THE 2014 UNIVERSITY OF ILLINOIS

Corn & Soybean Classic

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ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
College of Agricultural, Consumer and Environmental Sciences
Department of Crop Sciences

The Unusual Weather of 2013 and the Outlook for 2014

Dr. Jim Angel
Illinois State Climatologist
Illinois State Water Survey
Prairie Research Institute
2204 Griffith Drive
jimangel@illinois.edu
217-333-0729

Introduction

The 2013 growing season saw weather challenges including record rainfalls in spring that delayed planting, cool weather in July, and warm, dry weather in August, September, and October. The statewide monthly precipitation and temperature departures for 2013 in Illinois are presented in Figures 1 and 2.

Wet Spring

After the drought of 2012, there were still lingering concerns about the full recovery of soil moisture, stream flows, lake levels, and ground water levels as late as March 2013. However, Illinois experienced much above-average rainfall in April, May, and June. The statewide average precipitation in April was 7.1 inches, 3.3 inches above average. The statewide average precipitation in May was 7.2 inches, 2.4 inches above average. The statewide average precipitation in June was 5.4 inches, 1.2 inches above average. For the combined three months, the statewide total was 19.7 inches. In addition, the precipitation for this period was widespread across the state. However, the heaviest amounts of 20 to 22 inches occurred in western Illinois and south-central Illinois.

Looking at the first six months of 2013, the statewide average precipitation for January–June was 29.0 inches, nearly 9.5 inches above average and the wettest January–June on record. By contrast, the same period in 2012 was less than half that amount at only 12.7 inches. Because of the widespread heavy precipitation in the spring of 2013, Illinois experienced considerable flooding during that period.

After a mild winter, cold air finally arrived in Illinois in late February. March was cold with temperatures 6.6 degrees below average. April was cold as well with temperatures 2 degrees below average. May and June were much closer to average.

The combination of the cold spring and heavy precipitation caused considerable delays in fieldwork. Waterlogged fields were a common site across the state through June.

Strange Summer

Cooler than average conditions returned in Illinois in July. Temperatures were 2 to 3 degrees below average for the month. Precipitation was 25 to 75 percent of average in the northern half of the state and 100 to 175 percent of average for the southern half. After the planting delays in the spring and a cool July, some exceptionally cool weather in early August prompted concerns about the risk of early fall frost given how far behind the crops were in development.

Summer-like heat finally arrived in the second half of August and continued throughout September. Temperatures during this time were 2 degrees above average across the state.

The below-average precipitation that started in northern and western Illinois in July extended to the rest of the state in August and September. The statewide August precipitation was 1.6 inches, 2 inches below average, and the third driest August on record. The statewide September precipitation was almost as bad at 1.9 inches, 1.4 inches below average. While the warmer and much-drier conditions during this period helped get crop development back

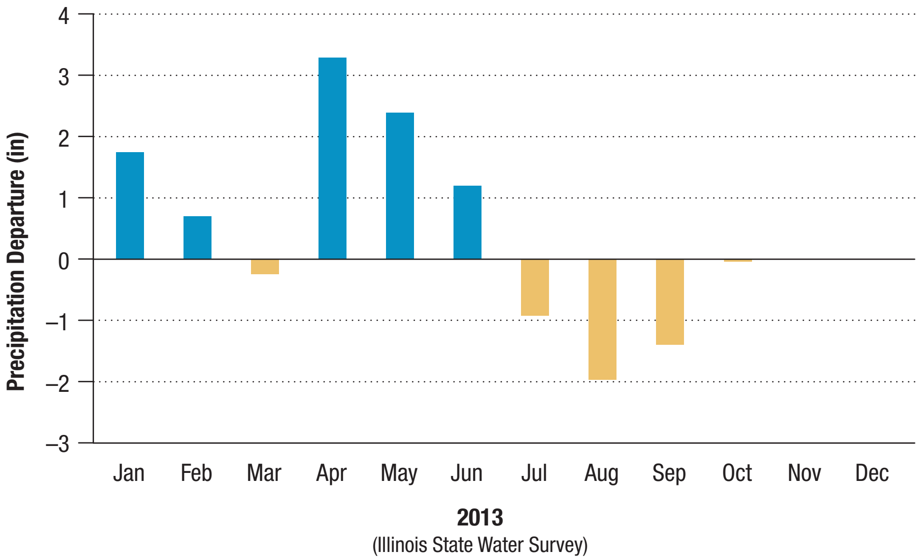

Figure 1 ■ Monthly precipitation departures for Illinois.

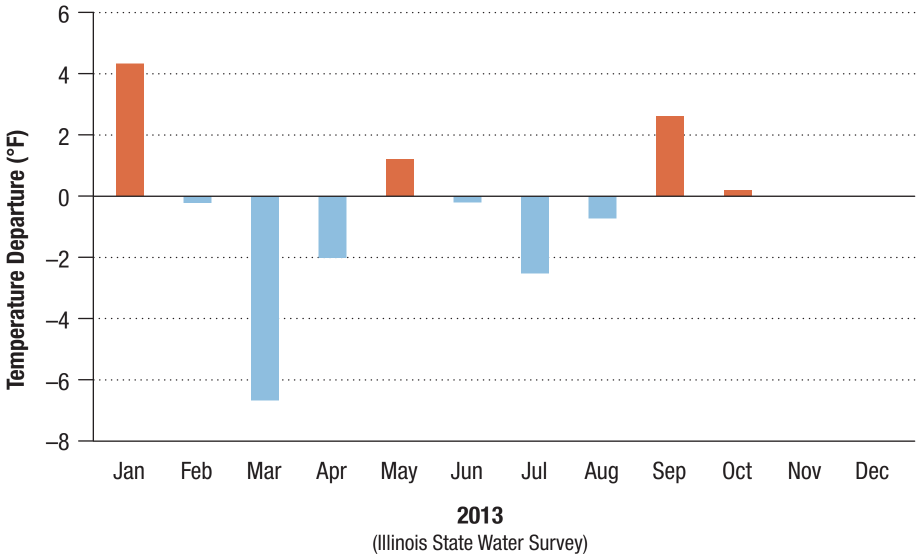

Figure 2 ■ Monthly temperature departures for Illinois.

on track, soil moisture was depleted rapidly in a matter of weeks. As a result, concerns of a late season “flash” drought emerged.

Mild Fall

During October and November, both temperatures and precipitation returned to near-average conditions. Precipitation was widespread. With the corn and soybeans reaching maturity, the demand on soil moisture was reduced. This allowed the precipitation to soak in and stay put, resulting in the slow but steady recovery of soil moisture.

Outlook for Winter and 2014 Growing Season

The National Weather Service outlook as well as other evidence for the upcoming growing season will be reviewed during the talk.

By Finesse or Force: Getting Soybeans to Produce High Yields

Emerson D. Nafziger
Professor of Crop Sciences
W-301 Turner Hall
ednaf@illinois.edu
217-333-9658

Soybean breeders and agronomists conducted a recent study in which they planted soybean varieties released in different years, starting in the 1920s and going up to recent releases. They found that the gain from breeding was similar to the actual gains in U.S. soybean yields over the past 80 years. This suggests that much of the yield gain has come from genetic improvements. Of course, management improvements, including herbicides, pesticides, and equipment, have enabled the crop to turn genetic potential into actual yield.

If yields improvements in soybean are closely tied to genetic improvement, can we expect use of the many inputs available today—products such as fertilizers, micronutrients, growth regulators, and combinations of these—to increase yield beyond what the genetic potential makes possible? That's the question we will address here.

Variety: Most land grant universities, including the University of Illinois, run variety trials at a number of locations each year. Entries are mostly those that are marketed by seed companies, but these trials do not include all varieties sold in the state. The range from top to bottom performers in a variety trial is typically about 15 bushels per acre. So variety selection is important. Because seed companies have access to much more data than any university, it's important to work with seed companies to identify the best varieties for fields in an area. Our data show that maturity of varieties is often less important than their genetic potential; the response to maturity in trials is usually less than the range of yields within a trial.

Planting date: We've conducted a number of planting date trials in recent years, and have found that in general, planting in late April or early May increases yields under high-yielding conditions, while under average or lower-yielding conditions, there is often not much response to planting early (Figure 1). While in these trials most of the lower-yielding sites were in southern Illinois, we know that early planting also raises yields in favorable seasons in southern Illinois; we don't see that as much because early planting is often difficult and high-yielding conditions are less common there. Since we don't know whether a season will turn out to be high-yielding, it makes sense to plant soybeans as early as practicable, beginning as soon as corn planting is finished. That will increase yields if the growing season turns out to be favorable.

Row spacing: We have compared 15-inch to 30-inch rows in many of our planting date studies in recent years, and have found that 30-inch rows almost never yield more than 15-inch rows, and that 15-inch rows have yielded significantly more than 30-inch in about half of these trials, with an average difference of 2.4 bushels per acre. This advantage doesn't seem to be greater or more common under high-yielding conditions than it is with average yields (Figure 2). This does not mean that everyone should use narrow rows, but if the savings from using wide rows are less than the cost of 2 bushels of soybeans, wide rows may not be the best choice. We don't have much data on 20-inch rows, but believe that they will yield about the same as 15-inch rows, and perhaps slightly better if rows aren't planted into wheel tracks.

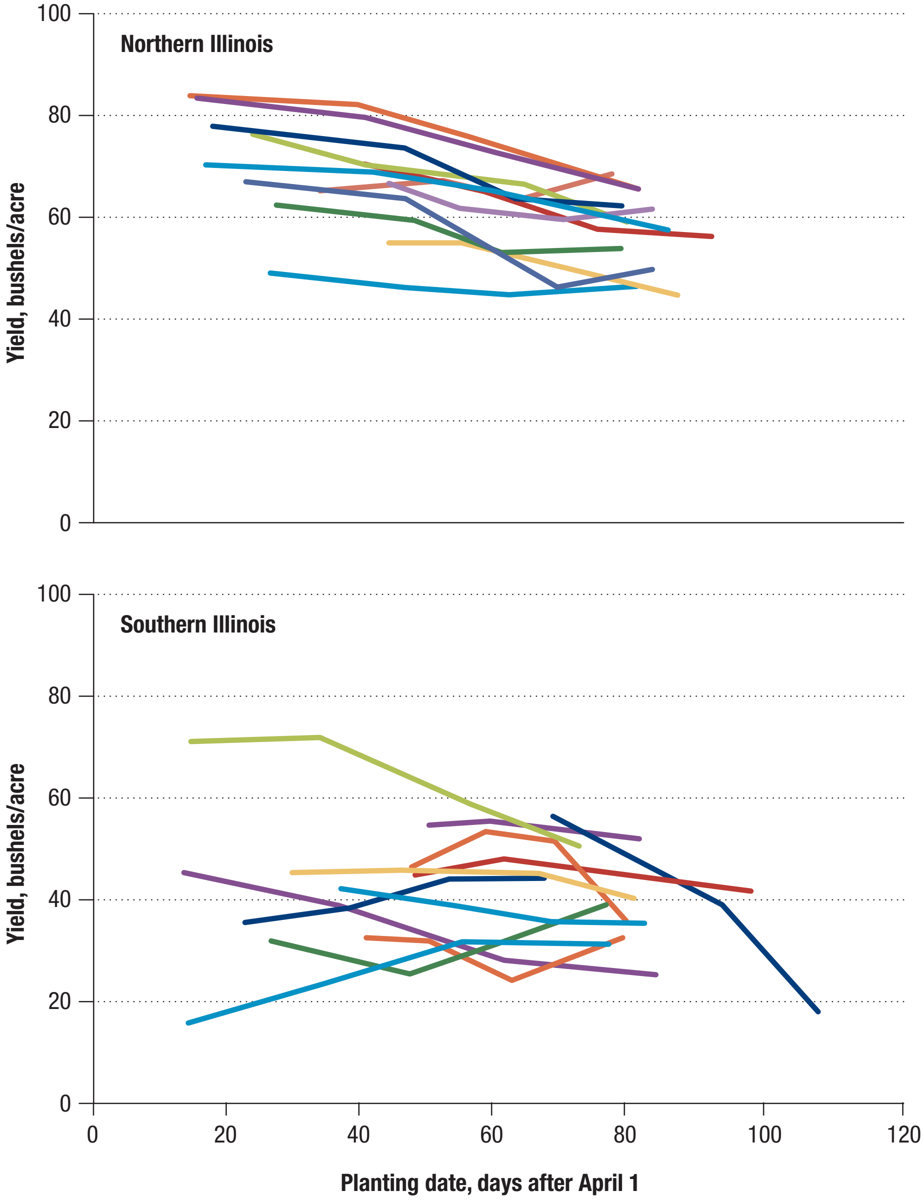

Figure 1 ■ Planting date responses in Illinois trials, 2010-2013

Seed treatments and seeding rates: We won't spend much time on these management aspects, since these are more or less "standard practice" now. Numerous trials over the past five years have shown that establishing 100,000 plants per acre will normally maximize yields, and seed treatments can often help assure that we get adequate stands when we seed 125,000 to 150,000 seeds per acre. Inoculants today are often combined with other products to make up combination seed treatments, often making them a more "routine" input than they have been historically. We have not found inoculants to increase yields routinely in fields where soybeans have been grown sometime in the previous 5 or 6 years. Since we would expect any such effects to be small, it's not likely that research trials will often identify them even if they do occur.

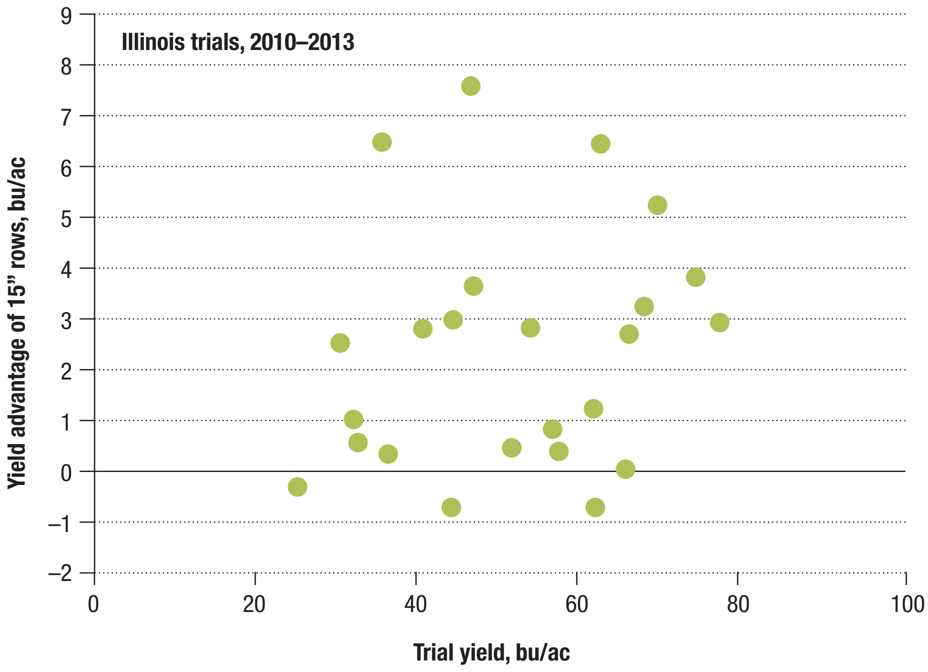

Figure 2 ■ Yield difference between 15-inch and 30-inch rows over 24 Illinois trials, 2010-2013. All yield differences greater than 2 bushels per acre were statistically significant; all those less than 2 bushels per acre were not significantly different.

Micronutrients: As do all crops, soybeans require very small amounts of elements like iron, manganese, zinc, and others in order to develop and yield normally. In a series of 14 studies over the past 4 years that included various mixtures of micronutrients, we have been unable to find a statistically significant response to these products (Figure 3). This does not "prove" that micronutrients never pay for themselves, but it does indicate that responses will not be consistent. Some people separate out nutrients like sulfur that are required in more than "micro" amounts and suggest these need to be added.

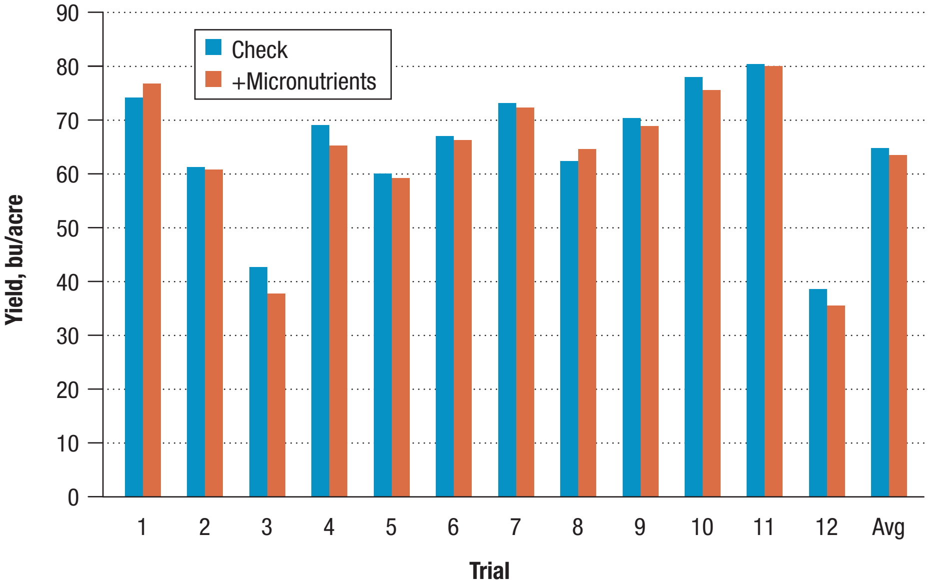

Figure 3 ■ Results of micronutrient trials in Illinois, 2012-2013. None of the differences was statistically significant.

Most attempts to raise soybean yields in Illinois by adding S fertilizer have not been successful, but on light or low organic matter soils, it's possible that soybeans might respond to S sometimes. We do not have a good way to know when that might be the case, though.

Growth regulators: Soybean plants need growth-regulating substances to develop normally. Soybeans, like all plants, produce such substances themselves. So the question is whether or not adding more of one or more of these substances to the crop during its growth will affect plant growth and physiology in a way that produces higher yields. We've done many trials using various products and combinations of products, and have not found a consistent response, or in most cases, any response at all (Figure 4). This does not mean such a response can never happen, but it does indicate that the soybean plant seems capable of producing the proper amounts (and ratios) of such substances without help from humans.

Nitrogen: Soybeans require a great deal of N—a 70-bushel crop takes up a total of about 330 lb of N per acre, and the harvested seed has about 240 lb of N, or about 3.45 lb of N per bushel (which is about 36% protein.) Although bacteria-containing nodules on soybean roots are normally capable of fixing (from the N in the air) all the N the crop needs in addition to what it gets from the soil N supply, there are some reports in the large body of published literature that soybeans sometimes respond to fertilizer N. Some have suggested that high soybean yields might require so much N that the plant can't fix enough. It also takes energy from the plant to fix N, and so it might make logical sense that saving that energy by providing fertilizer N might leave more energy to produce yield. We have applied N in different forms and amounts in Illinois, and have not been able to find a significant response, regardless of yield level, in recent trials (Figure 5). Most of the reports of yield responses are from areas with less-productive soils than in Illinois, and in some cases the bacteria that form nodules might not be present in high enough numbers. We're still interested in seeing if there might be a way to

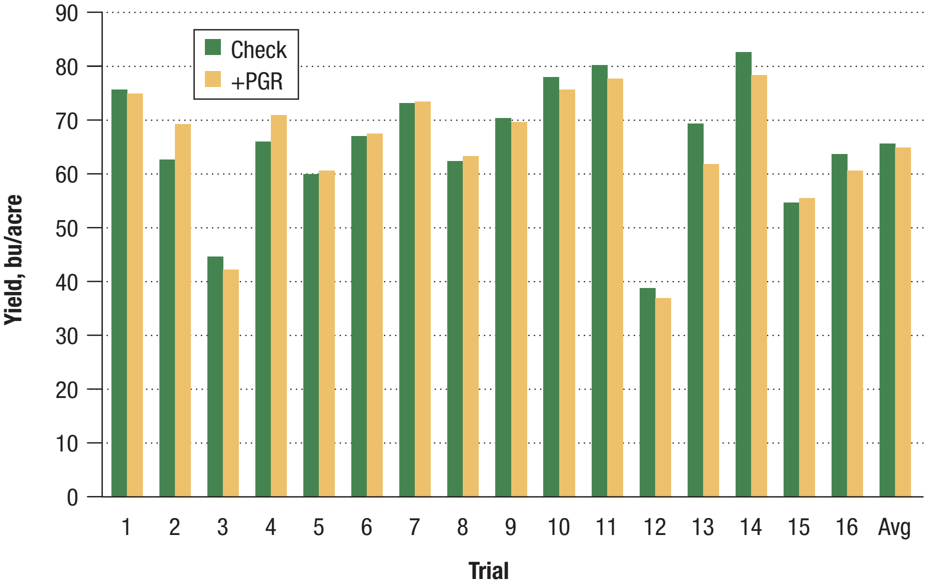

Figure 4 ■ Response of soybean yield to plant growth regulator in 16 Illinois trials.

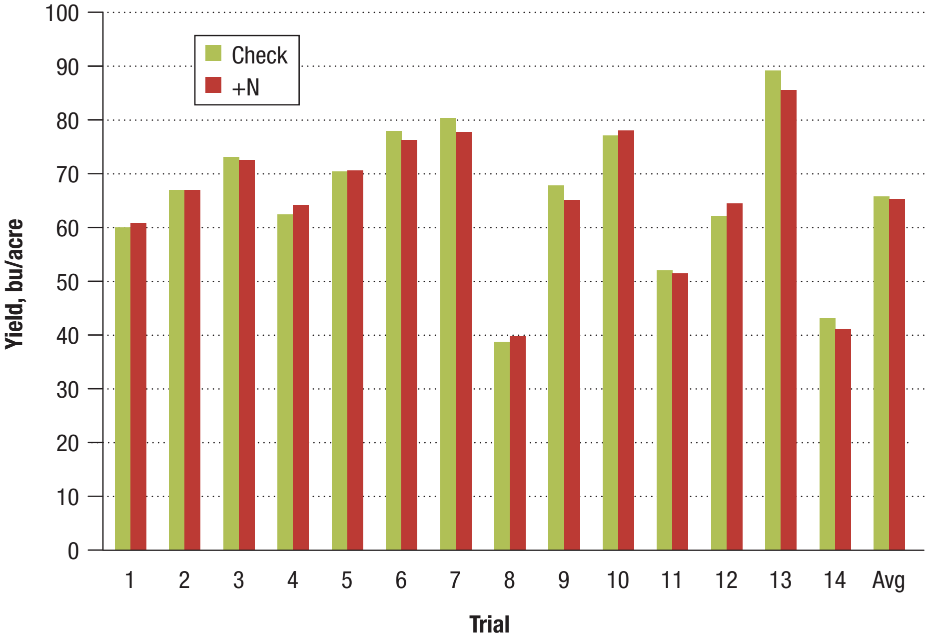

Figure 5 ■ Response to in-season N applied to soybeans in Illinois trials, 2010-2013.

raise soybean yields with N fertilizer, but for now, it seems unlikely that there will be enough response in Illinois fields to pay for this input.

Foliar fungicide and insecticide: Unlike many of the inputs we have tried, we have in some cases found a yield response to foliar fungicide. Diseases common on soybean in Illinois—sudden death syndrome, brown stem rot, soybean cyst nematode—are not controlled by fungicide, and Sclerotinia white mold is only partially controlled by some fungicide classes. So a response could come from control of less-visible diseases or those that might develop after application, or there may sometimes be a physiological response. Still, the average response to fungicide and fungicide + insecticide in trials over a 4-year period in Illinois was not significant, and the few positive responses were canceled out by a few negative responses (Figure 6). These years were relatively dry during July and August, which might have limited disease development. We do not see much evidence here that fungicide did much to lower the effect of stress conditions on yield. We have also compared fungicide, insecticide, and the combination of both in some trials in recent years, and have not found a consistent response to adding insecticide, either by itself or with fungicide.

Herbicide/defoliant: Several years ago some producers and agronomists started to use PPO-class herbicides such as lactofen (Cobra®) on soybeans during early vegetative growth, claiming that even though such herbicides cause some leaf damage, they can increase yields. Some physiological support for this idea stems from the fact that these herbicides can stimulate a response in plants that might help plants to better ward off disease or other stress effects. Though it has been known for years that defoliation of soybeans can under some conditions cause yield loss, we have tested this in a number of recent trials in Illinois. Not only did this herbicide fail to increase yield in any trial, it significantly decreased yield in about half of trials, and on average cost more than 4 bushels of yield (Figure 7).

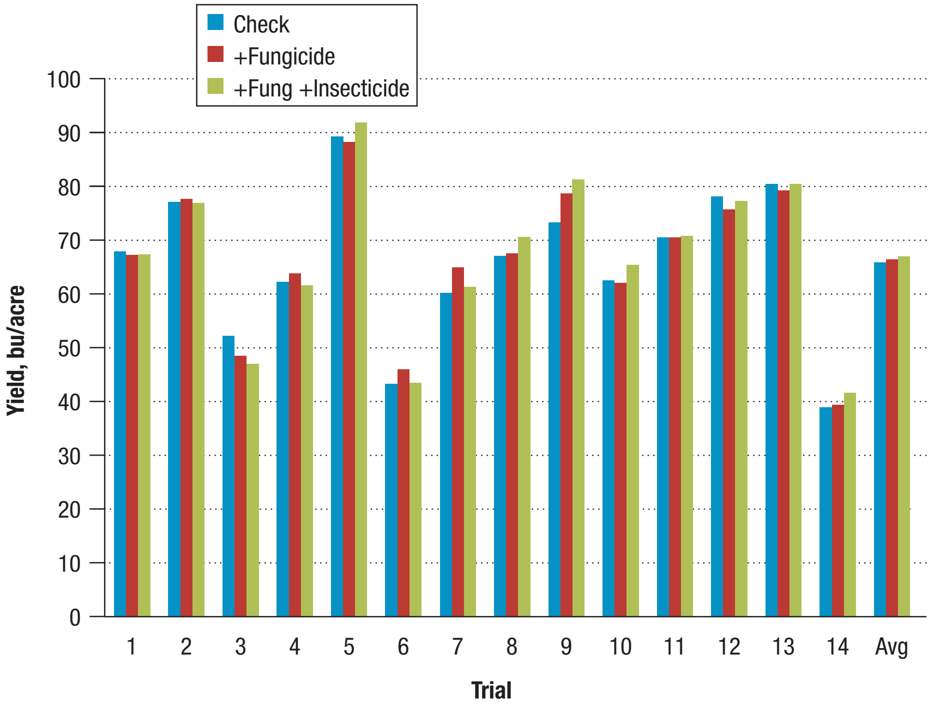

Figure 6 ■ Response of soybeans to foliar fungicide and fungicide + insecticide in Illinois trials, 2010-2013.

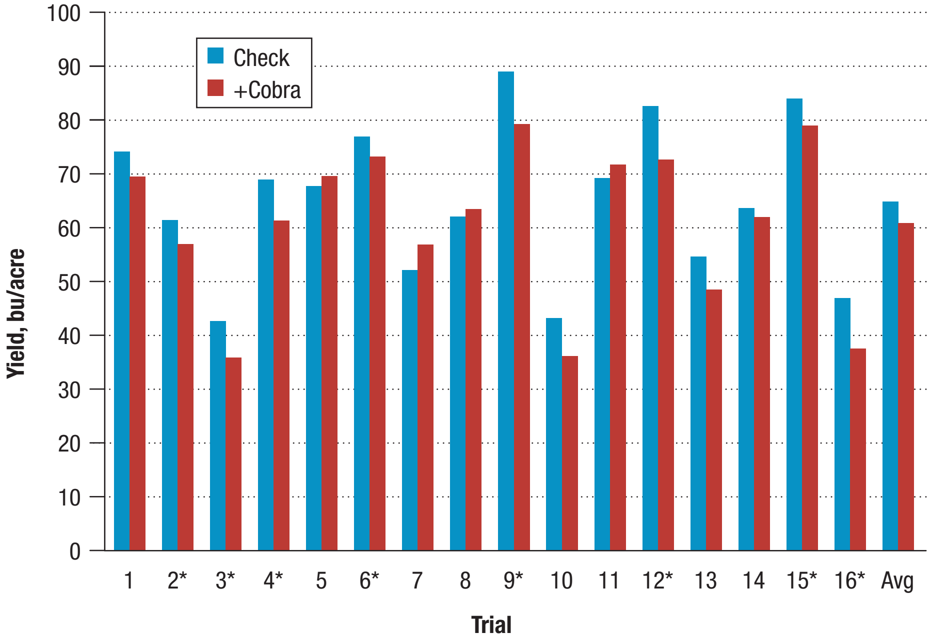

Figure 7 ■ Response to Cobra herbicide in Illinois trials. Trials marked with an asterisk are those in which Cobra significantly decreased yield.

"Packages": Perhaps as a way to explain lack of response to some individual inputs, some have claimed in recent years that "it takes a package to raise yields"—that we can't expect individual inputs to raise yields by themselves, since lack of other inputs will only limit yields. In studies that combined many of the inputs considered above (but not Cobra, since that tends to decrease yields), we have found that such input packages do in some cases produce significant yield increases (Figure 8). The average increase was less than 2 bushels, making it unlikely that such packages of inputs will provide a return on investment.

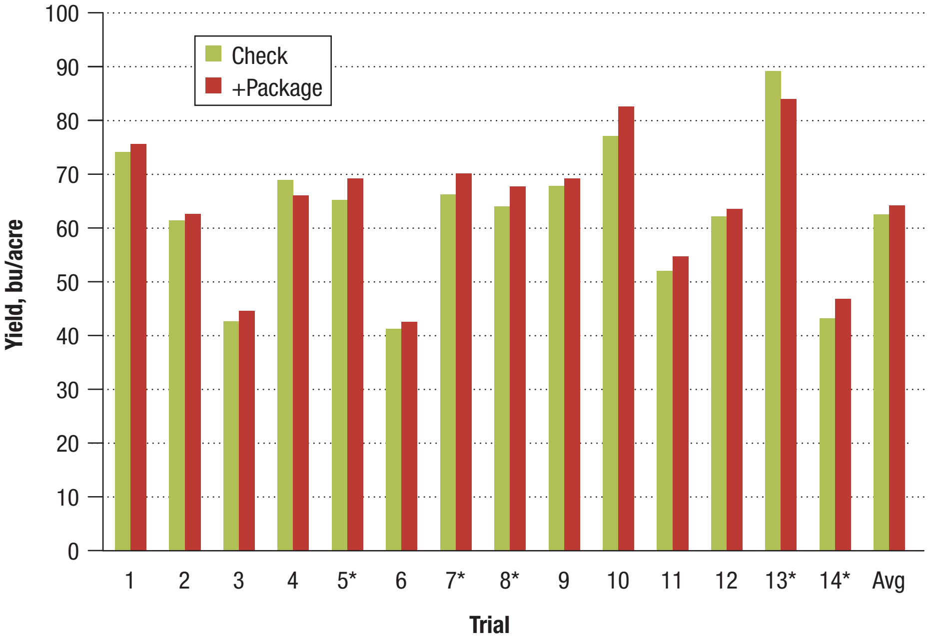

Figure 8 ■ Response of soybeans to a "package" of inputs—micronutrients, fungicide, insecticide, and nitrogen—in Illinois trials. Trials marked with an asterisk are ones in which the yield difference was significant.

While most of these data tend to show little or no positive response to inputs that are being sold for soybeans, there is no reason to give up and just "take what we get" when it comes to soybean yields. Genetic improvements continue, and we need to "keep the pressure on" with research and testing in order to have the information we need to optimize inputs and yields. It is clear, though, that we will need to keep looking to find ways to make any of these inputs consistently profitable. In the meantime, we need to cover the agronomic basics well, making sure that we leave as little as possible to chance when it comes to managing this great crop.

I wish to thank the Illinois Soybean Association, which provided the funding that made this work possible.

Managing Soybean Diseases and Pests with Genetic Resistance

Brian Diers
Professor of Crop Sciences
268 National Soybean Research Center
bdiers@illinois.edu
217-265-4062

Randall Nelson
Professor of Crop Sciences
232 National Soybean Research Center
rlnelson@illinois.edu
217-244-4346

Growers select soybean varieties based primarily on yield, as yield is a major driver of profits. This grower emphasis on yield is understood by the seed industry and increasing yield is a primary objective of soybean breeders. On-farm yields in the USA have increase at a rate of 0.35 bu ac^{-1} yr^{-1} from 1924 to 2012 and since 1983, the rate in the USA increased 25% to 0.44 bu ac^{-1} yr^{-1}. In Illinois, the rate of on-farm increase has been 0.39 bu ac^{-1} yr^{-1} from 1924-2012. Research shows that at least 2/3 of these yield gains were the result of breeders releasing new varieties.

What has been the contribution of disease resistance to these yield gains? This is a difficult question to answer because our current field environments are very different from those in the 1920's. We now have greater concentrations of soybean pathogens in fields, which make disease resistance important to simply maintain soybean yield. The importance of disease resistance is demonstrated by the change in yield over time of the milestone variety Williams, or its closely related backcross-derived Williams 82. From 1972 to 2009, Williams or Williams 82 was included in the University of Illinois Soybean Variety Test. Although there is considerable year-to-year variation in this test, we observed that the yield of Williams or Williams 82 decreased by 0.22 bu ac^{-1} yr^{-1} at Urbana over this time. In contrast, the average yields of varieties in this test increased by 0.20 bu ac^{-1} yr^{-1} (Figure 1). This increase was largely driven by the replacement of varieties by new releases over time. Variety test data from Dixon Springs, Carbondale, Brownstown, and Belleville showed similar trends. It is likely that most of the reduction in the yield of Williams and Williams 82 over these years is because of increases in pathogen pressure in the fields. For example, Williams and Williams 82 are both susceptible to soybean cyst nematodes (SCN) and during this period, we know that SCN pressure has increased in fields. This shows that for yields to increase, breeders must first overcome this pressure from diseases to lower yields.

USDA Soybean Germplasm Collection

The USDA Soybean Germplasm Collection is the source of genes for disease and pest resistance as well as genetic diversity for soybean breeding and other soybean research in the U.S. It was established at the University of Illinois in 1949 and currently contains over 17,000 soybean accessions (germplasm lines) introduced from other countries and over 1,100 soybean varieties developed in the U.S. In addition, there are nearly 2,000 accessions of species related to soybean. Each accession in the Collection is given a PI (plant introduction) number and we will reference these PI numbers as we discuss specific sources of resistance. The importance of this collection is highlighted by the fact that for the past five years, we have distributed an average of 38,000 seed samples from the Collection per year.

Screening the Collection for new disease and pest resistance is very important because most pathogens and pests are genetically highly variable and the deployment of resistant cultivars will select for biotypes that can attack commonly used sources of resistance. Screening the Collection is a resource-consuming task. It is a major challenge to accurately determine the reaction of thousands of soybean accessions to one or more strains of the pathogen or pest, and once new lines are identified as resistant, it is critical

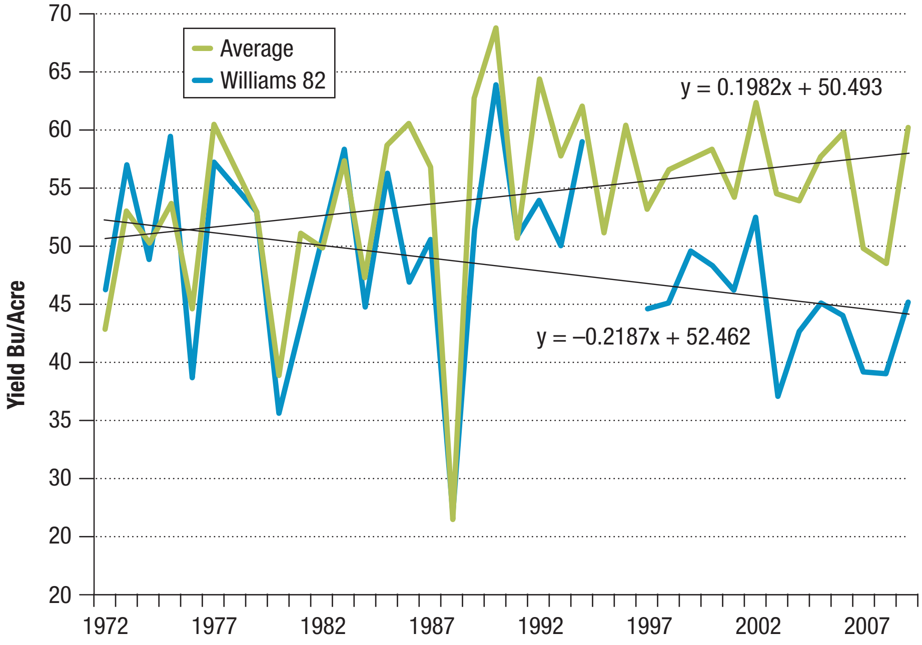

Figure 1 ■ Yield of Williams or Williams 82 (blue line) and the test average (green line) in the University of Illinois Soybean Variety Test in Urbana, Illinois from 1972 to 2009.

to determine if the new sources of resistance are genetically different from what is already being used. Transferring resistance to new cultivars is easier when the resistance is conditioned by major genes such as for Phytophthora or aphid resistance than it is for resistance to sudden death syndrome (SDS) or soybean cyst nematode (SCN) where multiple genes are generally needed. However, soybean breeders are highly reluctant to invest in breeding with new sources of resistance unless those sources contain new genes that can improve the level or scope of resistance.

To facilitate screening of the germplasm collection, we have established a core collection by statistically analyzing all of the data that we have on each accession in the Collection to estimate how closely related accessions are to each other. This analysis allows us to identify a sample of approximately 10% of the total collection that is likely to contain most of the variation of the collection (Oliveira et al. 2011). This subset would be the first place to look for new sources of resistance. More recently, we have characterized all of the soybean accessions in the Collection with nearly 50,000 DNA markers. These data will help us more precisely define the relationships among the accessions as well as identify differences near the known resistance genes that may indicate sources of new genes. Advances in other genetic technology will also help us more quickly determine if accessions have different genes for resistance.

Soybean Cyst Nematode (SCN)

Soybean cyst nematode (*Heterodera glycines* Ichinohe) is a microscopic round worm that feeds on soybean roots and is estimated to be the most important soybean pathogen in the USA based on yield loss. Most soybean varieties marketed in Illinois are SCN resistant, however, these varieties largely trace their resistance to PI 88788. A major reason for the overuse of the PI 88788 resistance is that breeders have been successful in breaking the negative association between resistance and yield in this source. In addition, resistance from PI 88788 has done an excellent job of protecting soybean yield in most fields in the Midwest. This is shown by Figure 2, where soybean yields of varieties with and without PI 88788 resistance are compared in Decatur, MI; West Lafayette, IN; Nevada, IA; and Urbana, IL. In West Lafayette, no SCN was detected in the field and there was no difference between the average of the varieties that were SCN resistant and those that were susceptible. In Decatur, which had high infestation levels of 6560 SCN eggs / 100 cc of soil at planting, there was an increase in yield of 0.5 bu ac^{-1} for each unit increase of resistance, as measured with the female index (female index values range from 0 for complete resistance to 100 for complete susceptibility). In the Nevada and Urbana sites with moderate SCN pressure, yields of resistant varieties were greater than susceptible varieties, but the trend was not as strong as observed in Decatur.

Researchers at the University of Illinois have studied the genetics of SCN resistance in PI 88788 and they found that this resistance is largely controlled by the major SCN resistance gene *Rhg1* (Glover et al., 2004). This gene has been precisely mapped on a soybean chromosome and the DNA sequence that makes plants SCN resistant has been determined. This identification has provided researchers leads on how we can further improve the resistance contributed by this gene.

The overuse of resistance from PI 88788 has resulted in the selection of SCN populations that can overcome PI 88788–derived resistance. A survey of soil samples collected in Illinois fields in 2005 revealed that 70% of the SCN-positive samples had populations that could overcome PI 88788–derived resistance (Niblack et al., 2008). To counter this, breeders are focusing on breeding varieties with alternative sources of resistance including resistance from PI 437654 (also called the Hartwig source of resistance) and Peking. There are few varieties with these resistances on the market because it has been very difficult for breeders to combine resistance from these sources with high yield. At the University of Illinois, we have also worked on SCN resistance from wild soybean (*Glycine soja*). We have mapped two SCN resistance genes from *G. soja* and have bred these genes into high yielding soybean backgrounds. These genes from *G. soja* promise to further diversify SCN resistance genes in soybean varieties (Kim et al., 2011).

Soybean Aphid

Soybean aphid (*Aphis glycine* Matsumura) is a relatively new pest in North America. It was first identified on soybean in Wisconsin in 2000 and since that initial discovery, it has spread throughout the northern soybean growing regions in the USA and in southern Canada. In Illinois, it is most prevalent in the northern part of the state. Soybean aphid feeding reduces crop yields directly by causing plant stunning, leaf distortion, and reduced pod set. Shortly after the identification of soybean aphid in the USA, Dr. Glen Hartman, a USDA-ARS soybean pathologist at the University of Illinois, started screening soybean germplasm for aphid resistance. His group did not find any resistance among the Illinois adapted varieties that he tested, but he did identify resistance in some old varieties from the southern USA

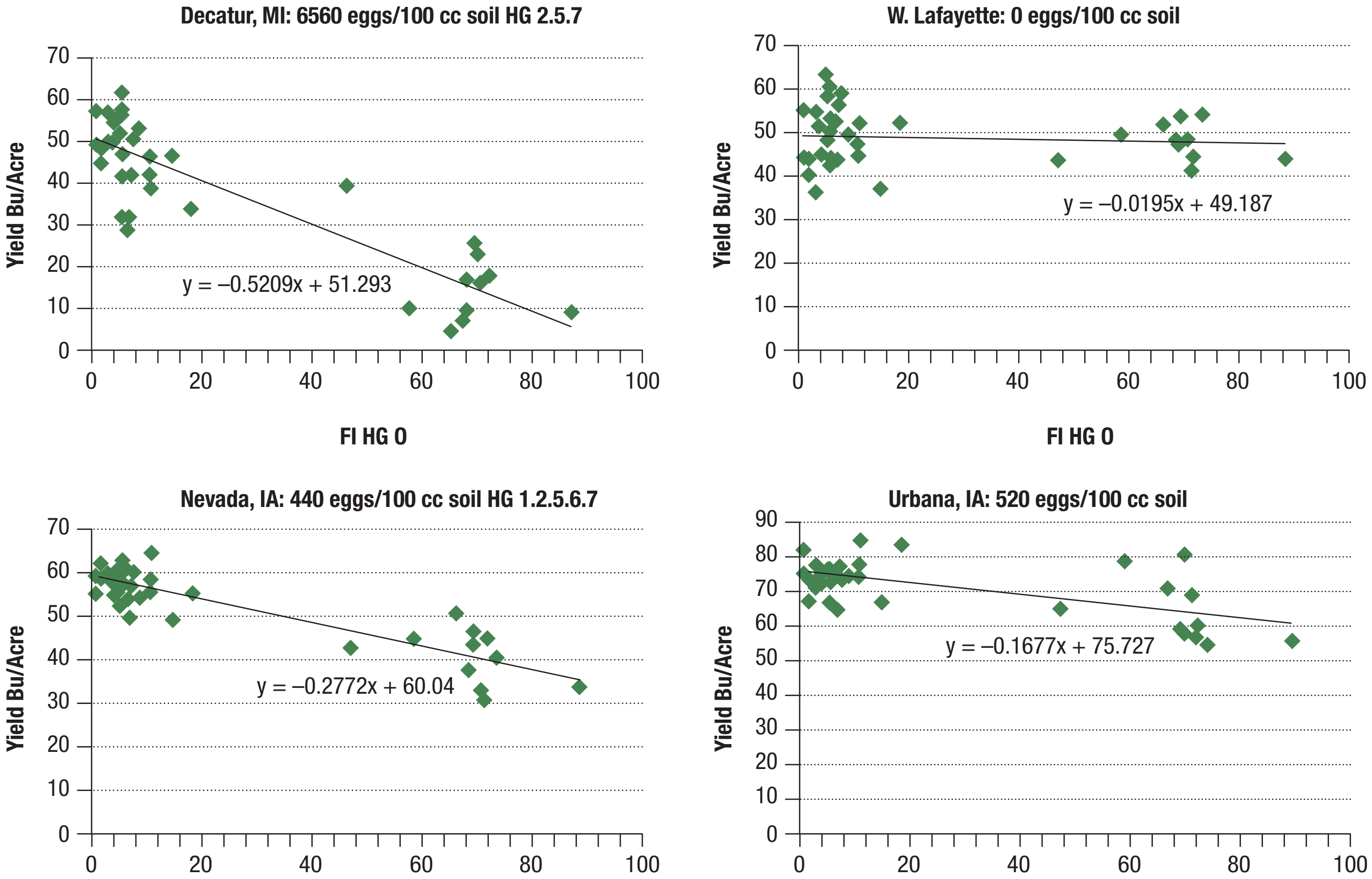

Figure 2 ■ Yield of soybean experimental varieties compared to their soybean cyst nematode (SCN) resistance, as measured by a female index (FI), in greenhouse tests. Field tests were grown in Decatur, MI; West Lafayette, IN; Nevada, IA; and Urbana, IA during 2012.

and in soybean introductions from Asia (Hill et al., 2004). Dr. Hartman, in collaboration with other researchers, showed that resistance in the sources he discovered is controlled by the two resistance gene *Rag1* and *Rag2* (Li et al., 2007; Hill et al., 2009). Researchers at other universities have more recently mapped the genes *Rag3* and *Rag4*.

Although soybean aphids have a short history in North America, there are already biotypes of the insect that can overcome resistance genes. The original aphid isolate used in experiments at the University of Illinois (Biotype 1) was controlled by *Rag1-Rag3*. Biotype 2 was then discovered which can overcome *Rag1*, but not *Rag2*, and then Biotype 3 was found that can overcome *Rag2* and is partially controlled by *Rag1*. A Biotype 4 was recently discovered that can overcome both *Rag1* and *Rag2*. This biotype diversity shows that breeders and growers cannot depend on only one resistance gene and expect consistent control of aphids. Breeders are focused on stacking resistance genes to achieve more durable resistance. Tests done in Iowa during 2013 showed excellent control of soybean aphids with a combination of *Rag1* and *Rag2*.

Sudden Death Syndrome

Sudden death syndrome (SDS) is a soybean disease caused by the soilborne fungus *Fusarium virguliforme*. The fungus infects plants through the roots and severely infected plants exhibit blackened and rotted taproots with few lateral roots. The most noticeable symptoms to growers are interveinal chlorosis (yellowing) and necrosis of leaves, premature leaf drop defoliation, and pod abortion.

Some practices that have been reported to reduce SDS occurrence include subsoiling compacted fields, delaying planting and planting early varieties. However, the use of resistant varieties is the most effective method for controlling SDS. Some varieties with good levels of resistance have been identified and information on the resistance levels of varieties can be found on the Variety Information Program for Soybeans website (www.vipsoybeans.org) or from company websites.

Studies on the genetic basis of SDS resistance have shown that resistance is not controlled by major genes, but instead by many genes that have small individual effects. This type of resistance makes it difficult to breed highly resistant varieties because many genes need to be combined together to achieve strong resistance. On the other hand, there is no evidence of biotypes of *Fusarium* that can overcome resistance. This means that although the level of SDS disease symptoms on a soybean variety may differ based on how much disease inoculum is in the soil or how conducive the environment is to the disease, the resistance of varieties should not be completely defeated.

Source of SDS resistance have been found in the USDA Soybean Germplasm Collection and genes that contribute to resistance from some sources have been mapped. These genes should help improve resistance and reduce losses from this disease. Research also has shown that the major SCN resistance gene *rhg1* is associated with improved SDS resistance. This was shown in a field test in Urbana, IL where we tested a population of experimental soybean lines that were mostly genetically identical except some had the resistance gene at *Rhg1* and others had the susceptible gene. Those plants with the resistance gene had a SDS disease index of 8.6 (0=complete resistance, 100=plants dead) while plants with the susceptible gene had a disease index of 23.5. It is not known whether the *rhg1* resistance gene also confers resistance to SDS or if the SDS resistance is controlled by another linked gene. Having resistance to SDS and SCN associated together is very useful and this has resulted in the more rapid development of varieties with resistance to both diseases.

Phytophthora Rot

Phytophthora rot is a common fungal disease of soybean caused by *Phytophthora sojae* that was one of the first diseases to affect soybean production in Illinois. Phytophthora is most prevalent in poorly drained soils and thrives when early spring soil moisture is high. Resistance to Phytophthora has been a part of soybean breeding for more than 50 years. As with soybean aphid resistance, resistance to Phytophthora is generally controlled by single, major genes. The first resistant varieties were developed through backcrossing the *Rps1a* gene into the popular varieties Harosoy and Clark to produce Harosoy 63 and Clark 63. Having pairs of varieties that differed only by a gene for Phytophthora resistance was very useful for definitively identifying those fields where Phytophthora was a significant problem. Since this first resistance gene was found in 1957 (Bernard et al. 1957), 13 additional genes have been identified. Varieties currently being sold in Illinois have predominately one of only 3 genes, *Rps1c*, *Rps1k, or Rps1a.* All of these are variants of the same gene, so they cannot be combined in single variety. A few varieties have a combination of *Rps1c* or *Rps1k* and *Rps3a.* Information on available resistance genes can be found at the Variety Information Program for Soybeans website (www.vipsoybeans.org).

Phytophthora is currently not a major problem across extensive areas in Illinois but does cause losses every year. The most recent survey for the presence of Phytophthora in Illinois was done in 2001 and 2002 (Malvick and Grunden, 2004). They found 22 races of Phyophthora but nearly 60% of the isolates were one of four races: 1 (21%), 4 (15%), 7 (12%) and 33 (10%). The three most commonly deployed resistance genes provide resistance to race 1. *Rps1k* and *Rps3a* provide resistance to Race 4, *Rps1c* and *Rps1k* provide resistance to Race 7, and only *Rps3a* provides resistance to Race 33. This diversity of the fungus can explain why some Phytophthora-resistant varieties can fail in specific fields. If you are growing Phytophthora-resistant varieties, it is a good management practice to rotate your sources of resistance. Growing a resistant variety will not induce changes in the fungus but it will select for races that can reproduce on that variety. Continuous selection over time will increase prevalence of those virulent types that can then overcome the deployed resistance. Periodically changing the source of resistance will also change the selection for Phytophthora races.

Genetic resistance is the most cost effective and environmentally sound strategy for managing soybean pests and pathogens. However, to keep the system operating successfully requires soybean breeders to continually find and incorporate new genes for resistance into soybean varieties and growers to wisely deploy these resistant varieties.

Acknowledgments

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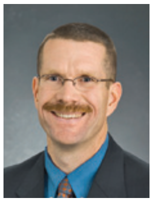
Marestail: A “Surprising” Weed Species in 2013



Aaron G. Hager
Associate Professor of Crop Sciences
N-321 Turner Hall
hager@illinois.edu
217-333-4424

Marestail infestations in soybean fields were a common occurrence across much of Illinois during the 2013 growing season. Many who experienced marestail in 2013 commented that they had not previously encountered this weed, and questioned from where it originated and why it was so common and difficult to control in 2013. What do we know about the origins and biology of this weed? Are there particular growth stages that can be targeted to improve overall management? Is herbicide resistance common in Illinois marestail populations? What options are available to control marestail in limited or no-tillage systems?

Conyza canadensis: Marestail or Horseweed?

Confusion often centers about the “correct” common name for the plant species described by the Latin binomial *Conyza canadensis*. While use of this Latin binomial is consistent throughout the world, common names of plants are more variable and often reflect local or regional origins. Many weed practitioners use marestail as the name for the plant described in greater detail herein, and use horseweed as another common name for giant ragweed (*Ambrosia trifida*). The Weed Science Society of America periodically publishes a list of approved common names for various weed species in North America. The WSSA recognizes marestail as the approved common name of *Hippuris vulgaris*, a creeping perennial plant species commonly found in the shallow waters and mud flats of California and other areas. Horseweed is the WSSA-approved common name for *Conzya canadensis*. As one might imagine, confusion often exists when horseweed is used to describe the species known to many as marestail. Therefore, the remainder of this paper will use marestail as the common name of *Conyza canadensis*.

Origin of the Species

Native to North America, marestail also is widely dispersed in countries around the world. Historically a weed common to orchards, vineyards, roadsides, waste areas and fallow ground, the advent of limited tillage agronomic cropping practices and the substantial increase in their adoption during the past 20 years has allowed marestail to populate agronomic production areas across much of the United States. The species has a relatively broad geographical distribution across North America, ranging from N 55 to S 45 latitude (Weaver 2001).

Biology

Life cycle: Marestail, like other annual plant species, completes its life cycle in one year. Unlike many other annual species, however, marestail can exist as a winter or summer annual. Populations of winter annual marestail typically emerge during the late summer or fall months, within a few days or weeks after seed is dispersed from the parent plant. Summer annual populations can emerge in early or late spring, perhaps as late as early summer in some instances. In central and northern areas of Illinois, marestail predominately demonstrates a winter annual life cycle, whereas a substantially higher proportion of spring emergence occurs in areas in Illinois south of (approximately) Interstate 70. Both winter and summer annual life cycles can be found across central Illinois.

Figure 1 ■ Young marestail plant in the rosette stage.

Fall-emerging plants form a basal rosette (Figure 1) that represents the plant's overwintering stage. Rosettes are merely a cluster of small leaves that appear to be attached together at a common point. In the spring, plants bolt by rapidly elongating the main stem. Leaves, very numerous and hairy, alternate around the stem and become progressively smaller in size toward the top of the plant. The leaves on mature plants lack petioles, and have entire or slightly toothed margins. As the plant matures, leaves toward the base of the plant deteriorate and fall off the stem.

Seed production and dispersal: Marestail reproduces only by seed. Flowers are produced in a panicle-type inflorescence at the top of the plant (Figure 2). Mature marestail plants can produce approximately 200,000 seeds. The seeds, known as achenes, are very small, lightweight, and possess a pappus (a modified portion of the inflorescence) that aids in long-distance wind dispersal of the seed. (Perhaps a more familiar example of a pappus is the white "parachute" attached to dandelion seed.) Research has demonstrated that the pappus of marestail effectively slows the settling velocity of the seed to one of the lowest among species in the Asteraceae plant family. A low settling velocity allows the seed to remain airborne longer, which increases its long-distance movement. Field experiments have demonstrated that marestail seed can travel between one-quarter to three-eighths of a mile from the point of dispersal. Dispersal distance ultimately is determined by seed interactions with numerous environmental variables, but this type of wind-mediated, long-distance seed movement serves as a mechanism to introduce marestail into previously uninfested fields. Long-distance seed movement becomes especially important when considering the spread of herbicide-resistant biotypes.

Figure 2 ■ The inflorescence of mature marestail. Note the white pappus attached to individual seeds that aids long-distance movement by wind.

Competitiveness with Crops

Research has demonstrated that marestail can reduce yields of various crop species, including corn and soybean. High marestail densities reduced soybean yield by over 80% (Bruce and Kells 1990). Researchers at Ohio State University observed the following soybean yields in a recent marestail experiment:

- 51 bu/A where the burndown treatment failed to control emerged plants
- 57 bu/A where the burndown treatment was effective, but there was no residual herbicide
- 65 bu/A where the burndown was effective and residual herbicides were used

Resistance to Herbicides

Evolution of herbicide-resistant marestail populations has occurred not only in the United States, but in countries around the world. Marestail populations resistant to triazine herbicides were identified in several European countries during the 1980s; paraquat-resistant marestail was first identified in 1980 in Japan. In the United States, marestail has evolved resistant to herbicides from four site-of-action classes, including PSII inhibitors (ex. atrazine, linuron), PSI inhibitors (ex. paraquat), ALS inhibitors (ex. cloransulam), and EPSPS inhibitors (ex. glyphosate). Biotypes with resistance to multiple herbicides from more than one site-of-action group also have been reported. Marestail plants resistant to both ALS inhibitors and glyphosate represent the most common type of multiple herbicide resistance.

Marestail was the first dicot weed species in North America to evolve resistance to glyphosate. It also was the first species to evolve resistance to glyphosate in Illinois (Figure 3). Glyphosate-resistant marestail populations can evolve in any particular field due either to independent selection or introduction of seed from populations already resistant to glyphosate.

Management of Marestail

Key elements to effective management of marestail include understanding its life cycle, seed movement, and whether or not plants are resistant to one or more herbicides. Herbicides and tillage can be effective tools to manage marestail, but resistance to certain herbicides in Illinois marestail populations and adherence to no-tillage production practices can increase the difficulties in controlling marestail before soybean fields are planted. The following recommendations were developed by extension weed scientists across the Midwest in a collaborative research and extension project funded by the United Soybean Board.

LibertyLink soybeans—the most effective strategy

- The LibertyLink soybean system is the most effective tool for management of herbicide-resistant marestail, especially in fields with high marestail populations.
- Use burndown and residual herbicides as outlined in subsequent paragraphs. Apply Liberty POST (29 to 36 oz/A) before marestail plants exceed 6 inches in height. Follow with a second POST application of Liberty as needed.

Figure 3 ■ Glyphosate-resistant marestail is very difficult to chemically control after soybean have emerged.

1. Use fall or early spring herbicide treatments in fields where marestail seedlings are observed and especially in fields with a history of marestail control problems. The primary goal of a fall or early spring treatment is control of emerged plants, and it is not a substitute for a preplant or preemergence herbicide treatment later in spring. An application of burndown and residual herbicides is still required closer to planting in fields that were treated with burndown herbicides in the fall or early spring. For fall applications, we suggest using 2,4-D as the base herbicide to control marestail and combining it with one or more of the following to ensure control of other winter weeds: glyphosate; dicamba (can use premix such as Brash or WeedMaster); Basis; a low rate of Canopy/Cloak EX or DF; Autumn Super, or metribuzin

   For early-spring applications, we suggest a similar approach using 2,4-D or dicamba as the base, and adding glyphosate and/or a reduced rate of a residual herbicide. Apply the remainder of the residual herbicide closer to the time of soybean planting.

2. Apply effective burndown herbicides in spring. Do not plant into existing stands of marestail. Start weedfree at planting by using one of the following preplant herbicide treatments, applied when marestail plants are in the rosette stage. Note—thorough tillage close to planting also effectively removes marestail.
   - 2,4-D ester or dicamba plus glyphosate (1.5 lb ae/A)
   - 2,4-D ester or dicamba plus saflufenacil (Sharpen/Verdict) plus glyphosate + MSO
   - 2,4-D ester plus Gramoxone (3 to 4 pts/A) plus a metribuzin-containing herbicide
   - Liberty (29 to 36 oz/A) or Liberty plus a metribuzin-containing herbicide
   - Saflufenacil (Sharpen/Verdict) plus MSO (1% v/v) plus either glyphosate or Liberty

   - ■ The mixture of glyphosate and 2,4-D ester or dicamba has become more variable for control of marestail in some fields. Plants should be in the rosette stage at the time of application for best results. In fields where this mixture has previously failed to provide effective control, use one of the other burndown treatments listed above.
   - ■ Use the highest rate of a 2,4-D ester product that is allowed, based on the interval between application and soybean planting. For all 2,4-D ester products, rates up to 0.5 lb active ingredient/A must be applied at least 7 days before planting. Rates between 0.5 and 1.0 lb ai/A should be applied at least 30 days before planting, with the exception of some products (e.g. E-99, Salvo, and Weedone 650) that allow 1 lb ai/A to be applied 15 days before planting. Refer to the specific product label to confirm the interval between application and planting.
   - ■ Dicamba can be more effective than 2,4-D on marestail in the spring, but risk of soybean injury is greater if the plantback guidelines are not followed. Dicamba product labels (e.g. Clarity) contain the following statement—"following application of dicamba and a minimum accumulation of one inch of rain, a waiting interval of 14 days until

soybean planting is required for rates of 8 oz/A or less, and 28 days for rates up to 16 oz/A." Refer to the specific product label to confirm the interval between application and planting.

- In marestail populations sensitive to ALS-inhibiting herbicides, the activity of any of the above can be improved with the addition of a herbicide that contains chlorimuron (e.g. Canopy/Cloak/Fallout, Valor XLT, Envive, Authority XL/MAXX) or cloransulam (Gangster, Sonic, Authority First). The addition of metribuzin to any burndown treatment can also improve control of emerged marestail.

3. Include residual herbicides with the preplant burndown treatment. Add one of the following herbicides or herbicide combinations to the burndown herbicides, for residual control of marestail until the soybean leaf canopy develops.
   - flumioxazin—Valor, Valor XLT, Envive, Enlite, Fierce, or Gangster
   - sulfentrazone—Authority First, Sonic, Authority XL, Authority Broadleaf, Authority Assist, Authority Maxx, or Spartan
   - Metribuzin—Metri DF, Tricor, etc. Use rates of at least 8 oz/A, and preferably 10 to 12 oz/A, but do not exceed recommended rate for soil type. Can add metribuzin to other metribuzin-containing products (e.g. Boundary, Canopy/Cloak DF, Intimidator, Matador, Authority MTZ) to bring total metribuzin rate to 0.38 to 0.5 lbs ai/A. Sensitivity to metribuzin varies among soybean varieties—check with seed supplier for more information.

   - The ALS-inhibiting (Group 2) component of premix products will not contribute to control of ALS-resistant populations, and product rates should be increased as necessary to maximize control from the non-ALS herbicide component. Adding 4 to 6 oz/A of metribuzin to flumioxazin- and sulfentrazone-based products can improve residual control of these populations.
   - Products that contain saflufenacil (Sharpen/Verdict) can improve residual control when combined with other preemergence herbicides, primarily at the higher rates (e.g. 1.5 to 2 oz of Sharpen). These rates of saflufenacil must be applied 14 to 44 days before soybean planting, depending upon soil type. Saflufenacil cannot currently be mixed with other PPO-inhibiting residual herbicides (e.g. flumioxazin, sulfentrazone, fomesafen).

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Captions for figures:

Palmer Amaranth: A Looming Threat to Soybean Production in Illinois?

Dr. Adam S. Davis
Research Ecologist
USDA-ARS Global Change and
Photosynthesis Research Unit
N-319 Turner Hall
asdavis1@illinois.edu
217-333-9654

Origins and Current Situation

Palmer amaranth (*Amaranthus palmeri*) is a large-statured dioecious summer annual broadleaf plant with an erect growth habit. This native warm-season species has its origins in the Sonoran Desert region of the Southwest U.S., but has spread widely as a weed of field crops throughout large areas of the mid-South and Southeast U.S. As reports begin to surface of Palmer amaranth infestations in increasingly northern locales, it is important to determine whether this species will be able to establish in the grain production systems of the north central region of the U.S.

Several factors have combined to make this weed, previously a manageable nuisance, into a formidable challenge for production agriculture. Palmer amaranth is a prolific seed producer, with large females able to set several hundred thousand seeds per individual. The seeds are small (< 1mm in diameter), and are therefore easily washed or blown into cracks in the soil or beneath plant residues on the soil surface, where they are protected from seed predators. Once in the soil seedbank, Palmer amaranth seeds can remain viable for several years when near the soil surface, and potentially much longer if buried deeper in the soil profile. Palmer amaranth seeds can germinate once soils are warm enough to support corn vegetative growth, and germinate steadily throughout the growing season. The ability of this species to germinate in late summer and complete its life cycle, including seed production, in a few weeks have allowed it to colonize an open niche in agricultural systems: the undisturbed period following active field operations and prior to harvest known as 'lay-by.'

Palmer amaranth may begin its colonization of a production field in stealth mode, during lay-by, however once its numbers have built up in the

Figure 1 ■ Mature Palmer amaranth in a Kankakee county, IL, soybean field (photo courtesy of Dr. Aaron Hager)

soil seedbank, it can be devastatingly competitive with field crops, including corn, soybean and cotton. Growth rates in this species are very high, and yield losses can be severe (78% in soybean, 91% in corn reported in the scientific literature). Because the tiny seeds are shed at the time of crop harvest, mechanical harvesting can act as a vector for seed dispersal, disseminating the seed widely and rapidly making an isolated patch into a full-field problem (Figure 1). This process can reach completion before growers are fully aware of the danger they face: reports from the University of Arkansas indicate that farms have gone from first sightings to full-field patches to complete loss of control and field abandonment within four years.

Our growing inability to control Palmer amaranth in field crop settings is largely due to its evolved resistance to a growing number of herbicide sites of action, including PS II inhibitors, glycines, dinitroanalines and HPPD inhibitors. Because Palmer amaranth is hyperdiverse (there is as much, or more, genetic variation within populations as among populations), there is much raw material for natural selection to work upon in developing herbicide resistance in this species. Its dioecious mating system, with both male and female plants, requires it to share genetic material among plants, thus spreading any new traits throughout a population. It is also able to hybridize with other weedy Amaranth species, which are abundant throughout Illinois. And its light, wind-borne pollen is dispersed many kilometers away, allowing herbicide resistance traits to find receptive female plants in previously uncolonized fields.

Palmer amaranth has been called a 'superweed' in the popular press, and it appears that it may well deserve the name, at least within the southern half of the U.S. Will it earn this status in the northern states as well?

The Evidence: Palmer Amaranth is On the Move

When reports of severe Palmer amaranth infestations in Arkansas and Missouri field crops in the summer of 2009 suggested that this species might be expanding its range northward, my colleagues Dr. Aaron Hager (UIUC) and Dr. Bryan Young (SIU) and I designed a study to determine whether Palmer amaranth could grow and cause soybean yield loss in Illinois. Our research questions centered on whether its ability to invade Illinois production fields would be limited by genotype ("Are some Palmer amaranth populations more invasive than others?"), environment ("Are some parts of Illinois too cold for Palmer amaranth to grow or compete with soybeans?"), or simply dispersal ("Palmer amaranth is coming to a farm near you—it just needs to be dispersed there first").

We developed a collection of Palmer amaranth seeds from eight different populations, mostly from the southern and south central U.S. These eight genotypes were then grown in competition with soybean in common garden locations in southern (Dixon Springs), central (Savoy) and northern (De Kalb) Illinois in 2011 and 2012. Great care was taken in the protocol to avoid introducing a seed bank of Palmer amaranth at the study locations: Palmer amaranth seeds were sown individually in soil blocks, and seedlings transplanted to the field; once plants reached anthesis, they were removed from the field and burned; on a select few plants, inflorescences were bagged and allowed to develop green seeds, after which the plants were removed from the field and burned.

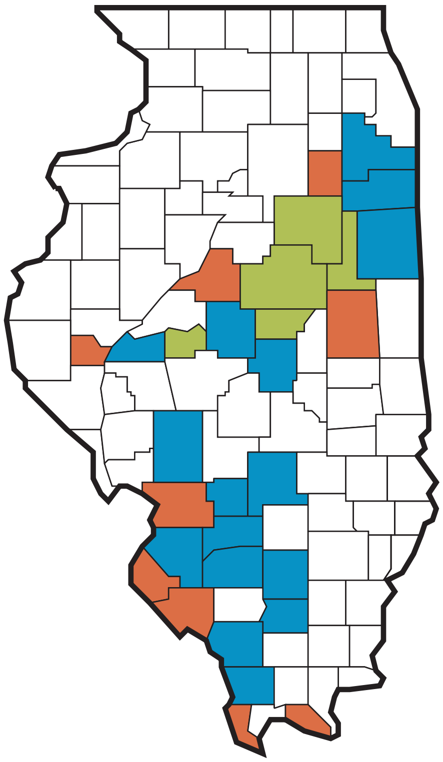
The results of the study were clear and disturbing: *all* of the Palmer amaranths were able to survive to reproductive maturity and to cause substantial yield loss with soybean (in spite of only being allowed to compete with the crop for a small portion of the growing season, before being terminated). This indicates that neither genotype nor environment are currently limiting the invasion of Illinois production fields by Palmer amaranth. Rather, Palmer amaranth is dispersal limited; once seed of this species finds its way to a farm, it is likely to stay and proliferate.

In the summer of 2013, the number of growers reporting Palmer amaranth infestations in their fields in Illinois increased rapidly. While infested fields are still relatively uncommon in Illinois, a growing cluster of counties in southern and central Illinois have confirmed reports of Palmer amaranth infestations (Figure 2). Palmer amaranth can and will invade Illinois field crop production.

What to Do About It?

Because Palmer amaranth is dispersal-limited in Illinois, this means that the number one management priority for this species for Illinois farmers is *prevention*. First, consider likely sources of introduction of Palmer amaranth seed to your farm. Key seed dispersal vectors for this species include contaminated feed grains and meals (especially cottonseed meal), animal manure, contaminated machinery, including combine harvesters and tillage equipment, and waterways.

Second, *vigilance* and monitoring will enable you to detect Palmer amaranth populations as soon as possible after they have colonized your fields. At this point, *containment* is critical. If you are noticing Palmer amaranth plants that have survived sequential herbicide applications, treat them as though they are herbicide resistant. The best course of action, if the invaded area is small enough, is to flag patch boundaries or take GPS coordinates so that the patch may be targeted for extra attention the following year, and physically remove all plants from the field (Palmer amaranth can re-root from its stems). If this is not possible, make sure that harvest operations



Palmer amaranth confirmed in counties colored **orange** or **blue**

Orange: counties with glyphosate-resistant Palmer amaranth

Green: samples to be processed

Figure 2 ■ Current distribution of confirmed Palmer amaranth reports in Illinois (figure courtesy of Dr. Aaron Hager) avoid this area, and then mow down the patch, leaving the plants on the soil surface, so that as many seeds as possible can be destroyed through post-dispersal predation.

Third, send seed samples to the University of Illinois Weed Science group (tinyurl.com/k34z3yf) for confirmation of identification and resistance screening, to determine what your chemical options are for future management of Palmer amaranth. The most successful strategies for continuing to produce crops in a farm invaded by Palmer amaranth include *diversification* of weed management strategies. Combining physical, cultural and chemical tactics will most likely be necessary to achieve long-term control over this species.

Finally, the University of Illinois Crop Sciences Department has issued a bulletin on the identification and control of Palmer amaranth, which can be accessed at bulletin.ipm.illinois.edu/wp-content/uploads/2013/09/Guidelines-for-the-Identification-and-Management-of-Palmer-amaranth2.pdf.

Effects of 24 years of Conservation Tillage Systems on Soil Organic Carbon and Soil Productivity

Kenneth R. Olson
Professor of Soil Science
Department of Natural Resources and
Environmental Sciences
S-224 Turner Hall
krolson@illinois.edu
217-333-9639

Abstract

The 24–year study was conducted in southern Illinois (USA) on land similar to that being removed from Conservation Reserve Program (CRP) to evaluate the effects of conservation tillage systems on: (1) amount and rates of SOC storage and retention (2) the long–term corn and soybean yields and (3) maintenance and restoration of soil productivity of previously eroded soils. The no–till (NT) plots did store and retain 7.8 Mg C ha^{-1} more and chisel plow (CP) –1.6 Mg C ha^{-1} less SOC in the soil than moldboard plow (MP) during the 24 years. That SOC amount was retained in the soil and not decomposed and re–emitted to the atmosphere as a result of cultivation or in the transported sediment moved off of the plots. However, no SOC sequestration occurred in the sloping and eroding NT, CP and MP plots since the SOC level of the plot area was higher at the start of the experiment than at the end. Pre–treatment SOC baseline measurements of the plot area were used to determine whether NT, CP and MP plots sequestered SOC. The NT plots actually lost a total of –1.2 Mg C ha^{-1}, the CP lost –9.9 Mg C ha^{-1} and the MP lost –8.3 Mg C ha^{-1} during the 24–year study. The 12–year MP corn yields were slightly higher than for NT and CP systems. The 12–year average soybean yield with NT was higher than with MP and higher than CP systems. Crop yields for 12–years corn and 12–years soybean appear to show long–term productivity of NT compared favorably with that of MP and CP systems.

Introduction

In the United States, the Food Security Act of 1985, the 1990, 1995, 2001, 2006 and 2011 Farm bills, and the Illinois T by 2000 Program have resulted in millions of hectares of erodible land previously in row crops being put into the CRP for 15 to 25 years. Any conversion of Conservation Reserve Program (CRP) land back to corn and soybean production could require the use of conservation tillage systems such as NT to meet soil erosion control standards. Evaluations of yield response of these conservation tillage systems over time are needed to assess returning this land to crop production. Franzluebbers and Follett (2005) reported the SOC content of timberland and prairie soils declined with cultivation in North America. The rate of decline as a result of cultivation was 22% ± 10% for the northeast; no value was reported for the central, 25% ± 33% for southwest and 36% ± 29% for southeast.

Shorter term tillage studies (Kitur et al., 1994; Olson et al., 2004; Olson et al., 2005) were extended to 24 years with the objective of evaluating long–term tillage systems (NT, CP and MP) effects on corn and soybean yields and the effects on the SOC storage or retention and the maintenance and restoration of soil productivity of previously eroded soils in southern Illinois. These SOC storage and retention values by tillage treatment at the end of the study will be compared to pre–treatment SOC levels to determine the amount and rate of SOC sequestration or loss as a result of the 24–years of tillage treatments (Olson et al., 2013) . The study was extended to show that NT system can be used instead of MP or CP systems to reduce soil erosion and maintain long–term crop yields.

Materials and Methods

A conservation tillage experiment was started in 1989 at the Dixon Springs Agricultural Research Center in southern Illinois. The soil at the study site was a moderately eroded phase of Grantsburg silt loam (fine–silty, mixed, mesic Typic Fragiudalf) (Soil Survey Staff, 1999) with an average depth of 64 ± 6 cm to a root–restricting fragipan. The area had an average slope gradient of 6 percent. Starting with corn in 1989, corn and soybean were grown in alternate years. The experimental design was two Complete Latin Squares and each square having three rows and three columns (Cochran and Cox, 1957) which allowed for randomization of the tillage treatments (NT, CP, and MP) both by row (block) and by column. This replication was used to control random variability in both directions. Each tillage treatment was randomized six times in 18 plots with a size of 9 m x 12 m. The columns were initially separated with 6 m buffer strips of sod. Later the buffer strips were planted to NT corn and soybeans to reduce deer damage. An electric fence was later used to protect the crops in the plots. There was a 60 m wide filter strip between the plot area and the drainageway.

Results and Discussion

The NT system maintained a significantly higher amount of residue on the soil surface as compared with that of the CP and MP systems at planting for each selected year (Table 1). Crop residue on the soil surface was higher with corn as previous crop, compared with that of soybean because of higher residue production from corn and lower rate of decomposition of corn residue (Eckert, 1984) than soybean residue. On Grantsburg soil with 5–7 percent slopes, the estimated annual soil loss, measured with USLE and RUSLE2, was 8, 20, and 30 Mg ha^{-1} with the NT, CP and MP systems, respectively **(**Table 1**)** (Walker and Pope, 1983; Widman, 2004, Olson et al., 2013). The higher the percentage of crop residue (Table 1) on the soil surface with the NT system protected the soil from erosion keeping it below the tolerance level of 8.4 Mg ha^{-1} yr^{-1} (Walker and Pope, 1983). On the other hand rill erosion was observed with the MP and CP systems due in part to less residue on soil surface compared with that of the NT system.

The 12–year average corn yield and the 12–year soybean yields were not affected by tillage (Table 2) (Olson et al., 2013). Twelve–year average MP soybean yield was 2 and 9% higher than NT and CP systems. The MP corn yields were 3% higher than for CP and NT systems as a result of significantly higher yields with MP system when planted into sod. At the beginning of the experiment, the MP system produced 21 and 11 percent higher yield compared with that of the NT and CP systems during 1989. The NT yields were lower in the early years of study but improved with the passage of time. The NT performance relative to MP and CP (Table 2) was better during dry years (1999) or years with extended dry periods than wet years. The only year that CP treatment had the highest yield was 2006 when compared to other tillage systems. The growing season rainfall that year was higher (75 cm) than average.

The NT crop yields were lower during the 3 early years (1989 to 1991) of the study but the NT system yielded as well as the MP system during the last 21 years of study. No–till yields lower than MP system in wet years (except

Table 1 ■ Effect of different tillage treatments on plant residue after planting and soil loss at Dixon Springs. Odd years have soybean residue and even years have corn residue (Olson et al., 2013).

	Residue present from previous crop (% Cover)									Soil loss
Tillage	**1996**	**1997**	**1998**	**1999**	**2005**	**2006**	**2007**	**2011**	**2012**	**(Mg ha^{-1})**
Notill	91a*	75a	95a	73a	85a	90a	78a	74a	88a	8c
Chisel Plow	21b	18b	29b	21b	18b	28b	24b	20b	28b	20b
Moldboard plow	6c	6c	17c	5c	5c	10c	8c	6c	9c	30a

* For each year, means with in a same column followed by same letter are not significantly different at the P = 0.05 probability level.

**Soil loss is calculated by Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation 2 (RUSLE2).

2002 with a dry period from June to August) but were higher in relatively dry years (Table 2). The higher yields with the NT system in dry years (1994, 1999, 2002, and 2012) were probably due to the conservation of more soil water than the MP system. Chisel plow yields were lower in wet years and higher in dry years as compared to MP system (Table 2).

Soil carbon sequestration (SOC) is the process of transferring carbon dioxide from the atmosphere into the soil through plants, plant residues and other organic solids which are stored or retained as part of the soil organic matter (humus) (Olson, 2010). The retention time of sequestered carbon in the soil can range from short term (not immediately released back to atmosphere) to long–term (millennia) storage. The sequestered carbon process should increase the net soil organic carbon storage during and at the end of a study to

Table 2 ■ Effect of different tillage treatments on corn and soybean yields during 1989-2012 at Dixon Springs (Olson et al. 2013).

Tillage	**Crop yield (Mg ha^{-1})**						
Corn							
Year	**1989**	**1991**	**1993**	**1995**	**1997**	**1999**	**2001**
NT	8.99b*	6.57a	11.79a	11.60a	9.87a	8.12a	9.73b
CP	9.99b	6.10a	11.61a	11.55a	9.32a	6.78b	9.60b
MP	11.26a	6.60a	10.98a	10.37a	9.59a	6.98b	10.34a
Year	**2003**	**2005**	**2007**	**2009**	**2011**	**12-yr average**	**% of MP yield**
NT	6.67a	11.40a	6.46a	13.10a	6.13a	9.18a	96
CP	7.33a	11.82a	6.80a	13.60a	6.85b	9.24a	97
MP	7.82a	11.41a	7.33a	14.03b	7.68ab	9.53a	100
Soybean							
Year	**1990**	**1992**	**1994**	**1996**	**1998**	**2000**	**2002**
NT	2.37a	3.74a	2.87a	2.63a	2.63a	2.32a	2.37a
CP	2.62a	3.46a	1.81b	2.27a	2.63a	2.38a	2.07a
MP	2.62a	3.65a	1.49b	2.43a	2.75a	2.32a	1.98b
Year	**2004**	**2006**	**2008**	**2010**	**2012**	**12-yr average**	**% of NT yield**
NT	0a	3.17ab	2.84a	2.94a	2.65a	2.54a	100
CP	0a	3.37a	2.84a	2.79a	1.96b	2.35a	93
MP	0a	3.10b	3.04a	2.88a	1.82b	2.34a	92

* For each crop, means with in a same year followed by same letter are not significantly different at the P = 0.05 probability level.

above pre–treatment baseline levels and result in a net reduction in the carbon dioxide levels in atmosphere.

Much of the literature suggested that paired comparisons between conservation tillage and conventional tillage at the end of a short– or long–term study can be used to determine SOC sequestration rate. Researchers assumed that the conservation and conventional tillage plots have the same SOC level at the start of the tillage experiment, the conventional tillage plots maintained the SOC over time (at steady state) and any increase in SOC of the conservation tillage treatment above the conventional tillage plot at end of study represented the amount of SOC sequestered by the conservation tillage system. However these studies often lacked or did not report a pre–treatment baseline SOC content in the plot areas collected prior to or at the start of the tillage experiment. Without such pre–treatment baseline data the SOC sequestration magnitude and rate findings cannot be verified. If SOC sequestered in conservation tillage plots at the end of the experiment is higher than the initial SOC of the plot area then SOC sequestration would have occurred in the conservation tillage (NT) plots and at the measured rate. Alternatively, if the conservation tillage plots did not have more SOC content at the end of the study than at the start of the experiment (pre–treatment baseline) then no SOC content sequestration occurred and the SOC sequestration rate is not correct. This 24–year tillage study was conducted on a plot area that was previously in sod for 15 years and on a 6 percent slope. The Grantsburg soils were previously eroded as a result of cropland use between 1860 and 1973. If the comparison approach (Table 3) (Olson et al., 2013) is used the projected SOC storage and retention (not sequestration) rate for NT would have been 0.32 Mg C ha^{-1} yr^{-1} which was lower than the published regional SOC sequestration rate averages (0.40 ± 0.61 Mg C ha^{-1} yr^{-1}) for the

Table 3 ■ Paired comparisons using MP as baseline to determine no-till (NT) and chisel plow (CP) effects after 24-years of tillage treatments on the volumetric SOC content change of the Grantsburg soil (Olson et al. 2013).

Tillage treatment	Depth	June 2012	Comparison method NT or CP vs. MP 24–yr total SOC retained above MP)	Paired comparison annual SOC retention rate above MP the comparison baseline
	cm		Mg C ha^{-1} layer^{-1}	
NT	0–15	26.3a**	+7.5	+0.31
	15–75	24.6a	+0.3	+0.01
	0–75 (all)	50.9a	+7.8	+0.32
CP	0–15	20.3b**	+1.5	+0.06
	15–75	21.7a	–2.6	–0.11
	0–75 (all)	42.0b	–1.1	–0.05
MP	0–15	18.8b		
	15–75	24.3a		
	0–75 (all)	43.1b		

**Mean of six replications with the same letter and in the same year and depth with a different tillage treatment are not significantly different at P = 0.05.

Table 4 ■ Use of pre-tillage treatment (1988), 2000 and 2012 SOC during 24-years of tillage treatments (Olson et al. 2013).

Tillage treatment	Depth	September 1988 (pre-treatment baseline)	August 2000	June 2012
	cm	Mg C ha^{-1} $layer^{-1}$		
NT	0–15	28.5a**	26.8a**	26.3a**
	15–75	23.6a	20.2a	24.6a
	0–75 (all)	52.1a	47.0a	50.9a
CP	0–15	28.4a	25.0a	20.3b
	15–75	23.5a	18.7ab	21.7a
	0–75 (all)	51.9a	43.7ab	42.0b
MP	0–15	28.3a	19.9b	18.9b
	15–75	23.1a	17.8b	24.3a
	0–75 (all)	51.4a	37.7b	43.1b

**Mean of six replications with the same letter and in the same year and depth with a different tillage treatment are not significantly different at P = 0.05.

north central USA region (Johnson et al., 2005). Regional studies included both nearly level and sloping and eroding plot areas.

Since the SOC content in the Dixon Springs plot area was measured before the establishment of the tillage experiment (pre–treatment baseline) (Table 4), it was possible to determine that the NT plots had lost –1.2 Mg C ha^{-1} (or 2%) and the MP and CP plots had loss SOC –8.2 Mg C ha^{-1} (or 16%) and –9.9 Mg C ha^{-1} (or 19%), respectively over the 24–years (Table 5). Contributing substantially to the above SOC losses from the tillage plots as a result of SOC rich sediment being transport off of the plots for the 24–yr study was 2.4 Mg C ha^{-1} for NT, 5.3 Mg C ha^{-1} for CP and 7.2 Mg C ha^{-1}

Table 5 ■ Use of pre-tillage treatment (1988) SOC values (sod) as baseline to determine the total SOC change in first 12 years and during 24-years of tillage treatments. The 2000 SOC values for each plot were used as baseline to determine the total SOC content change during the last 12 years for the Grantsburg soil (Olson et al. 2013).

Tillage treatment (6 replications)	Depth	First 12-yr tillage effect on SOC total change by treatment using 1988 baseline	Last 12-yr tillage effect on SOC total change treatment 2000 baseline	24 year tillage effect on SOC by total change by using treatment using 1988 baseline
	cm	Mg C ha^{-1} $layer^{-1}$ (% change)		
NT	0–15	–1.7 (–6)	–0.5 (–2)	–2.2 (–8)
	15–75	–3.4 (–14)	+4.4 (+22)	+1.0 (+4)
	0–75 (all)	–5.1 (–10)	+3.9 (+8)	–1.2 (–2)
CP	0–15	–3.4 (–12)	–4.7 (–19)	–8.1 (–28)
	15–75	–4.8 (–20)	+3.0 (+16)	–1.8 (–8)
	0–75 (all)	–8.2 (–16)	–1.7 (–4)	–9.9 (–19)
MP	0–15	–8.3 (–29)	–1.1 (–5)	–9.5 (–34)
	15–75	–5.3 (–23)	+6.5 (+36)	+1.2 (+5)
	0–75 (all)	–13.6 (–27)	+5.5 (+14)	–8.2 (–16)

for MP (Olson et al., 2013). The NT plots did retain more SOC than MP plots, however, they did not sequester SOC. NT treatment only reduced the magnitude and rate of SOC loss over time. It is true that if a farmer had decided to use MP instead of NT the amount of SOC retained in the soil after 24–years of NT treatment would be 7.8 Mg C ha^{-1} greater than after 24–years of MP treatment and therefore the greenhouse gas emissions from the SOC in the NT plots would be lower than from the SOC in the MP plots (but still higher than if the plot area had remained idle or in sod).

Conclusions

Using the comparison method with MP the baseline, the NT plots did store and retain 7.8 Mg C ha^{-1} more SOC in the soil than MP and the CP stored and retain –1.6 Mg C ha^{-1} less SOC in the soil than MP. That SOC amount was retained in the soil and not decomposed and re–emitted to the atmosphere as a result of cultivation or in the transported sediment moved off of the plots. However, no SOC sequestration occurred in the NT, CP and MP plots and SOC were actually lost since the SOC level of the plot area was higher at the start of the experiment than after 24–years of tillage treatments. At the end of the study the NT plots had 2% less SOC than the pre–treatment plot area, CP had 19% less SOC and MP had 16% less SOC.

The comparison tillage study method with MP as baseline and with SOC measured in the last year of a 24–yr study was used to determine the magnitude of SOC storage and retention rate for the conversion of MP tillage system to a NT or CP tillage system (Table 6). However, the SOC storage and retention rates could not be validated as SOC sequestration since the pre–treatment had significantly higher SOC in pre–treatment plot area than in the NT, CP and MP plots after a 24–year tillage study. The use of the tillage comparison method without establishing a pre–treatment baseline (the SOC

Table 6 ■ Use of pre-treatment SOC baseline (1988) to determine the rate of SOC change. During first 12 years and for 24-years of tillage. A 2000 baseline was used for last 12 years on the volumetric SOC content (Mg C ha^{-1} layer^{-1} yr^{-1}) of the Grantsburg soil (Olson et al, 2013).

Tillage treatment	Depth	1988 to 2000 tillage effect on SOC rate of change by treatment (baseline 1988)	2000 to 2012 tillage effect on SOC rate of change by treatment (baseline 2000)	24 year tillage effect on SOC rate of change by treatment (baseline 1988)
	cm		Mg C ha^{-1} layer^{-1} yr^{-1}	
NT	0–15	–0.14	–0.04	–0.09
	15–75	–0.28	+0.36	+0.04
	0–75 (all)	–0.42	+0.33	–0.05
CP	0–15	–0.28	–0.39	–0.33
	15–75	–0.40	+0.25	–0.08
	0–75 (all)	–0.68	–0.14	–0.41
MP	0–15	–0.70	–0.09	–0.39
	15–75	–0.44	+0.54	+0.05
	0–75 (all)	–1.14	–0.45	–0.34

content of the plot areas prior to establishment of the tillage experiment) could in some cases, including this study, overestimate the amount of SOC sequestration, the SOC sequestration rate and an underestimate the amount greenhouse gas released to the atmosphere from SOC during the study.

Findings suggest a pre–treatment SOC baseline was needed in this tillage comparison study to determine whether or not the NT and CP SOC storage and retention amount and rate findings actually resulted in SOC sequestration or loss. There was no SOC sequestration in the NT, CP or MP plots since the SOC level of the plot area was higher at the start of the experiment than at the end of the 24–yr study. Findings suggest a pre–treatment SOC baseline is essential in all tillage comparison studies when determining the amount and rate of SOC sequestration especially on sloping and eroding soils with a more intensive cropping rotation (more row crops and few years of forages) during the study than in previous years. Based on 24 years of crop yield measurements (12–years corn and 12–years soybean), the NT system appears to have resulted in similar long–term productivity compared with that of the MP and CP systems. The results of this study should be applicable to similar root–restricting, sloping, and moderately eroded soils in Illinois, Indiana, Missouri, and Kentucky.

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Fungicides for Corn and Soybean—Does it Make Sense (*Cents*)?

Carl A. Bradley
Associate Professor of Plant Pathology
N-533B Turner Hall
217-244-7415
carlbrad@illinois.edu

Application of foliar fungicides to corn and soybean fields has become a more common management practice for farmers in Illinois compared to 10 years ago. In addition to providing protection against fungal diseases, foliar fungicides have been touted to improve plant health and performance, and to improve the integrity of corn stalks. These potential benefits of applying a foliar fungicide are desirable and can lead to improved profitability, but how consistently are these benefits observed? Evaluating the effect of foliar fungicides in replicated field trials across multiple environments is the best way to measure their consistency in providing benefits that lead to improved profitability.

University of Illinois Corn Fungicide Trials

From 2008 to 2013, fungicide research trials have been conducted on corn across different locations in Illinois. In each of those years, foliar fungicides were tested on corn in replicated research trials at 5 to 7 locations each year. Overall, this dataset is made up of 33 different environments (locations, years) (*please note that the 2013 yield data were not yet available at the time this was written*). In these trials, foliar fungicides (treatments consisted of several of the following fungicides: Headline, Headline AMP, Quilt, Quilt Xcel, Stratego, Stratego YLD) were applied between the VT (tassel emergence) and R1 (beginning silking) stages.

When compared to the untreated checks at each location, the average yield response achieved with fungicides across all of these environments was 5.8 bu/A (Fig. 1). Based on 2013 corn prices and foliar fungicide prices, a yield response somewhere between 5 and 8 bu/A would be considered "profitable." Based on the overall results, achieving at least a 5 or 8 bu/A yield response occurred 58% or 48% of the time, respectively.

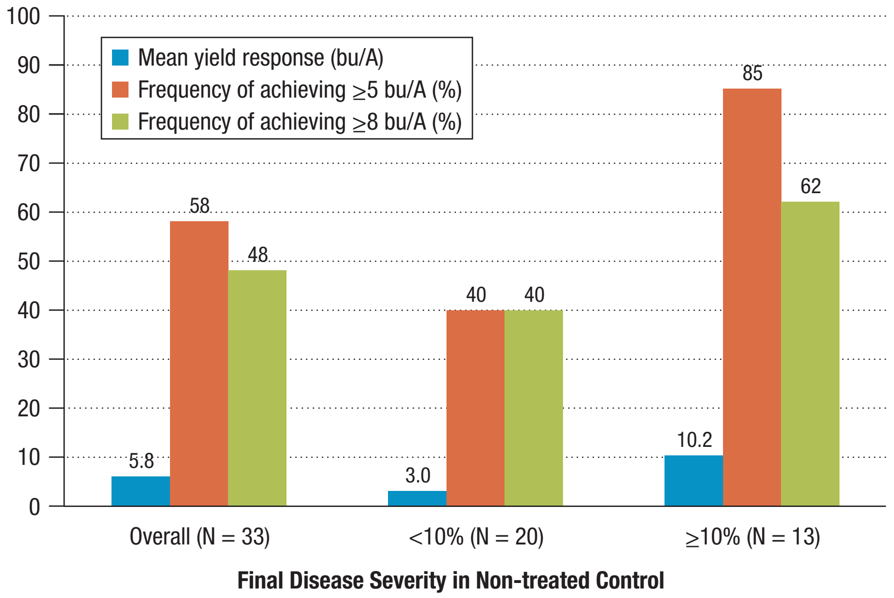

Figure 1 ■ Effect of fungicides on corn yield response and frequency of achieving at least 5 or 8 bu/A yield response across 33 environments in Illinois and under different disease pressure environments (2008-2012, with several locations each year).

When these results are broken down into two categories (1. disease severity of less than 10% severity in the untreated check (low disease pressure), and 2. disease severity of at least 10% severity in the untreated check (moderate to high disease pressure)), the overall average yield responses and frequencies of being profitable are different. In the low disease pressure environments (20 environments), the average yield response was 3 bu/A, and a yield response of at least 5 or 8 bu/A would have been achieved less than half of the time (40%) (Fig. 1). In the moderate to high disease pressure environments (13 environments), the average yield response was 10.2 bu/A, and achieving at least 5 or 8 bu/A would have been achieved 85% or 62% of the time, respectively (Fig. 1).

Foliar fungicides applied to corn also may have an effect on corn stalk integrity, which may improve standability. Previous research has shown that stalk health is affected by the "photosynthetic stress-translocation balance" (Dodd, 1980; Dodd, 1980). In this balance act, when corn plants are stressed and unable to sustain rates of photosynthesis needed to keep up the carbohydrate demand of the ear, carbohydrates are translocated from the roots and stalk to fulfill these demands. This movement of carbohydrates out of the roots and stalk predisposes the stalk to infection by stalk rot fungi, which reduces stalk integrity and increases the likelihood of lodging. The results of the University of Illinois fungicide trials indicate that stalk health can be improved by the application of foliar fungicides, but large improvements generally were observed only when foliar diseases that were significantly affecting ear leaves in the non-treated control plots were controlled in plots where fungicides were applied. When this occurred, the fungicide-protected plants were better able to sustain the rates of photosynthesis needed to keep up with the carbohydrate demands of the ear. This suggested relationship

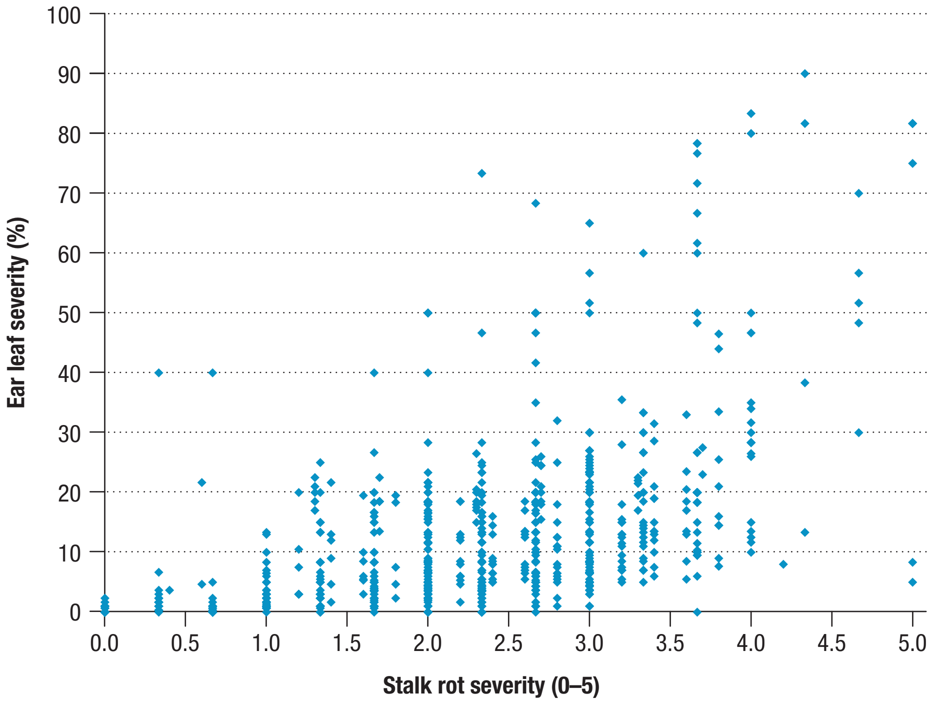

Figure 2 ■ Scatter plot of foliar disease severity on the ear leaf vs. stalk rot severity. A positive and significant correlation ($R = 0.46$; $P = 0.0001$) was observed (N = 962 total observations).

between foliar disease severity and stalk rot severity is validated by the significant positive correlation ($R = 0.46$; $P = 0.0001$) observed between these two diseases in over 950 observations collected from University of Illinois corn fungicide trials (Fig. 2).

The results of the University of Illinois foliar fungicide research trials on corn indicate that disease pressure is an extremely important consideration when making a fungicide application decision, since it has a major influence on overall yield responses, profitability frequencies, and stalk health. Basing foliar fungicide application decisions on disease risk (weather, hybrid susceptibility, previous crop, planting date, history of disease in field) will increase the likelihood of making profitable fungicide application decisions.

University of Illinois Soybean Fungicide Trials

University of Illinois foliar fungicide trials were conducted on soybean in an Illinois Soybean Association-funded project from 2007 to 2011. In this project, fungicides were evaluated on 4 different soybean varieties at each location, which varied from 5 to 10 locations each year. At each location, a minimum of 3 replications were used. Fungicides were applied near the R3 (beginning pod) development stage. Fungicide treatments changed slightly year to year, but three treatments evaluated in every year and location: an untreated control; Quadris at 6 fl oz/A; and Headline at 6 fl oz/A. When statistically analyzed across all locations and years (total of 368 observations for each treatment), both Quadris and Headline provided approximately a 2 bu/A yield response over the non-treated control (Fig. 3). In general, foliar disease severity levels were moderate to low in the environments in which the trials were conducted. The amount of rainfall accumulation during the

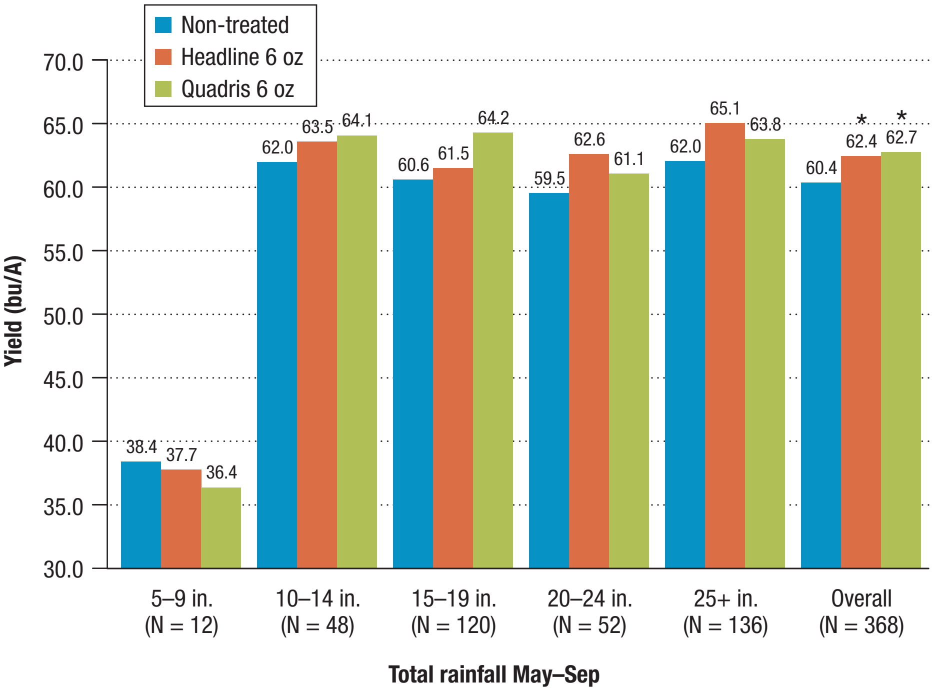

Figure 3 ■ Effect of foliar fungicides on soybean yield across different environments that received different amounts of rainfall during the season (trials conducted from 2007 to 2011; "*" indicates that treatment provided yields that were statistically different than the non-treated control).

season appeared to have little effect on the level of yield response achieved with the fungicides (Fig. 3.). In general, yield responses of around 2 bu/A were achieved during seasons in which a minimum of 10 inches of rain fell during the season. However, when less than 10 inches of rain fell during the season, positive yield responses with foliar fungicides were not observed.

The results of these soybean fungicide trials indicate that in seasons where typical rainfall is received during the season (at least 10 inches), applications of foliar fungicides at the R3 growth stage generally will result into a yield response of approximately 2 bu/A. Based on 2013 soybean price and fungicide application costs, a 2 bu/A yield response would be near the "break-even" mark.

Fungicide Resistance

One of the risks associated with foliar fungicide applications becoming a "standard" practice is that fungicide-resistant strains of important fungal pathogens may be selected and increase in population. This was documented in 2010 with the fungus that causes frogeye leaf spot of soybean (*Cercospora sojina*). Frogeye leaf spot is considered one of the most serious foliar diseases of soybean because of its ability to reduce yields on susceptible varieties under warm and humid conditions. In 2010, strains of *Cercospora sojina* resistant to fungicides in the strobilurin (a.k.a. QoI) chemistry class were detected for the first time. From 2010 to 2012, strobilurin-resistant strains of this pathogen were found in 44 counties/parishes in 8 states (Fig. 4). When these strobilurin-resistant strains are present in a field planted to a susceptible soybean variety, fungicides that contain a single strobilurin active ingredient will not be effective in managing the disease, and yield losses likely will occur. It is possible that this scenario could eventually occur with other fungal pathogens of corn and soybean, which stresses the importance of practicing fungicide resistance management. Important fungicide resistance management tactics include: using other management tactics to control diseases (resistant varieties, etc.), applying fungicides that contain more than one mode of action, and applying fungicides only when needed based on disease risk and scouting observations.

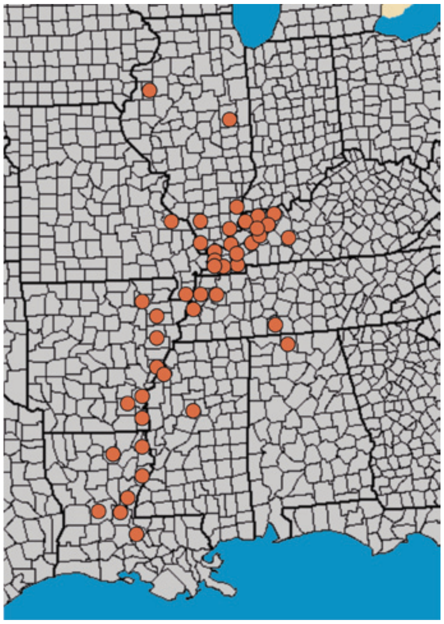

Figure 4 ■ Areas where strobilurin fungicide-resistant strains of the frogeye leaf spot pathogen of soybean (*Cercospora sojina*) have been detected (2010 to 2012).

Summary

Foliar fungicides are valuable tools that can be used to help manage corn and soybean diseases and protect yield potential and corn stalk integrity. Research results from University of Illinois fungicide trials indicate that:

Larger yield responses from fungicide application are more likely to be observed under moderate to high levels of disease pressure compared to low disease pressure.

Profitable yield responses from fungicide application (those large enough to pay for the fungicide application) will occur more frequently under moderate to high levels of disease pressure compared to low disease pressure.

Reduction of corn stalk rot severity with a foliar fungicide application is mostly a function of protecting leaves from foliar diseases, which allows them to produce enough photosynthates for the ear to prevent self-cannibalization of the stalk. This is more likely to occur on corn hybrids that are susceptible to foliar diseases under environments that are favorable for foliar diseases. However, fungicides may reduce stalk rot on hybrids that are resistant to foliar diseases if harvest is delayed for an extended period of time.

Foliar fungicides consistently provided approximately a 2 bu/A yield response in soybean grown under different moisture conditions when at least 10 inches of rainfall accumulated during the season.

Strains of important fungal pathogens that are resistant to fungicides may be selected and increase in nature if proper fungicide resistance management tactics are not followed.

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Machinery, Farm Structure, and Profits

Gary Schnitkey
Department of Agricultural and Consumer Economics
300a Mumford Hall
schnitke@illinois.edu
217-244-9595

Likely as a result of higher incomes in the past several years, many grain farmers updated a significant portion of their machinery inventories. This updating has led to higher machinery costs on farms. In this article, machinery costs on Illinois farms are examined and related to soil productivity, farm size, and percent of acres in corn. Linkages between machinery costs and farm profitability also are made. Following the examination of costs, strategies for lowering machinery costs are discussed.

Calculation of Power Costs

Machinery costs are examined using data from farms enrolled in Illinois Farm Business Farm Management (FBFM). FBFM is a farmer owned cooperative in Illinois that provides financial record-keeping and consulting services to over 6000 farms in Illinois. Acres on farms enrolled in FBFM constitute approximately 25 percent of the acres farmed in Illinois.

Per acre machinery costs are analyzed for farms that meet the following criteria:

- Farms have at least 500 tillable acres.
- Farms have to receive the majority of their income from grain farm operations. This criterion focuses the analysis on grain farm operations. Per acre costs of farms with livestock operations likely would differ from those farms focusing of grain operations.
- Farms have records certified usable by FBFM field staff. This ensures the integrity of the data.
- Farms have to receive less than $10 per acre in custom farming receipts. Farms that have significant portions of their income from custom farming may have larger machinery complements to perform custom operations. Hence, on a farmed acre basis, farms that are custom farmed may have higher costs.

Approximately 1400 farms in each year met the above criteria. Custom farming to $10 per acre eliminates approximately 500 farms per year from the analysis

On FBFM summaries, machinery costs fall under the category of "power" costs. Power costs include:

1. Machinery hire—costs paid to others to perform machinery operations. This category includes charges for applying fertilizer and chemicals.
2. Utilities,
3. Repairs,
4. Fuel and Oil, and
5. Deprecation

Power Costs over Time

Between 1996 and 2006, per acre power costs were relatively stable at $61 per acre on Illinois grain farms (see Figure 1). Since 2006 power costs have increased dramatically: $68 per acre in 2007, $77 in 2007, $91 in 2008, $92 in 2009, $104 in 2010, $119 in 2011, and $125 in 2012.

Most of this increase has been due to higher machinery expenditures during recent years. Between 2011 and 2012, capital expenditures have

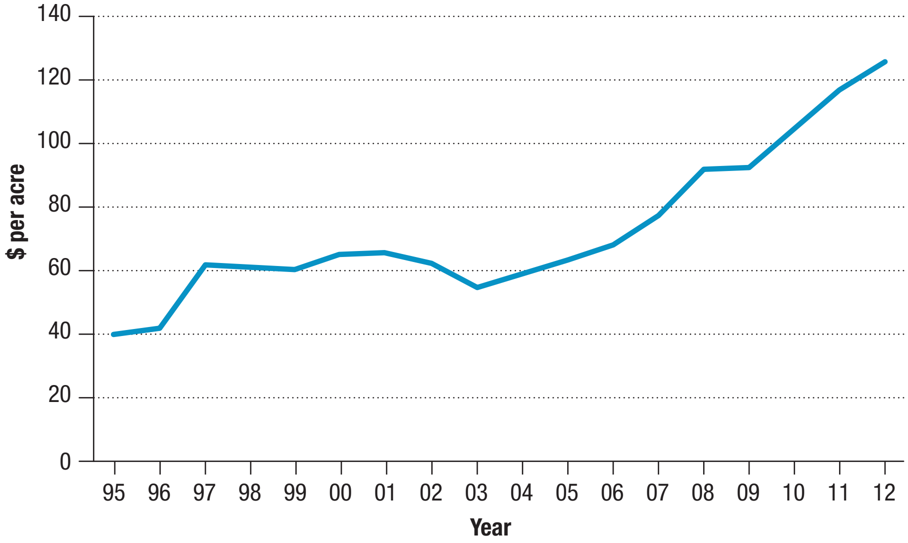

Figure 1 ■ Per acre power costs on grain farms in Illinois, 1995 through 2012.

averaged over $100 per acre. This compared to an average near $45 per acre in the 2000s.

A number of factors could have caused the increase in capital expenditures. Global Positioning System and variable rate technologies have been introduced, likely leading to purchases of new equipment. Equipment prices also rose dramatically during the past six years. While these are important factors, likely the most important factor has been increases in commodity prices since 2006. Between 2006 through 2012, higher commodity prices have led to higher incomes than prior to 2006. Higher incomes provided funds for machinery purchases. Moreover, accelerated depreciation methods for tax purposes allowed quick expensing of machinery purchases, sheltering farm income from taxes.

Profits and Power Costs

There is a linkage between power costs and farm profits, as illustrated in Figure 2. Each dot in Figure 2 represents a farm in northern and central Illinois that have complete data for the ten years between 2003 and 2012. The average per acre power costs are given on the horizontal axis and the average per acre operator and farmland returns are given on the vertical axis. Operator and farmland return is a measure of profits and equals gross revenue minus non-land costs. Land costs would need to be subtracted from operator and farmland return to arrive at the farmer's return.

As can be seen in Figure 2, operator and farmland returns tend to decrease as power costs increase. The trend-line fit through the data suggests an almost one for one relationship. As power costs increase by $1 per acre, operator and farmland returns decrease by $.90 per acre. From Figure 2, it also is obvious that there is great variability around this trend-line. There are farms that have high power costs and still maintain profitability and vice versa.

The negative relationship between power costs and operator and farmland returns was stronger prior to 2006. That is, the range in the scatter shown in Figure 2 would have been smaller if data only prior to 2006 were used. This

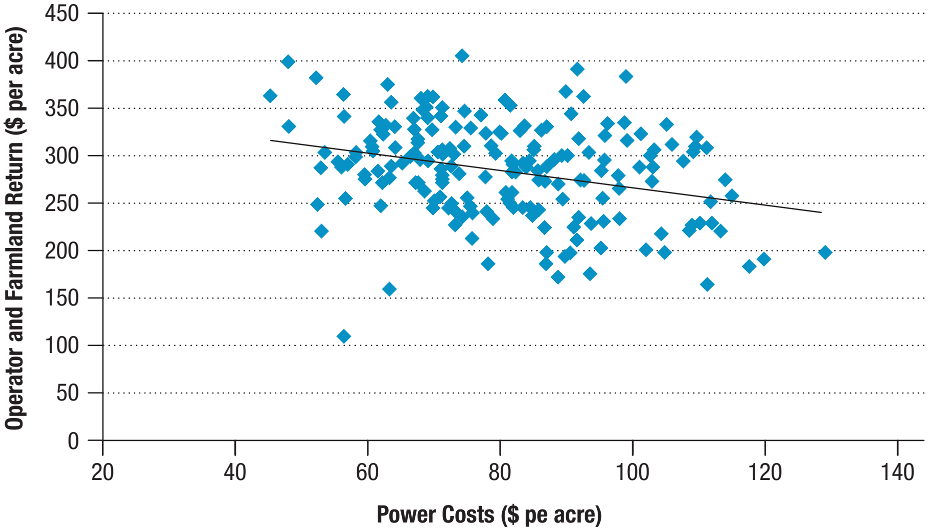

Figure 2 ■ Relationship between ten-year average power costs and operator and farmland returns, 2003–2012.

suggests that the relationship between returns and power costs may become more important in times of lower commodity prices.

Power Costs and Farm Structure

Average farm data from 2010 to 2012 are used to show the linkages between power costs and farm structural characteristics such as farmland productivity, farm size, and percent of acres in corn and soybeans. While these factors influence power costs, there is considerable range in power costs, similar to that shown in Figure 2. Therefore, these relationships should be taken as tendencies. Many farms will have either higher or lower costs than suggested by the explanations below.

Soil productivity: FBFM measures soil productivity with a soil productivity rating (SPR). Power costs exhibit a decreasing relationship with SPR. On average, power costs decrease with higher soil productivity ratings. As an example, a farm that has an expected corn yield of 195 bushels per acre is projected to have an $8 lower cost than a farm with an expected yield of 180 bushels per acre.

A number of reasons could be speculated for this relationship. Farmland with higher productivity may have land that becomes workable quicker than farms with lower productivity, meaning there are more working days to complete field operations. More working days than a lower productivity soil, then require a smaller complement of machinery to complete work, thereby lowering costs

Farm Size: There is a statistically significant relationship between power costs and tillable acres. This relationship suggests that the lowest power costs are on farms with between 3,000 and 4,000 tillable acres. Power costs are higher for farms not in this range; however, the differences are not large. For example, a farm that has 1,500 acres would be projected to have $8.70 per acre in higher costs than a farm in the 3,000 to 4,000 acre range. Similarly, a farm with 6,000 acres would be projected to have $8.70 per acre higher costs than a farm in the 3,000 to 4,000 acre range.

The 3,000 to 4,000 acre size having the lowest costs may relate to combine use. The 3,000 to 4,000 acre range likely is close to the range where one combine can be used to complete harvest. Smaller farm sizes may not fully use a combine, causing costs to increase. (Sharing a combine across farms of smaller sizes can result in low power costs for farms with less than 3,000 acres.) Larger farm size may face problems in matching harvesting capabilities with acres. One combine may not be enough and two combines may be too many to achieve the lowest possible costs.

Percent acres in corn: Farms with a higher percentage of their acres in corn have higher costs than farms with a lower percentage of their acres in corn. For example, a farm with 66% of their acres in corn typically has $10.50 higher costs than a farm with 50% of their acres in corn. A farm with 75% of their acres in corn typically has $8.90 per acre higher costs than a farm with 66% of their acres in corn.

Two factors likely contribute to higher costs for farms with more acres in corn. First, harvesting costs are higher for corn than for soybeans. As farms switch to more corn, harvesting costs increase. Second, a higher percentage of corn acres often results in more tillage, particularly on corn-after-corn acres. These tillage operations, particularly if they go deep and require a large tractor to pull the implement across the field, are costly.

Much of the profit advantage of planting more corn can be eliminated if more tillage occurs than in a more traditional 50% corn–50% soybean rotation. Evaluating whether these tillage passes are necessary would be prudent.

Strategies for Lowering Power Costs

Power costs almost invariably revolve around use of machinery on a farm and machinery inventory. Timing of machinery trading does not influence per acre costs as much if reasonable trading strategies are used. Herein, three strategies for lowering costs are discussed.

Combine Use: Strategies for lowering machinery costs mostly revolve around fully utilizing machinery or, in other words, matching equipment size properly with farm size. The largest costs associated with machinery are ownership costs which include depreciation and interest. These machinery ownership costs are lowered on a per acre basis by using the machinery over more acres. Of course, use of machinery has to be weighed against timeliness issues. Overall, however, machinery costs generally are lowered as the equipment is used over more acres.

In this process of matching equipment with farm size, focus on those operations with the largest costs. Table 1 shows a list of per acre costs on typical field and harvesting operations. These costs are taken from *Machinery Cost Estimates* publications available in the management section of *farmdoc* (www.farmdoc.illinois.edu).

As can be seen in Table 1, the highest costs are combining at $33.70 for corn and $28.30 for soybeans. These costs only include the cost of combining itself and do not include the costs of moving grain away to on-farm storage or commercial sites. Inclusion of combining and handling costs result in

Table 1. Costs of Performing Field Operations

Operation	Costs per Acre
Combining—corn	33.70
Combining—soybeans	28.30
Strip tillage	16.90
Offset disk	14.60
Chisel plow	14.50
Grain drill	12.80
Planter	12.70
Field Cultivator	9.80

Source: *Machinery Cost Estimates: Summary*, 2012, available in the management section of farmdoc.

harvesting costs to be over 50% of the machinery costs on farms.

One way of minimizing these costs is to use the combine over more acres, with some farms approaching near 3,000 acres with one combine. Farms with fewer acres can achieve efficiencies by combine sharing over several farms.

Perform Only Necessary Tillage Operations: Primary tillage operations often have a high cost. Hence, judging the necessity of these operations often is key in determining whether they should be performed. A chisel plow operation costs $14.50 per acre. Higher yields must be obtained for this field operation to be warranted. At a $4.50 corn price, the chisel plow operation must return 3.2 bushels per acre.

Inventory of Equipment: Unnecessary or little used pieces of equipment on a farm will increase machinery costs. This occurs because depreciation and interest are incurred for all owned equipment whether they are used or not. Number of relatively new tractors has a large impact on costs. Minimizing tractors lowers costs.

Summary

During the past several years, many farmers have updated a large portion of their machinery. This updated line of equipment can serve as a financial resource in future years, allowing farmers to postpone capital purchases. Over the next several years, lower machinery costs may be important as we move into a period of lower incomes. Machinery costs on farms can be lowered by fully using machinery and by owning only necessary pieces of equipment.

Results from Statewide Insect Surveys and an Update on the Troublesome Rootworm Injury to Rotated Bt Corn

Michael E. Gray
Professor & Assistant Dean,
ANR Extension
Department of Crop Sciences
N-305 Turner Hall
megray@illinois.edu
217-333-4424

Co-Authors: **Ronald E. Estes, Nick Tinsley** and **Dennis Bowman,**
Department of Crop Sciences, University of Illinois, Urbana-Champaign

Introduction

In August 2013, statewide (28 counties) insect surveys were conducted in corn and soybean fields. Within each county, five corn and five soybean fields were selected at random. In each cornfield, western corn rootworm densities were estimated by counting the number of beetles on 20 consecutive plants. In soybean fields, 100 sweeps were taken and the abundance of several insect species was determined. This survey was sponsored by a grant from the United States Department of Agriculture (USDA) National Institute for Food and Agriculture (NIFA). Results from this past year's survey will be compared with the statewide survey conducted in 2011, the results of which were reported during the 2012 *Corn and Soybean Classics* series of meetings. Overall, statewide pest densities were very low in soybeans in 2011 as were western corn rootworm numbers in corn and soybean fields. Specific reasons for these low insect densities in 2011 remain elusive but may relate to high adoption of Bt hybrids along with increasing use of planting-time soil insecticides in corn, widespread use of insecticidal seed treatments in corn and soybean fields, and more common applications of tank-mixed fungicide and insecticide broadcast treatments to corn and soybeans. Environmental factors also may play a role in reducing insect numbers in some fields. For instance, heavy spring precipitation that leads to saturated soils at the time of corn rootworm larval hatch (late May, early June) may suppress rootworm larval survival and lessen injury to root systems. Hot and dry summer conditions may result in lower soybean aphid densities as observed in 2013.

Western Corn Rootworm Numbers

In 2013, western corn rootworm adult densities exceeded the 0.75 adult per plant threshold (corn following corn) in several counties (Figure 1) during

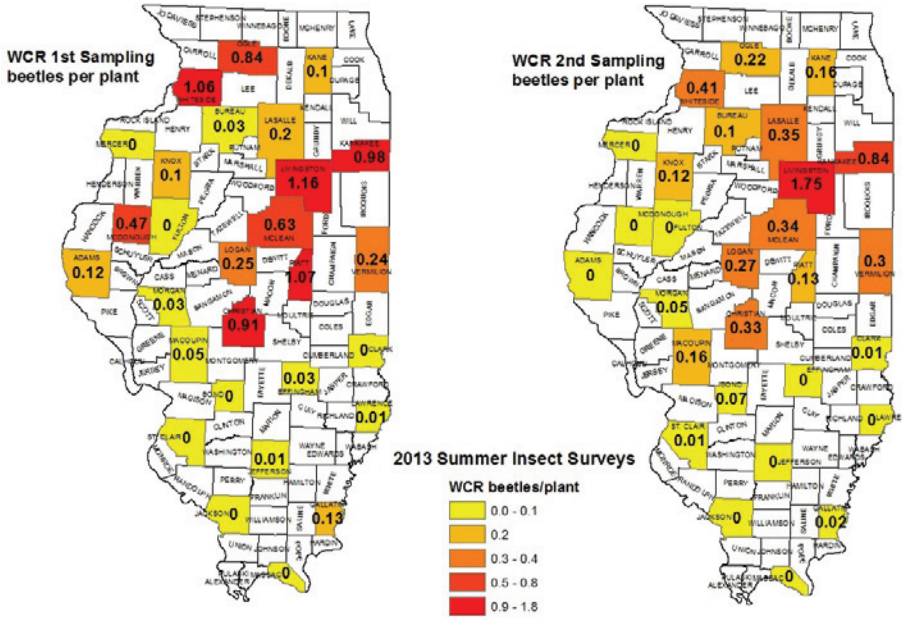

Figure 1 ■ Average number of western corn rootworm adults per plant in selected counties of Illinois for two sampling periods, August 1 through 6, and August 14 through 16. Means were derived by counting the number of beetles on 20 consecutive plants in each of five randomly selected cornfields per county (n = 100).

the first sampling period (August 1 to 6) and included: Christian (0.91), Kankakee (0.98), Livingston (1.16), Ogle (0.84), Piatt (1.07), and Whiteside (1.06). The western corn rootworm adult threshold used in first-year corn is 0.5 beetle per plant. The threshold is lower in rotated cornfields because a greater percentage of the beetles are females. Producers who have western corn rootworm densities at these levels should make management decisions to avoid potential economic losses in their corn during the 2014 growing season. Appropriate management decisions could include rotation to another crop such as soybeans, use of a Bt hybrid (preferably pyramided), or use of a non-Bt hybrid along with a planting-time soil insecticide. Western corn rootworm numbers generally declined (Table 1) in corn during the second sampling period (August 14 to 16); however, in Livingston County the number of western corn rootworm adults per plant increased to 1.75 (Figure 1). Overall, densities of western corn rootworms were greatest in east central, central, northeastern, and northwestern counties. Numbers of western corn rootworms were very low across the southern one-third of the state. This pattern has been observed for many years and calls into question the wisdom of routine use of corn rootworm products in southern Illinois. Producers would be wise to scout (corn and soybeans) for western corn rootworm adults in southern Illinois and make informed management choices regarding whether or not to invest in corn rootworm protection products in this region of the state.

Table 1 ■ Mean[1] number of western corn rootworm beetles per plant by region for two sampling periods, Department of Crop Sciences, University of Illinois, 2013.

Region[2]	**Sampling period**[3]		**Change**
	I	**II**	
Northeast	0.61	0.69	+0.08
Northwest	0.41	0.17	–0.24
East central	0.45	0.15	–0.30
West central	0.17	0.06	–0.11
Southeast	0.04	0.01	–0.03
Southwest	0.01	0.06	+0.05

[1] Means were derived by counting the number of western corn rootworm beetles on 20 consecutive plants in each of 5 randomly selected cornfields per county in 4 or 5 counties per region (n = 400 or 500).

[2] See state maps to view the counties surveyed in each region.

[3] Sampling period I occurred between 1 and 6 August; sampling period II occurred between 14 and 16 August.

The number of western corn rootworm adults in soybean fields was greatest in central and northeastern counties (Figure 2) during the second sampling period (August 14 to 16). Densities were greatest in the following counties: Kankakee (15.2 beetles per 100 sweeps), LaSalle (30.2), and Livingston (28.6). More moderate densities of western corn rootworm adults in soybeans were found in the following counties: Kane (8 beetles per 100 sweeps), Logan (9.6), McLean (6.8), and Piatt (11.8). Producers in these counties should be prepared to make the necessary management decisions to protect against economic infestations of corn rootworm larvae in first-year cornfields during 2014. Densities of western corn rootworm adults in soybean fields across much of southern and western Illinois were relatively low during both sampling periods in August. An important reminder—***producers should always scout their individual fields to make corn rootworm management decisions and not rely exclusively on county or regional estimates of rootworm densities***. As compared with 2011, western corn rootworm densities trended somewhat higher in 2013 for central, east central, northeastern, and northwestern Illinois. Reasons for this increase are difficult to pinpoint;

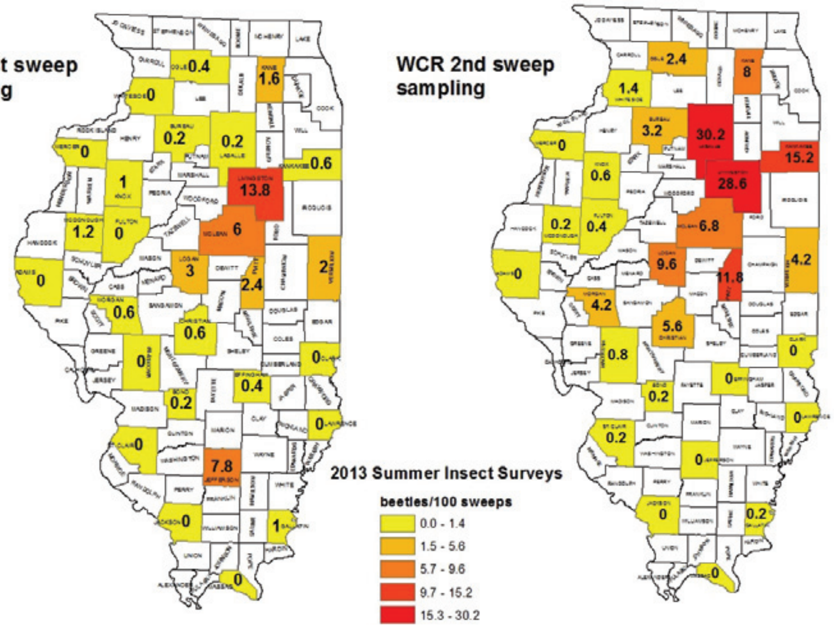

Figure 2 ■ Average number of western corn rootworm adults per 100 sweeps in a soybean field. Means were derived by taking 100 sweeps in the interior of five randomly selected soybean fields per county (n= 5). The first sampling period was August 1 through 6 and the second sampling period was August 14 through 16.

however, explanations may include environmental factors (drier soil conditions during larval hatch) in some fields, compromised Bt performance in some fields due to resistance, and compromised soil insecticide performance in some fields due to excessively dry soil conditions.

Soybean Insect Numbers

Similar to the survey results reported for 2011, overall insect densities remained low in soybean fields across the state in 2013 for both sampling periods (Table 2). Continuing concern that some new stink bug species will become a significant threat to soybean producers prompted us to carefully monitor sweep net samples for the brown marmorated stink bug (*Halyomorpha halys*), redbanded stink bug (*Piezodorus guildinii* Westwood), and redshouldered stink bug (*Thyanta custator accerra* McAtee). Fortunately, we found none of these species in our sampling of soybean fields. However, it should be made clear—brown marmorated stink bugs are now confirmed in 11 counties in Illinois and will become much more problematic in coming years, especially across southern counties of the state. Densities of Japanese beetles were greatest in north central and northwestern counties (Figure 3) during the second sampling period (August 14 to 16) and included the following counties: LaSalle (22.8 beetles per 100 sweeps), Ogle (67.8), and Whiteside (54.8). The number of Japanese beetles during the first sampling period (August 1 to 6) in Mercer County also was significant at 28 beetles per 100 sweeps. Across the southern two-thirds of Illinois, Japanese beetle numbers in soybean fields were low. Bean leaf beetle densities were very low throughout the state, never exceeding 5 beetles per 100 sweeps for any county (Figure 4). Similarly, the numbers of other less prominent soybean insect pests such as brown and green stink bugs, soybean loopers, green

Table 2 ■ Mean[1] number of various insect pests per 100 sweeps by region for two sampling periods, Department of Crop Sciences, University of Illinois, 2013.

Sampling period[2]	Region[3]	Bean leaf beetle	Grape colaspis	Japanese beetle	Northern corn rootworm	Southern corn rootworm	Western corn rootworm	Grasshopper	Green cloverworm	Soybean looper	Brown stink bug	Green stink bug
I	Northeast	1.8	0.3	5.9	0.2	0.1	4.4	0.8	0.2	0.2	0.0	0.0
	Northwest	0.3	0.1	20.3	0.1	0.2	0.3	0.2	0.0	0.0	0.2	0.0
	East central	0.8	0.2	0.9	0.0	0.1	1.1	0.6	0.1	0.0	0.0	0.2
	West central	0.8	0.0	2.9	0.0	0.2	1.0	0.0	0.1	0.0	0.1	0.1
	Southeast	0.8	0.2	0.9	0.1	0.3	2.2	0.1	0.7	0.3	0.0	0.3
	Southwest	0.9	0.7	1.4	0.0	0.5	0.1	0.7	0.7	0.0	0.1	0.1
II	Northeast	0.7	0.0	8.8	3.6	0.2	17.8	0.7	0.3	0.0	0.0	0.0
	Northwest	0.3	0.4	28.9	10.1	0.3	1.5	0.5	0.0	0.0	0.1	0.0
	East central	1.6	0.4	0.4	0.4	0.4	4.3	0.6	3.2	0.0	0.0	0.0
	West central	1.2	0.0	3.0	1.4	0.7	2.9	0.3	1.0	0.0	0.2	0.0
	Southeast	0.3	0.1	0.2	0.1	0.3	0.1	0.2	3.8	0.0	0.1	0.4
	Southwest	1.0	0.2	1.3	0.1	0.8	0.3	0.3	4.9	0.0	0.2	0.2

[1] Means were derived by taking 100 sweeps in the interior (> 12 rows from the edge) in each of 5 randomly selected soybean fields per county in 4 or 5 counties per region (n = 20 or 25).

[2] Sampling period I occurred between 1 and 6 August; sampling period II occurred between 14 and 16 August.

[3] See state maps to view the counties surveyed in each region.

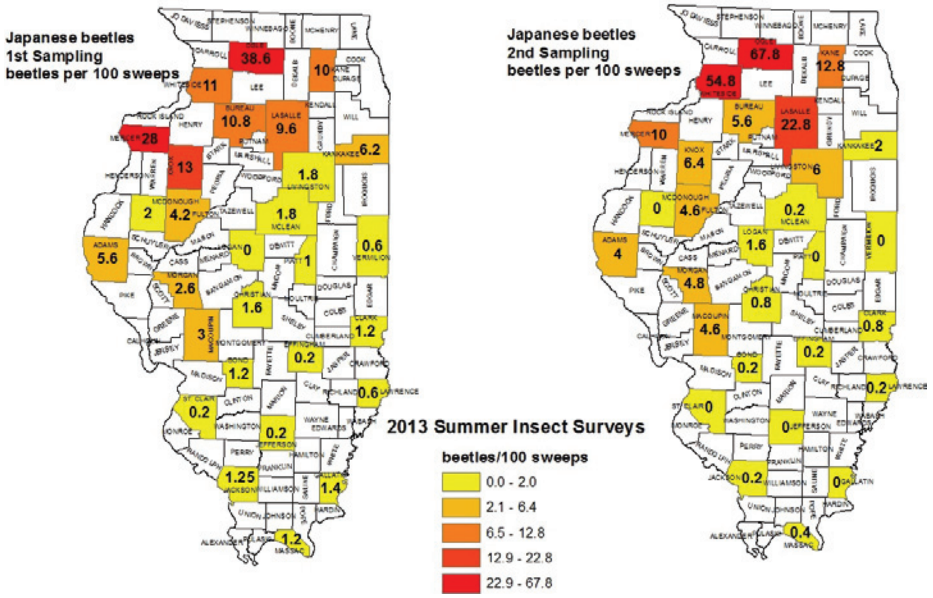

Figure 3 ■ Average number of Japanese beetle adults per 100 sweeps in a soybean field. Means were derived by taking 100 sweeps in the interior of five randomly selected soybean fields per county (n= 5). The first sampling period was August 1 through 6 and the second sampling period was August 14 through 16.

cloverworms, and grasshoppers were very low (Table 2). Future surveys will be conducted to determine if this downward trend in densities of soybean insects continues well into the future. Results from 2011 and 2013 clearly document the importance of scouting soybean fields, estimating defoliation and pod injury levels, and becoming knowledgeable about economic thresholds before any treatment decisions are made. Insecticide applications that are simply insurance-based may not be justified in many soybean fields and primarily serve to reduce natural enemy abundance.

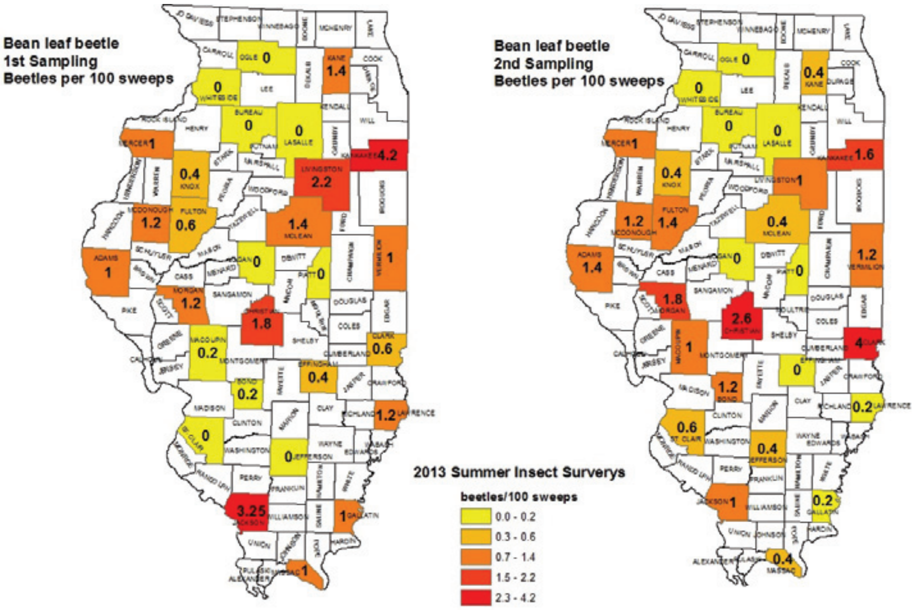

Figure 4 ■ Average number of bean leaf beetle adults per 100 sweeps in a soybean field. Means were derived by taking 100 sweeps in the interior of five randomly selected soybean fields per county (n= 5). The first sampling period was August 1 through 6 and the second sampling period was August 14 through 16.

Western Corn Rootworm Injury to Bt in First-Year Corn

On August 26, Dr. Joe Spencer, an entomologist with the Illinois Natural History Survey, and I confirmed that significant root pruning had occurred in some rotated cornfields of Kankakee (Figure 5) and Livingston (Figure 6) counties. The first-year cornfields in question had been planted to VT Triple PRO RIB hybrids that express the Cry3Bb1 rootworm protein. Significant lodging was evident in these rotated cornfields. We also observed densities of western corn rootworm adults that were very high in the damaged corn and adjacent soybean fields. Interestingly, our statewide survey data of western corn

Figure 5 ■ Severe root injury to Bt plants (VT Triple PRO), rotated corn, Kankakee County, Illinois, August 26, 2013.

Figure 6 ■ Severe root pruning to Bt Plants (VT Triple PRO), rotated corn, Livingston, County, August 26, 2013.

rootworm adults in corn (Figure 1) and soybeans (Figure 2) discussed earlier, confirm that densities of this pest were very high in these counties. Even though it is well documented that crop rotation no longer affords absolute protection against rootworm injury across many areas of Illinois (especially east central and northeastern counties), the severity of pruning to these Bt hybrids suggests that rotation resistance and resistance to the Cry3Bb1 protein may both be present in some western corn rootworm individuals. ***To date—this has not been proven and bioassays need to be conducted to confirm this hypothesis***. Dr. Joe Spencer collected adults from these affected fields (damaged corn and adjacent soybean fields) and the appropriate bioassays are being conducted.

Recommendations for 2014

The key to successful management of the western corn rootworm is to adopt a long-term battle plan—in essence, utilize an integrated approach, the foundation of IPM. This means an honest consideration and implementation of at least some of the elements outlined below:

- Adopt a more diversified cropping system. A corn and soybean rotation is not diversified enough from an ecological perspective. Evidence for this includes the evolution of the variant (rotation resistant) western corn rootworm in the mid-1990s across east central Illinois and its spread to other areas of the Corn Belt.
- Consider the use of a non-Bt corn hybrid especially if a more diversified crop rotation plan is implemented.
- Consider the use of a carefully managed adult suppression program that reduces the egg load into a cornfield. This approach has been used successfully for decades in the western Corn Belt. Caution: Where this approach was not integrated with other tactics, resistance to methyl-parathion and carbaryl eventually occurred.
- Consider the use of a planting-time soil insecticide with a non-Bt hybrid. To date, resistance to the soil insecticides applied in-furrow or in a band at planting has not developed. Resistance has not occurred because producers have in effect deployed refuges (untreated areas) between rows with these products for decades.
- If a corn rootworm Bt hybrid is chosen, consider planting a pyramided product (a hybrid that expresses more than one rootworm Cry protein). A planting-time soil insecticide is not recommended for use with a pyramided Bt hybrid.
- Consider rotating Bt hybrids that express different Cry proteins.
- Consider rotating soil insecticides (across classes of insecticides).
- In 2014, a significant increase in the use of planting-time soil insecticides is anticipated. In many areas of the state, especially those with Bt failures in 2013, soil insecticides will be used with Bt rootworm hybrids. I am familiar with some reports that indicate adult control programs also will be utilized in these fields. Integration does not imply all these approaches should be used simultaneously. Producers did not get into this tough rootworm management challenge overnight and it will take a careful long term series of well-thought-out steps to reduce this economic threat.

Notes

Notes