SUSTAINABLE SOYBEAN PRODUCTION IN THE U.S.

INTRODUCTION

The word “sustainable” in relation to agriculture is being bandied about nowadays, and means different things to different people or members of particular groups based on their agenda or understanding of food production.

Sustainable crop agriculture is an integrated system that should:

- Meet the current and future demands for human food and fiber, and animal feed;
- Enhance environmental quality by maintaining or improving the soil, air, and water resource base;
- Make the most efficient use of nonrenewable resources such as fossil fuels and mineral fertilizers;
- Be commercially competitive to maintain economic viability of farm operations; and
- Enhance the quality of life for producers and be viable enough to support the rural agriculture community.

Thus, sustainable agriculture can be described as farming systems that incorporate practices that result in the equal maintenance or enhancement of environmental quality and profitability; i.e., a production system that is environmentally sound must be profitable for it to be adopted and used by producers over the long term.

Sustainable soybean production is not to be confused with “organic farming”, which is often misrepresented as the only form of “sustainable agriculture”. Organic farming occupies a niche that can be described as small-scale sustainable agriculture.

An integral part of sustainable crop production that usually is not mentioned in this context is the complementary area of maintaining a viable production research base that will continue to produce the new technology and innovations that are necessary to sustain current and future agriculture productivity

Soybean production in the United States has changed since its introduction into the Corn Belt in the mid-1800s. Initially, the crop was produced mainly for forage and received only minimal inputs. Its husbandry evolved to become a grain crop that is a major source of both protein in animal diets and vegetable oil for human consumption.

Today, soybean production in the U.S. is a significant agricultural enterprise involving large acreage and intense management with myriad inputs. Thus, it follows that the definition of sustainable soybean production mimics that of sustainable agriculture in general.

This article presents and discusses the soybean farming tools that are available, and how they and their application may change or evolve to affect sustainable Midsouth soybean production into the future. This discussion will include soybean farming tools in the areas of production and management, irrigation, breeding/genetics/variety development, and disease, nematode, insect, and weed management/control.

The contents of this article include current and forthcoming practices, concepts, and technology that will be available and/or necessary to produce sustainable soybean yields in the Midsouth on a large scale, and that will be necessary to meet the needs/demands of a growing domestic and international market.

PART I.
PRODUCTION/MANAGEMENT PRACTICES

Growing soybeans in the Midsouth (generally below 37 deg. latitude and west of Alabama) is affected by production environments that include:

- Both alluvial and upland soils;
- Planting dates from late March through mid-June;
- Both dryland and irrigated systems;
- A doublecropping system with wheat;
- Rotation systems with cotton, corn, or grain sorghum;
- Summer drought with high temperatures;
- Infrequent inundating rainfall events from late-summer tropical storms;
- Maturity dates from late July—mid-Oct.

Sustainable production and management practices for soybeans in the Midsouth should be directed toward maintaining the regional yield average to a level that equals or exceeds the national average (click here to see article). The following management categories are discussed in this context.

Tillage. Equal or greater yields coupled with decreases in erosion, water runoff, and fuel use support the premise that growing soybeans in the Midsouth with conservation tillage is more economically and environmentally sustainable than with any other tillage system. In fact, conservation tillage is the only tillage approach that realistically supports environmentally sustainable soybean production in the Midsouth.

Research is needed to determine the need for and how to integrate periodic operations such as deep tillage to remedy soil compaction and row-crop cultivation to control herbicide-resistant weeds into a conservation tillage system.

Cover Crops. Cover crops are not widely used in soybean production systems in the Midsouth. However, cover crops provide positive environmental benefits, especially in the winter months between successive soybean crops on upland soils.

The drawback to their use is the lack of income to offset the cost of establishment and destruction. This can be offset somewhat by developing technologies that lower costs associated with their use, by instituting a program of government incentive payments to encourage their incorporation into a production system, and by using a cover crop such as wheat that provides income in a doublecrop system.

Crop Rotation. The perception in the Midsouth is that crop rotation provides positive production and environmental benefits to both soybeans and the rotated crop for the following reasons.

- Rotation of a grain crop with soybeans decreases erosion potential because of the greater residue after harvest of the grain crop.
- Energy output:input ratios favor rotating soybeans and a grain crop.

Long-term soybean:corn rotation research conducted in the Midwest has determined the allowable reduction in nitrogen (N) fertilizer requirement for a grain crop following soybeans. However, the amount of this reduction is unknown in a Midsouth soybean:grain crop rotation. Thus, it is unreasonable to assume that results from Midwest research will directly transfer to the Midsouth. The reasons are:

- Midsouth soil properties present a much different environment for off-season maintenance of soil N levels because of higher soil temperatures and frequent long-term soil saturation that results in anaerobic conditions. This results in greater losses of soil N during the winter months.
- Higher temperatures in the Midsouth during the winter months will result in greater decomposition of crop residues between harvest and next season's planting. This also will affect residual soil N levels.
- Lower dryland yields in the Midsouth will presumably result in different N use patterns by corn, and subsequently, less crop residues.

Midsouth corn and soybean researchers should make a concerted and cooperative effort to initiate and conduct research that will ascertain the perceived benefits/effects of a soybean:grain crop rotation system of production.

Soil Fertility. The tenets of soil fertility management for sustainably growing soybeans in the Midsouth are unchanged.

- Sustainable and environmentally sound soil nutrient management continues to rely on the "tried and true" process of accurate soil sampling and soil tests. A systematic process of sampling over time and space should be used to ensure accurate fertilizer additions based on crop yields and the different soil properties within and among production fields.
- Variable rate technology can be used to prevent over-fertilization of portions of a field. This will help to ensure that wasteful application of expensive fertilizers will be minimized on fields that have variable fertilizer requirements.
- Application of both soil- and foliar-applied N fertilizer to soybean is unjustified and incurs unnecessary expense with no benefit.
- Maintaining soil pH in the range of 6.0 to 7.0 will enhance availability of fertilizer nutrients, decrease availability of toxic elements, and improve microbial activity.

Agronomic research in collaboration with Agricultural Economists is needed to verify current soil test recommendations to ensure that expensive fertilizer elements are applied only in an amount that will ensure maximum economic return from their use. This may mean that application of a fertilizer element in an amount recommended by a soil test result is not fully applied in a current crop season in the hope that its future price will decline so that a makeup application can be made in a subsequent growing season.

Planting Date. Early planting (late March through mid-April) of soybeans (ESPS) in the Midsouth is now commonplace and has been associated with a higher yield plateau for the last decade. The ESPS is used as a mechanism to avoid drought, avoid or reduce susceptibility to late-season pest infestations, reduce amount of irrigation water applied, and ensure early harvest.

Current and future research results should soon provide sound guidelines for managing the late-season seed decay problem that plagues the widely-used ESPS for growing soybeans in the Midsouth.

PART II. BREEDING AND VARIETY DEVELOPMENT

Breeding and variety development will provide advances that arguably will have the greatest impact on sustainable soybean production in the U.S. and the Midsouth.

The U.S. soybean germplasm collection contains genetic material that can be screened for new traits and genes that will provide enhanced genetics for improved yield potential, host-plant resistance, and enhanced seed traits in forthcoming new varieties. Soybean breeders and geneticists also have access to global germplasms that may have additional genes that can be incorporated into new genotypes to impart resistance to plant pathogens and insects, and management of abiotic stresses.

These resources, coupled with advances in transgenics or biotechnology, have provided and hopefully will continue to provide the genotypes necessary to increase actual and net yields through improved resistance to both biotic and abiotic stresses.

The following points emphasize how soybean breeding efforts and advances in genetics research will continue to enhance production sustainability and efforts supporting Midsouth soybean farming.

Conventional breeding strategies have been and will continue to be successful in developing soybean lines and varieties with traits that improve yield and resistance to pests. Examples are the identification of genes that confer resistance to Asian soybean rust and the development of lines and varieties with resistance to soybean aphid.

- Varieties that possess specialty or value-added traits that improve or enhance seed quality for human food and animal feed uses are available or forthcoming. Examples are high-oleic/low-linolenic oil lines/varieties and low phytate lines. Development of varieties with these and other enhancements will improve soybean's position in the marketplace and further contribute to sustainability of production.
- Breeding lines that offer potential drought tolerance have been developed, and are available for incorporation into variety-development programs.
- Transgenic varieties with resistance to nonselective herbicides have been and continue to be developed. New transgenic traits have imparted resistance to more than one herbicide or class of herbicides. An example is the Enlist™ weed management system from Dow AgroSciences.
- Both public and private soybean breeding programs currently use transgenic varieties as parent material for future variety development. This allows new soybean varieties to have resistance to multiple pests and herbicides since the new varieties that are developed will build on the transgenic traits present in the parent material.

The challenge for Midsouth soybean breeders and geneticists will be to ensure that past advances that have provided resistance and/or tolerance to pathogens such as stem canker and nematodes, and herbicides such as metribuzin and glyphosate, are not lost in the progressive development of new varieties.

The challenge for Midsouth soybean producers will be to identify specific conditions and pests that can be managed by varietal traits. This will be important since not all varieties will contain all the genetic traits that may be necessary to control problems or conditions that exist in all fields. Thus, using variety yield as a selection criterion must be supplemented with also looking at pest resistance and herbicide tolerance traits in newly-released varieties.

PART III.
DISEASE MANAGEMENT

Diseases can and do cause economic losses in midsouthern soybeans. The below points outline the soybean farming tools that can/may be used to reduce or prevent these losses and enhance the sustainability of soybean production in the region.

Until the early 2000's, many diseases could be managed only with resistant varieties or with cultural practices that were marginally effective as soybean farming tools. This use of resistant varieties has now been complemented by the development and use of fungicides that are effective against many of the pathogens that cause soybean diseases.

Click here to access a summary of major midsouthern soybean diseases and soybean farming tools that can be used for their prevention/control.

Several important diseases (e.g. stem canker, sudden death syndrome [SDS], Phytophthora root rot [PRR], seed and seedling diseases, charcoal rot) of soybeans have no curative control; i.e., these diseases may be prevented but not cured once present.

- Stem canker, SDS, and PRR can be prevented or avoided by using less-susceptible or resistant varieties. Development of varieties with resistance to stem canker is an example of a major development in using genetic resistance to effectively manage a devastating soybean disease.
- Seed and seedling diseases (caused by numerous fungi that include *Cercospora, Fusarium, Phomopsis, Pythium, Phytophthora*) can be effectively prevented in the early season by using seed treatments.
- There are no resistant varieties or fungicides for charcoal rot management. Additionally, it is likely that the majority of germinating seed are infected with the causal agent *Macrophomina phaseolus*. Thus, it is considered a major problematic disease.

An array of foliar fungicides is available for application to prevent several prominent soybean diseases. Preventive fungicides (e.g. strobilurins such as azoxystrobin [Quadris] or pyraclostrobin [Headline]) are most effective when applied prior to or at the earliest appearance of a disease.

Soybean rust can be managed with applications of preventive and curative (e.g. triazole, such as flutriafol [Topguard] or tetraconazole [Domark]) foliar fungicides timed according to occurrence of rust in sentinel plots or Extension advisories. Additionally, and based on previous years' experience, rust may be avoided in the Midsouth by planting early-maturing varieties early so that R6 or full seed stage is reached before about August 1. This is an example of a cultural practice that is an effective soybean farming tool to use against a potentially problematic disease.

Soybean breeders, geneticists, and pathologists in the Midsouth are currently working to identify and/or provide genetic sources of resistance to *Phomopsis* seed decay (PSD) and charcoal rot. Results so far are promising. Resistance to PSD has been identified in soybean plant introductions (PIs), and a line with moderate resistance to charcoal rot has been released. These accessions can be used to develop varieties with resistance to these two diseases.

Presently, there are no transgenic disease management traits in soybeans. However, disease management through molecular genetic approaches may be forthcoming as an additional soybean farming tool that will be available for disease prevention and/or control.

From the above discussion, the sustainability of Midsouth soybean production from a disease management standpoint rests on the following points.

- Soybean breeders should (and presumably will) continue to develop varieties that are either resistant to or tolerant of the damaging effects of the prevalent diseases that can plaque susceptible soybean varieties in the Midsouth. This should involve the continual screening of potential varieties in disease nurseries to ensure these new varieties have the disease resistance necessary to withstand infection from prevalent pathogens in the Midsouth. Also, the process of new variety development must ensure that already-incorporated pathogen resistance (e.g. resistance to stem canker) is carried forward into the new genotypes.
- Charcoal rot and PSD, two diseases that are considered major problems, must receive increased research attention to ensure that the needed resources are available to continue the screening of germplasm and incorporation of identified resistance genes into new varieties. These two diseases should receive priority research attention since they can be associated with large economic losses when environmental conditions favor their prevalence.
- For fungal diseases where host-plant resistance has not been identified and fungicides are the only tools available for their management, current effective fungicides and those that may be forthcoming should be used in an integrated management approach to mitigate development of resistance in fungal populations and to avoid secondary environmental impacts.
- For fungal diseases where resistant varieties are available, they should be used. This is even more important for future sustainability since frogeye leaf spot resistance to strobilurin fungicides has been identified in several states. The Fungicide Resistance Action Committee classifies the strobilurin fungicides as being at high risk for targeted fungi developing resistance to them.
- A promising avenue for control of fungal pathogens that cause soybean diseases is the use of biological pesticides (e.g. biopesticides) that can be applied to control targeted pests. This is discussed here.
- Soybean rust, though devastating if allowed to infect soybeans, should not be a major disease threat to Midsouth soybean production sustainability if fungicide applications, when needed, are timed according to sentinel plot data (if still in place) and Extension recommendations. Furthermore, planting early-maturing varieties early is a proven effective management tool to avoid rust infestations in the Midsouth. Resistant varieties should be considered since resistance genes have been identified.
- Click here to access a White Paper that discusses disease management topics.

PART IV. NEMATODE MANAGEMENT

Soybean producers in the Midsouth must contend with nematode pests that include soybean cyst nematode (SCN), southern root-knot nematode (RKN), and reniform nematode (RN). A guide to nematode management in midsouthern soybeans can be accessed on this website.

<u>What We Know</u>

Accurate identification of the nematode species and population levels present in a field requires that soil samples be collected and sent to a diagnostic lab for evaluation. The ideal time to sample is in the fall, either shortly before or soon after harvest when nematode numbers are highest.

SCN is the most damaging pest to soybeans in the U.S.

RN has not been a major threat to growing soybeans in the Midsouth.

Using resistant varieties is the best tactic to prevent yield-reducing damage from all three nematode species.

The number of current varieties that are resistant to RKN colonization is low. Using varieties that are only moderately resistant will allow RKN populations to be maintained or increased.

Resistance to RKN is more prevalent in Maturity Group (MG) 6 through MG 8 varieties than in MG 5 and earlier varieties.

Breakdown of resistance to RN in soybean has not been reported.

Major damage to soybean by SCN infestation occurs when the crop is grown on medium- and coarse-textured soils. RKN tends to be associated with sandy soils.

Crop rotation, an effective tool for managing all three nematode species when growing soybeans, should be considered along the following lines.

- **<u>SCN</u>**: Growing nonhost crops such as corn, cotton, and grain sorghum successfully reduces SCN populations.
- **<u>RKN</u>**: Growing soybeans in a rotation with rice that is flood-irrigated or grain sorghum will lower RKN numbers dramatically. The commonly used rotational crops of corn, cotton, and wheat all serve as hosts for RKN, so growing soybeans in rotation with these crops is not a control measure.
- **<u>RN</u>**: Growing soybeans in a biennial rotation with rice, grain sorghum, or corn, which are poor hosts for RN, is an effective management tactic. Rotating soybeans with cotton, which is an excellent host for RN, should not be done on infested fields.

Continuous planting of a soybean variety with resistance to a specific population of a race or type of SCN could lead to the development of a different SCN race that damages the crop, making that variety useless for SCN control.

It is important to determine the race of SCN in a field and the race-specificity of the resistance gene of a previously planted soybean variety when planning to use a new resistant variety for SCN management.

Resistant varieties are more reliable and cost-effective than nematicides for managing and/or reducing nematode populations.

Nematicides applied to seed or used in-furrow can reduce early-season root infection by nematodes, but do not provide season-long control.

Nematicides will not replace the use of resistant varieties and variety/crop rotation as primary nematode control practices.

Nematicide products (e.g. Votivo, Poncho/Votivo, Activa Complete Beans, and Clariva Complete Beans) are available, but their effectiveness in situations with known populations of nematodes is not well known. Therefore, there is no supposition that they will or should replace the accepted practices for nematode control and/or management.

What We Need to Know/Have for Sustainability

Research to determine the damage potential of nematodes and to establish action thresholds for injury or control when growing soybeans is lacking in much of the southern U.S. Damage thresholds for recent "newcomers" such as RN to the soybean arena have not been well established.

The newly-available Bt soybean for control of SCN must be thoroughly evaluated for efficacy against this most damaging pest of soybean.

Widespread use of MG 4 and earlier varieties in the Midsouth has become common. Therefore, early-maturing varieties with RKN resistance are needed for use in Midsouth rotation systems that may include corn, cotton, and wheat on coarse-textured soils that have threshold levels of this nematode.

SCN resistance in the majority of varieties is derived primarily from one genetic source. This has led to the adaptation (race shift) of some SCN populations. To sustain soybean production on SCN-infested soils, more genes for resistance need to be incorporated into the public germplasm pool so that resistant varieties continue to become available for use as the most effective management tool against future SCN populations.

Research is needed in soil environments with known levels of nematode infestations to determine the long-term effectiveness of and economic return to nematicides that are now available for use on soybeans. Click here to access a White Paper on this website that provides details about the nematicides that are available.

PART V.
INSECT MANAGEMENT

Insects can and do cause economic losses in soybeans that are grown in the Midsouth. The below points outline the current tools that can/may be used to reduce or prevent these losses and enhance the sustainability of Midsouth soybean farming, along with potential new technologies that may become available in the future.

Integrated Pest Management (IPM) has been promoted and used for insect management in Midsouth soybean farming, and has resulted in significant cost savings and limited environmental impact. Some IPM components for soybean insect control include:

- Scouting fields for insect pests to determine if/when curative measures are needed based on thresholds that have been established for individual insect species;
- Relying on and protecting native insect predators and pathogens to allow them to play a key role in regulating some insect pests;
- Adjusting planting date to avoid damaging infestations of late-season defoliators and pod feeders; and
- Applying insecticides when damaging insect outbreaks occur.

Three factors contribute to soybean insects being managed differently than other pests.

- Host-plant resistance in soybeans is available and has been for many years, but high-yielding varieties with resistance to insects that are problematic in the Midsouth have not been developed.
- Transgenic insecticidal soybeans based on *Bacillus thuringiensis* (*Bt*) endotoxins are efficacious against defoliating insects. However, varieties with these traits have not yet been marketed in the U.S. The demand for them will be based on their efficacy against the most problematic insects affecting U.S. soybeans. This in turn will determine whether or not breeding material will become available for use in future U.S. soybean variety development.
- Because of the above two factors, control of damaging populations of soybean insects presently relies mainly on the timely application of insecticides.

There are documented cases of evolving soybean insect resistance to various insecticide chemistries that are being applied to crops in addition to soybean in the Midsouth. This resistance to insecticides can decrease sustainability of soybean production in the region by reducing or eliminating insecticides as options for insect control.

To ensure that current soybean insect management strategies remain effective for soybean insect control and that future insect management is sustainable for Midsouth soybean farming, the following points should receive attention.

- Thresholds used to trigger insecticide applications to control soybean insects should be verified for the various soybean production systems used in Midsouth soybean farming. It is likely these thresholds will differ among production systems—e.g., irrigated vs. nonirrigated, monocropped vs. doublecropped.
- The effectiveness and economics of using insect-resistant and/or transgenic soybeans as part of the strategy for control of soybean insects in the Midsouth should be evaluated to determine if their use will affect economic yield and/or subsequently reduce dependence on insecticides as a management option.

PART VI.
WEED MANAGEMENT

Weeds in soybean fields arguably pose the greatest threat to sustainable soybean production in the Midsouth. The battle to control/manage weeds has been at the forefront of soybean production issues since soybeans became a major US crop.

US soybean farming based on weed management tools can be divided into four distinct periods.

Period before herbicides

Tillage, both pre- and post-plant, was the only available tool for weed control in soybeans. Wide-row spacings were used so that post-plant cultivation could be effectively conducted. Weed escapes were common, resulting in reduced yield and difficult harvest. Late in this period, over-the-top applications of 2,4-DB were applied at or soon after layby to provide late-season control or suppression of problematic broadleaf weeds. Johnsongrass became a major weed problem in many fields.

Period before glyphosate-resistant (GR) soybean varieties (pre mid-1990's)

Before transgenic GR soybean varieties appeared in the mid-1990's, weeds in soybeans were controlled/managed by a combination of tillage and "conventional" or non-glyphosate herbicides, followed later in the period by sole reliance on pre- and post-plant applications of conventional grass and broadleaf herbicides.

Early in this period, preplant herbicides such as Treflan were applied either in the fall or before planting in the spring. This operation required tillage but did aid in early-season weed management, especially of johnsongrass and pigweed.

Glyphosate (Roundup) entered the weed management scene as an in-season herbicide applied to conventional (non-transgenic) varieties through recirculating sprayers and rope-wick applicators. This methodology was directed at weeds that were taller than soybean plants; thus, it was only effective later in the season after early-season competition between weeds and soybeans had already occurred.

In the late 1970's/early 1980's, Roundup and paraquat came into use as preplant, foliar-applied (burndown) herbicides that were effective without tillage. This use of herbicides in place of preplant tillage allowed a major acreage to shift to the various conservation tillage systems and the stale seedbed planting system.

During the latter part of this period, pre- and post-emergence selective herbicides became available to control most grass and broadleaf weeds. Narrow row culture of soybeans and limited and no-tillage systems became manageable.

Period of GR soybean varieties (mid-1990's to late 2000's)

Development of transgenic GR soybean varieties was arguably the most significant step toward a sustainable weed management system for soybean production. Glyphosate used on GR soybeans became the primary weed control system because this one herbicide killed both grass and broadleaf weeds when applied either pre- or post-plant. Limited and no-till systems became widely used, weed control costs were lowered, total poundage of applied herbicides declined, labor inputs declined, and narrow row culture became the norm. GR soybean varieties were planted on nearly all of the US soybean acreage toward the end of this period.

The period of GR weeds (present and future)

The selection for resistance to glyphosate by numerous weed species has tempered the effectiveness of relying solely on applying glyphosate to GR soybeans. In fact, weed resistance to glyphosate has generated possibly the most intense discussions and activity in the history of soybean weed management. It is widely agreed that this problem will change the soybean farming tools available for weed management. Suggested solutions have included reverting to a conventional weed management system (non-glyphosate herbicides and non-GR soybean varieties). Problems with the sustainability of this system are:

- Producers will have to consider tillage as a component in a conventional weed management system. This would necessarily require reverting to wider row spacings for post-emergence cultivation. Increased pre- and post-plant tillage are not feasible or practical in today's agricultural environment because of erosion concerns, labor constraints, and farm size.

- Available non-glyphosate herbicide chemistries are becoming less effective.
- No new non-glyphosate herbicide chemistries are forthcoming.
- The number of conventional varieties has decreased to a level that will not sustain a large acreage of their production.
- Weed management solely with conventional herbicides was not/will not be all that successful.
- Future soybean breeding efforts likely will use transgenic, herbicide-resistant parents to develop new varieties.

Soybean varieties with transgenic traits will be the soybean farming tools that will provide the foundation for future sustainable weed management systems in the U.S. and Midsouth. Factors supporting this statement are:

- Transgenic varieties with resistance to nonselective, non-glyphosate herbicides have been and will continue to be developed. These include Liberty Link, Optimum GAT, and varieties with 2,4-D and dicamba resistance.
- Varieties are available that have transgenic traits that will impart resistance to more than one herbicide or class of herbicides. An example is the Enlist™ weed management system from Dow AgroSciences.
- Forthcoming transgenic varieties with multiple transgenic weed management traits will be necessary to slow or stop the development of weeds that are resistant to particular herbicides.
- All of the tools for weed management in conventional soybeans can be used with transgenic herbicide-resistant varieties. Using conventional herbicides with current and forthcoming new herbicide-resistant varieties in an integrated approach will ensure that glyphosate and GR soybean will continue to be a major component of a sustainable, environmentally acceptable system for weed management in soybeans.
- As stated previously, new herbicide chemistries are not forthcoming. However, the use of transgenic varieties with multiple weed management traits allows for the use of myriad herbicide tank mixes and premixes that contain ingredients with more than one mode of action.

Using soybean varieties with transgenic traits as the primary weed management tool in production systems that include soybeans presents the following challenges.

- The use of varieties and hybrids, all with transgenic herbicide resistance traits, in a soybean:grain crop rotation will require that producers and consultants acquire a thorough knowledge of the transgenic traits in each crop and herbicide mode-of-action to ensure control of targeted weeds and support of resistance management.
- Weed scientists, specialists, and consultants must be trained and skilled in cross-crop weed management since most crops in a rotation system will be transgenic, with genetic traits for resistance to multiple herbicides.
- Controlling volunteer plants of an alternate-season rotation crop will be more complex since all crops in a rotation system likely will contain transgenic herbicide resistance traits that are effective for use with the same herbicides or classes of herbicides.

The dynamics of weed populations and species composition in response to soybean production practices and weed management systems creates a moving target for management that nullifies attempts to create a static sustainable weed management system in soybeans. However, the above points can be used to ensure that soybean farming tools used for future weed management are as sustainable as possible.

PART VII.
IRRIGATION MANAGEMENT

Producers growing soybeans in Mississippi irrigate the third most acres in the U.S., second only to Nebraska and Arkansas (also in the Midsouth). The facts about irrigating soybeans in the Midsouth include:

- The vast majority of the irrigated soybean acres are in the Delta;
- Properly irrigated soybeans will yield at least 20 bu/acre more than nonirrigated soybeans;
- Irrigation results in consistent soybean yields that are more profitable than yields from nonirrigated soybeans;
- Amount of irrigation water applied to soybeans is a significant portion of the total applied to Midsouth crops; and
- Most of the water used for irrigating Delta soybeans is pumped from the Mississippi River Valley Alluvial Aquifer (MRVAA).

Each year, the Yazoo-Mississippi Delta Water Management District makes measurements throughout the Delta to estimate water volume changes in the alluvial aquifer. Across the 2005-2010 period, the estimated change in the aquifer level averaged a loss of about 234,000 acre-ft/year–the change was negative in 5 of the 6 years. In fact, over the last 24 years that these measurements have been made, 15 years have shown estimated declines in the aquifer level. Obviously, this adds two more facts to the above list.

- The current level of water extraction from the MRVAA aquifer is not sustainable, and
- Both physical and management changes must occur to sustain irrigation as a viable management practice for growing soybeans in the Midsouth.

Physical changes that can help change this trend include land leveling to zero grade, reducing runoff and/or recapturing excess irrigation water, and using water from on-farm surface water storage structures and/or impoundments. Using water saving technologies such as surge valves, soil moisture sensors, and PHAUCET/Pipe Planner will lessen the amount of water that is applied to a crop.

Management changes will be directed toward applying less water to soybeans during the growing season. This approach is important because even a small reduction in groundwater withdrawal will stabilize the aquifer's water level. Consider the following.

- If soybean irrigation in the Delta is cut by 1 acre-inch each year, an estimated 75,666 acre-ft. of water will be conserved.
- If soybean irrigation in the Delta is cut by 2 acre-inches each year, an estimated 151,333 acre-ft. of water will be conserved.
- If soybean irrigation in the Delta is cut by 3 acre-inches each year, an estimated 227,000 acre-ft. of water will be conserved. This amount is essentially equal to the average drop in the aquifer during the measurement period.

Another option that may be harder to accomplish is irrigating with limited water, a concept explained in the article that can be accessed here. It may be what the future holds in the

Midsouth if irrigation and crop management practices for water conservation are not widely adopted or are not successful on a wide scale over the next few years.

Recently, a producer friend emailed a novel approach (not to him) to the above. His comments (with some editing) follow. "You may recall that years ago I asked you for a steady source of information on non-GMO MG 3 soybean trials. You might recall that my rationale was that I didn't wish to irrigate soybeans because it was expensive, we often yielded nearly as much by not irrigating, and someday we might be faced with aquifer problems. You suggested I peruse Midwestern university trial results. After a few trials, I settled on mainly University of Illinois information, and now annually order all seed from sources there."

"The last 2 years, we have had to irrigate to get a respectable crop. Although my yields may not be the area's best, they are near the top and are economically and sustainably more viable to produce. Last year, many that looked rather poor yielded 50 to 55 bu/acre, and this year that same rather shabby appearance yielded between 65 and 83 bu/acre. The key is they are planted at rates between 260 and 400 thousand seeds/acre, with expected stands of 10-15% less than that. This forces them to grow upward. They are planted flat with water furrows every 80 ft. to allow drainage and irrigation water to flow down the field. In the driest of conditions (and I have had them) on land rotated with rice or corn, they require only two irrigations. If this could be adopted on a wide scale, it could be an important part of conserving the Delta's aquifer." This may be the type of new approach that is needed to sustain soybean irrigation capability in the Delta.

Three research approaches are needed in the coming years to determine what route to take to reduce the amount of irrigation water applied to soybeans while still maintaining near maximum profitability.

- Determine the yield and economic effects of reducing seasonal irrigation amounts applied to normal soybean plantings over the usual irrigation period,
- Determine how and when to irrigate with less water during the irrigation period in order to minimize or negate the effect on soybean yields and net returns, and
- Determine if a new paradigm is needed for growing soybeans that are to be irrigated as per the above email quote. It is unlikely that the above specific approach can be adopted on a wide scale at the present time because 1) there will not be enough seed of non-GMO varieties, or 2) seed of GMO varieties likely are not affordable at the above seeding rates.

While none of these options may be acceptable in the short term, they may be required for the long-term sustainability of the alluvial aquifer and subsequently the future availability of water for soybean irrigation.

When it comes to irrigating soybeans in the Delta, the new thinking will necessarily become "how to produce a maximum sustainable yield rather that how to produce maximum yield". Research will be required and should be planned and conducted to determine how to accomplish this on an economical scale.

U.S. SOY SUSTAINABILITY ASSURANCE PROTOCOL

The American Soybean Association (ASA) and the United Soybean Board (USB), working with the U.S. Soybean Export Council (USSEC), have formulated and compiled the Soy Sustainability Assurance Protocol (SSAP) to provide guidelines that will support SSAP certification of soybeans that are produced in the U.S. The SSAP describes the regulations, processes, and management practices that, when implemented by producers, will ensure certification of sustainable soybean production.

APRIL 2024 UPDATE

It has been written in many venues that financial incentives from both private and public agencies will be required to encourage crop producers to adopt environment-friendly conservation production practices such as cover crops [CC], conservation tillage [CT], nutrient and irrigation management [NIM], and conservation crop rotation [CCR]. However, it is likely that such incentives will not last forever, and may even have a designated time frame of years beyond which the financial incentive(s) will end. Little is known about how the discontinuation of these financial incentives will affect the continued adoption of conservation production practices. An article titled "Persistence and disadoption of sustainable agricultural practices in the Miss. Delta region" by Pathak et al. addresses this issue. Pertinent points from this article follow.

- About 2 million acres in the Delta region of Ark., La., and Miss. have some type of conservation practice applied to them, and the rate of adoption of these practices is increasing at a rate of about 25% annually.
- Of the three states, Miss. had a relatively higher proportion of acres with conservation practices applied to them during the 2005-2021 period.
- In the Delta region, producers are more likely to continue NIM and CCR at the end of a cost-share contract. Conversely, producers tend to disadopt CC's and CT at the end of such a contract.
- These results indicate that producers are likely to stick with conservation production practices that show a positive economic return in the short-term at the end of a cost-share contract [in this case, NIM and CCR].
- These results also show that, at the end of a cost-share program for a conservation practice, the acreage devoted to conservation practices predominantly transitions among different conservation practices rather than reverting to a no-conservation-practice status. Thus, incentivizing conservation is important since it likely leads to a consideration of conservation agricultural practices in general.

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