to setups using Pipe Planner. Pipe Planner is an invaluable tool for ensuring even distribution of water down rows of unequal length in a field. Click the Pipe Planner link to access the latest information that explains how to configure the setup for an irrigated field.

On clay soils, proper irrigation scheduling will ensure irrigation water is applied before large cracks develop. Watering alternate middles is an accepted practice and is widely used on the clay soils. This is addressed in an article titled "Trouble irrigating cracking clay? Try wide skip rows".

Surface irrigation–Border. This system is a cross between flood and furrow irrigation. It best fits straight-levee rice fields or fields with no side slope. It is a flush system that moves water down the slope in a shallow flush between two small levees or dikes [borders]. The border spacing is based on the well's flow rate and the length of the field.

A border system should be designed to move water through a bay in no more than 24 hours. It provides uniform distribution of water to soybeans on a cracking clay, and is simple to operate once it is set up. The system works best where there are no side slopes, and has an efficiency of 60 to 80 percent.

Overhead irrigation. An overhead system [especially center pivot] can supply smaller amounts of water more frequently than can the flood or furrow methods. Most pivots are nozzled with capacities to apply 1 inch of water in 4 days. This results in a net application of at least 0.2 inch per day, which should meet minimal demand for soybeans. With this type of system capacity, the pivot is designed to run 24 hours per day, 7 days per week during peak water use.

Budgets. Irrigation costs are a significant factor because of high fuel prices and a relatively high capital investment. Arkansas and Mississippi have published budgets for the above methods. Budgeted costs for irrigation vary from state to state; they approach or exceed $100/acre. Each state's budgets can be used to get a general idea of the financial commitment required for soybean irrigation in a given area, and the yield increase necessary to cover direct and total specified costs.

Irrigating with Limited Water

There may be cases where only a limited amount of water for irrigation is available, and it is not enough for full reproductive phase irrigation. The use of limited irrigation early in the reproductive phase [R3 to R5] can ensure maximum number of pods, and is advantageous if rains are received during the latter stages of reproductive development. The use of limited irrigation only during the seedfill period can be advantageous for ensuring maximum weight of seed, but this approach assumes that adequate rain was received during the R3 to R5 period to achieve adequate podset and number of seed.

The probability of receiving rain during the early reproductive period is greater than the probability of receiving rain during the seedfill period [late July through early September] in regions with a high percentage of irrigated soybean. Thus, in cases with limited irrigation water, irrigation during the podset and seedfill periods appears to provide the greatest probability for maximizing yield with limited water for irrigation. This appears less risky than irrigating earlier and depending on infrequent late-season rain to enlarge seed that were set as a result of irrigation during early reproductive development.

This approach assumes that a reasonably high number of pod sites were formed in the absence of irrigation during early reproductive development. In hot and dry years that provide an extremely low yield potential, a single irrigation with a small amount of water, e.g. 1 in., at any reproductive growth stage is of no consequence toward improving yield to profitable levels.

The estimated dates of stages in **Table 2** can be used as a guide for planning application of limited water later during the season. For extremely limited irrigation that is initiated at R5, R5 dates fall roughly halfway between the dates for R3 and R6.

Irrigation Myths

Irrigation causes beans to wilt and die.

- During extended dry periods, roots will grow deeper into the soil profile. Soybean roots can easily go to depths of over 4 ft. As roots go deeper, the upper soil profile is left dry and large cracks appear in clay soils. When irrigation water is applied to these dry clay soils, water flows to the bottom of the cracks and fills the dry soil profile from the bottom up. Soil oxygen declines and roots die. The decimated root system is unable to supply water to the plant even though the soil is wet. Root regeneration slowly occurs as oxygen reenters the drying upper soil profile. Recovery often takes as long as 3 weeks. During this time, soybean plants wilt because the reduced and damaged root system is unable to support a mature canopy. Irrigation applied earlier in the season before severe soil drying occurs will prevent this condition in most cases.
- On medium- and coarse-textured soils that are low in organic matter and have surface crusting, water applied late in the season following a long dry spell may not be able to infiltrate in an amount necessary to alleviate drought stress. Thus, plants growing on these soils may wilt even after water has been applied. Irrigating before soil water deficit becomes severe on these soils, followed by timely subsequent irrigations, should prevent this from occurring.
- **The key to preventing this condition on all soil textures is to start irrigation early and before significant water deficits occur to ensure minimal root damage from the initial irrigation and to prevent severe soil water shortage.** Click here to access a guide to using soil moisture sensors to prevent this occurrence.

Irrigation does not increase yield.

- **Properly managed and applied irrigation will increase yield and profits even in "wet" years.** No year has perfect weather during the entire reproductive period. Therefore, irrigation timed to relieve drought stress in the "dry" periods of "wet" years will increase yields. The yield increases may be smaller in "wet" years, but they should still increase profits.
- **Irrigation isn't needed every year**. Yield increases vary from year to year, but properly irrigated soybeans always outyield nonirrigated ones, even in years with greater-than-normal rainfall. The key is proper

management according to the guidelines given above.
- **Remember, the fixed costs of irrigation are in place every year. Yield increases needed to cover variable costs aren't that great**.

Irrigation is too expensive.
- **It is expensive, but will result in increased profits if managed and applied properly.** See links to Midsouth states' budgets for irrigated soybeans to determine what yield increase is needed for profit. Remember, fixed costs for already-in-place irrigation setups are incurred even if irrigation is not used in a given year.

Some varieties water better than others.
This is hard to prove or disprove, but is probably not the actual case. Here is likely what really happens.
- Soybean varieties developed for the Midsouth are mostly selected and evaluated under irrigated conditions. So, their performance with irrigation is already known before they are released. Soybean varieties differ in their performance in general, and this should not change with irrigation.
- **The perception that some varieties water better than others is more than likely just a difference in the performance of the varieties *per se.***
- All of the Midsouth states conduct irrigated variety trials. When evaluating varietal performance in these tests, ensure that each variety, or more correctly the varieties within individual MG's, were irrigated according to the developmental patterns for that MG. Otherwise, invalid comparisons of irrigated yields among varieties of different MG's will be made.

Irrigation and Other Management Practices

Management practices and inputs for soybeans that are to be irrigated should be maximized–i.e. they should be geared toward producing the maximum potential yield. Certain management decisions are more important when irrigation is used, and they are discussed next.

Planting date/MG

Soybeans are planted from late March through June in the midsouthern U.S., a span of over 3 months. Choice of variety based on MG within this planting window is an important production and marketing decision. Assessment of long-term yield trends and DTM lead to the following conclusions for irrigated soybean production.

April Plantings. MG 4 varieties produce greater yields with less water, and thus have a greater irrigation efficiency [more bushels per inch of irrigation water] than do MG 5 varieties. They achieve these higher yields with a 16- to 20-day shorter growing season.

May 1-15 plantings. Using MG 4 varieties results in greater yields and greater irrigation efficiency than using varieties from later MG's. Again, they are also in the field for a shorter time.

May 16-31 plantings. Using varieties from MGs 4 through 6 result in similar yields, but irrigation efficiency is greater with MG 4 varieties. This, plus the longer DTM of later-maturing varieties, indicates that early-maturing MG 4 varieties should be planted in this period.

***Plantings after May 31*.** Varieties from all MGs produce relatively low yields even with irrigation.

Overall trends. Yields from and irrigation efficiencies of irrigated April and May plantings of MG 4 varieties are high relative to those of all other MG's. Planting varieties that are later than necessary for maximum yield increases DTM and the concurrent risk of detrimental late-season effects from insects, pathogens, and drought regardless of planting date. These increased risks may not be reflected in yield, but certainly will be reflected in the increased costs associated with their prevention and/or control.

Irrigating soybean varieties planted in April or early May almost always results in greater yields than does irrigating the same varieties planted later. To realize maximum yield potential with the least irrigation input, plant at the earliest acceptable time for an individual variety/MG and location.

Irrigation for emergence

A common dilemma sometimes faced when planting into dry soil is whether to water before or after planting to effect emergence. Crusting soils should be watered before planting to prevent the crusting and subsequent emergence problems that occur if irrigation follows planting. These soils dry quickly following preplant irrigation and planting can proceed with little delay. Shrink-swell soils [clays] can be watered before or after planting, but the advantages of watering after planting are greater than the disadvantages of watering before planting as indicated below.

- Planting is not delayed by waiting for the soil to dry that occurs if watering precedes planting on these soils with slow internal drainage.
- Rows planted in dry soil can be preplant cultivated or bedded for furrow formation to effect rapid down-slope movement and drainage of post-plant irrigation water.
- Preemergence/residual herbicides will be activated, and this has become increasingly important since they are now being used to introduce more modes of action into soybean weed control programs in order to control herbicide-resistant weeds.
- Seeds can be planted shallow to effect quick emergence.
- Irrigation water is not wasted as a result of watering unplanted acres that may receive rain before planting can occur.
- The earlier planting option offered by after-planting irrigation is valuable.

The disadvantage of after-planting irrigation is the effect that rain following irrigation and subsequent prolonged wet soil, along with low air temperatures, can have on germinating seeds and emerging seedlings. Thus, it will be paramount to apply a broad-spectrum fungicide seed treatment to provide protection against soil-borne pathogens that may reduce germination and emergence in cool, wet soils in the spring.

Weed control

Irrigation results in the development of the greatest plant height and main stem and branch leaf area, and the longest maintenance of canopy structure. Therefore, an assumption for any weed control strategy in irrigated soybeans is that this optimum canopy development and maintenance will facilitate or enhance weed control. In other words, it is possible that irrigation can serve effectively as an additional weed control tool through its enhancing effect on the soybean canopy. It follows, then, that weed control strategies for irrigated soybeans should be no more complex, and maybe even less complex, than those used for nonirrigated production.

Irrigation will exacerbate late-season weed infestations in soybeans that do not form a complete canopy during development. Thus, narrow rows should be used to ensure canopy closure, especially for early-maturing varieties planted early. Application of residual herbicides late in the season should be considered as a management option to control irrigation-enhanced weed infestations that may appear through incomplete canopies.

Insects

Irrigated soybeans provide a more favorable environment for insect development than do nonirrigated ones. Percentage yield reductions from uncontrolled insect infestations are greater in irrigated than nonirrigated soybeans. **Thus, soybean plants growing in a well-watered soil should be monitored closely for timely insect control to prevent yield-reducing damage**.

Soybean cyst nematode [SCN]

Optimally wet silt loam soil will promote and sustain increased populations of SCN. SCN infection of susceptible soybean varieties reduces seed yields, and irrigation will not overcome SCN-induced stress. Irrigation may slightly increase yield of susceptible soybean varieties grown in SCN-infested fields, but yields will be well-below yields from irrigated, non-infested fields or irrigated, infested fields planted with resistant varieties. Thus, irrigation efficiency will be low and irrigation probably will be unprofitable. Therefore, irrigation is not a viable management strategy to overcome SCN damage in SCN-infested fields.

Quick Guide

- Know the soil texture of irrigated fields. This governs the amount of water available to soybeans, especially before the start of irrigation. Texture is also an important factor in 1) determining the need to irrigate during vegetative development, and 2) determining how frequently to irrigate after initiation. Coarse-textured soils have the least plant-available water, and medium-textured soils have the most.
- Find or construct a reliable weather station that will produce accurate rain and pan evaporation data. See the University of Georgia link below for instructions for building, maintaining, and using an on-site pan evaporation device.
- Daily PE for many Mississippi locations can be found on the Delta Research and Extension Center website. Care should be taken when using offsite PE data to ensure that weather [rainfall, temperature, and sunlight] at both locations [data collection site and irrigation site] are the same. University of Georgia scientists have devised a home-made pan evaporation device that can be placed on-site. This can be a valuable irrigation tool when maintained properly.
- Put a rain gauge in every irrigated field.
- A good variety will be a good variety when irrigated, and a bad variety will be a bad variety when irrigated.
- Start irrigating April-planted MG 4 varieties no later than R3. Start irrigating May- and later-planted soybeans of all MG's no later than R1.
- Plan on a water use rate of at least 0.25 in./day during soybean reproductive development, which is the irrigated period in a majority of soybean plantings.
- Once irrigation is started, re-irrigate soybeans on clay soils with surface methods when a 2-inch water deficit has been reached to achieve maximum yield. Re-irrigate soybeans on other soils according to texture. Coarse-textured soils require the most frequent irrigations, while medium-textured soils require the least frequent. Re-irrigate with overhead systems based on system capability and estimated daily water use.
- Starting irrigation too soon or re-irrigating more frequently than advised here will not cause harm or reduce performance. However, any of these unnecessary irrigations go against water conservation principles and will result in lower net returns and overuse of water.
- Determine the total length of the irrigation period for a particular MG and ensure that irrigation system capacity and time allotments for each dedicated well will match the length of that period. Having too little of either will result in less than maximum yield and return.
- Waiting too late to start irrigation during persistent drought may cause irreversible damage to soybeans, and can be worse than not irrigating at all.

- Terminate irrigation to have optimally wet soil when R6 occurs in soybeans growing on medium and fine-textured soils. Coarse-textured soils may require additional irrigation between R6 and R7.
- Terminating irrigation too soon will result in lost yield because of less-than-maximum weight of individual seeds. The lost revenue from the lost yield likely exceeds the cost of a final irrigation that is skipped.
- All methods of irrigation will produce equivalent yield gains if they are managed properly.
- If irrigation water is limited, postpone irrigation until R3 or R5 rather than watering earlier and quitting.
- Insects prefer irrigated over nonirrigated soybeans; therefore, scout closely for late-season insect infestations in irrigated plantings.
- Irrigation will not overcome stresses from SCN.
- Irrigated soybeans require the highest level of pest management to realize the full benefit from irrigation. Remember, with proper irrigation drought stress will not occur to limit or minimize the effect of yield-enhancing inputs. Irrigated beans are the ones to receive the highest level of management.

From years of research with soybean irrigation, the following tenets were determined.

- Planting clay beans on beds guarantees the highest response from irrigation.
- Stopping irrigation before R6 can result in as much as a 10 bu/acre yield loss.
- Insects prefer irrigated over nonirrigated beans.
- Irrigation never decreased yields, even in so-called wet years.
- Soybeans will not wilt when initial irrigation is applied early in the reproductive period before severe drought stress occurrs.
- Flood irrigation, when properly managed, results in soybean yields that were on a level with those that were furrow- and border-irrigated. When soybeans are irrigated with the first flood application at the proper time, they quickly adapt to this semi-saturated soil culture and are very responsive to subsequent flood applications.
- Irrigated beans were always more profitable than those not irrigated.
- Irrigation is the only management practice that will consistently result in high yields and profits.
- Irrigation never replaced good management of other inputs or overcame bad management decisions. It worked best with the highest level of management of all other factors.
- Cracking clay soils should be irrigated before large cracks appear.
- Crusting soils generally allow less than 1 inch of water to infiltrate before runoff occurs under an overhead system.
- Many of the declarations of yield increases that should be realized from irrigating soybeans are too low. This misrepresentation of the value of irrigation in soybean production does a disservice to its true worth, and could discourage some producers from investing in the one management input that can result in long-term success and profitability. Properly managed irrigation of soybeans should result in yield increases of 20 bu/acre or more.
- Many research studies and variety trials that claim to be irrigated are really “watered”–i.e. water is applied to these sites when convenient or when it is subjectively determined they are under drought stress. Irrigation applied in this manner without proper scheduling based on stage of development and the determination of soil moisture status will usually result in under-watering and attainment of less yield than would have been achieved if irrigation had been properly scheduled. Management of irrigation in these studies should be just as intense as that for weed and pest control to ensure that drought stress is not a factor that confounds the results.
- When soybeans are damaged by inundative surface irrigation too late following a lengthy drought period, they take about 3 weeks to recover. This lost 3 weeks severely reduces yield potential. In fact, if it occurs late in reproductive development, they may never recover and can yield less than nonirrigated soybeans.
- Irrigation was the only input that when properly managed never disappointed at harvest. This simple statement is the most powerful testimony for irrigation’s importance in Midsouth soybean production.

Conservation of Irrigation Water

In 2014, the MSPB launched the SIP (Sustainable Irrigation Project) initiative to address the need to curtail the amount of water that is withdrawn from the MRVAA to irrigate Mississippi crops. The SIP initiative is designed to highlight and promote the use of practices and management tools that will result in a reduction in the amount of irrigation water that is applied to the state's irrigated crop acres.

The first phase of the project involved soliciting commitment from Mississippi producers to using water conservation tools such as:

- ***PHAUCET (click here for details and description)***. The PHAUCET program was developed to improve distribution uniformity of irrigation water delivered from gated pipe. The PHAUCET program is used to determine the size of holes to punch along the length of a polypipe irrigation set. This is based on pressure change along the tubing, pipe diameter, the different row lengths that will be encountered along an irrigation set, and the elevation changes that occur down the length of the pipe. The program is especially valuable for irregularly shaped fields. Using this program may allow irrigation of a greater number of rows in a set, should allow irrigation water to reach the end of variable length rows more evenly, and can help reduce runoff and irrigation pumping time. A wide range of experiences has shown at least a 25% reduction in pumping time and applied water, and a reduction in irrigation costs.
- Pipe Planner has supplanted PHAUCET as an easy-to-use tool that can be used for the above purpose. Its setup and design examples are shown on the Pipe Planner site.
- ***Surge irrigation on furrow-irrigated soybeans***. With furrow irrigation, continuous flow from the entire line of irrigation pipe is the norm for applying water. However, applying water intermittently to an irrigation furrow results in water moving to the end of irrigated furrows quicker than when applied by continuous flow. This can be accomplished by using a surge valve with an automatic controller, which automatically cycles irrigation water between the two sides of the valve. The net result is smaller applications of water applied with each irrigation and less total irrigation water applied during the season, concurrent with equal yield and net returns.
- ***Multiple/Side inlet (video) water application to fields divided into multiple paddies***. Click MP 192, Ark. Rice Prod. Handbook, Chapter 10 to access details about this method.
- ***Zero grade for flood irrigation***. Mississippi's crops are often irrigated by the flood method, which is the inundation of a field or paddy with water from one or a few sources vs. irrigation water that is delivered into individual furrows from multiple outlets in a line of pipe that is placed on the upper end of a field. This irrigation method results in irrigation water running to the low end of a field or paddy before filling the area contained within levees that separate individual paddies. This then results in more water on the lower than on the upper end of a paddy at the end of an irrigation cycle. Zero grade is the term used to describe the process of making a field completely flat. This tool is used to remove slope within a field so that irrigation water is distributed at an even depth over the entire field during flood irrigation. Levees are not required within the irrigated area. The net result will be that less water is required to flood an individual paddy at each irrigation event. Click here for an economic analysis of zero grade irrigation by Univ. of Arkansas specialists.
- ***Tail-water recovery [TWR] from surface-irrigated crops.*** Tailwater recovery is a planned system to collect, contain, and transport water runoff from irrigated areas for use in subsequent irrigations. It is commonly used to collect and reuse water from surface irrigation of crops. Benefits from this process are 1) conservation of irrigation water by capturing and reusing the irrigation runoff water from a field, and 2) improvement of off-site water quality by preventing the downstream movement of sediments, nutrients, and chemicals that are suspended in the runoff irrigation water. Collection facilities may include ditches and on-farm water storage structures that are built for this purpose. Tailwater recovery systems may improve irrigation efficiencies from 25 to 30%. Click here for a video describing the process and here [447-CPS-1, Sept. 2020] for an NRCS publication that provides complete details about a TWR system. A publication titled "Pesticide trends in a

tailwater recovery system in the Mississippi Delta" by Nelson, Moore, and Witthaus provides details about and findings from a study that was conducted in the Mississippi Delta to assess the trends in pesticide concentrations that may be contained in water that is collected in a TWR system. Results from this study showed that pesticides commonly applied to fields devoted to soybeans, corn, cotton, and rice were frequently detected in TWR system ditches and reservoirs. These findings show the potential for cross-crop injury and sensitivities to the pesticides that may be contained in irrigation runoff from fields devoted to those aforementioned crops. Thus, 1) water in a single TWR system reservoir that is collected from fields devoted to more than one of the aforementioned crops should be evaluated for pesticides that may adversely affect any of the other crops that will have water from this reservoir applied to them, and 2) it may be advisable to have a separate TWR system reservoir devoted to the collection of runoff water from each individual crop during a growing season to ensure that this water is only reused to irrigate that crop. This will likely increase the costs associated with construction of TWR systems, so this should be evaluated economically to ensure that it is cost-effective.

- **Conclusions**. The voluntary adoption of the above and other forthcoming water conservation techniques and technologies should provide a significant contribution toward conserving the Delta's water resources as well as increasing irrigation efficiency and lowering producer costs. The commitment of Midsouth soybean producers to this effort will provide a meaningful impetus toward increasing the adoption of these and other practices that will conserve water and sustain the Delta's irrigation capability. These efforts will be required to ensure the continued sustainability of the MRVAA as the major source of water for irrigating Midsouth crops.

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