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Corn and Soybean Basis: Will Weakness Persist?

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Background

In commodity markets, basis is defined as the difference between the cash price of the commodity in a specific market location and the price of the futures contract of that commodity (basis = cash price minus futures price). Basis for corn and soybeans, then, must be specified as to cash market location, the cash price considered (spot cash or forward cash), and the futures contract considered.

For example, the spot cash price of corn at Champaign, Illinois, on November 6, 2007, was $3.76. The price of December 2007 corn futures on that date was $3.8575. The spot basis was –$0.0975, usually stated as "9.75 under." On the same day, the July 2008 corn futures price was $4.22, so the basis relative to July futures was –$0.46, or "46 under."

Cash prices of corn and soybeans are generally less than futures prices in surplus production areas, such as Illinois, and often above futures prices in deficit areas, such as the ports for export. The magnitude of the basis in a local market at any time is generally influenced by three factors: (1) the cost of owning and storing the crop, (2) transportation costs, and (3) the supply of and demand for storage space in the local market.

For example, if the cost of storage, including interest on the value of the stored crop, were high, then the spread in futures prices would be expected to be larger than if costs were low, and the basis relative to the nearby futures contract would be expected to weaker than if storage and ownership costs were low. Similarly, a large harvest and increased demand for a fixed amount of storage space would be expected to result in a weaker basis, at a given level of storage costs, than if the crop were small and storage space were in surplus.

In areas where cash prices are less than futures prices, a strong basis refers to a basis that is currently less negative than would typically be expected at that time of year, and a weak basis refers to a basis that is currently more negative than would normally be expected. Similarly, a strengthening basis refers to the basis becoming less negative over time, and a weakening basis refers to the basis becoming more negative over time.

In areas where cash prices are above futures prices, a strengthening basis refers to the basis becoming more positive, and a weakening basis refers to the basis becoming less positive. The terms "narrowing" and "widening" are often used to describe a strengthening and weakening basis, respectively. However, those terms are correct only if cash prices are less than futures prices. In markets where cash prices are above futures prices, the terms have just the opposite meaning.

Convergence

In general, the spot cash basis in surplus production areas is expected to strengthen as the futures contract approaches maturity. That is, cash and futures prices are expected to converge at maturity of the futures. That occurs because it is expensive to own and store the cash crop, but it is relatively inexpensive to own futures contracts. As a result, cash prices are lower relative to futures the longer the period of time that the crop must be stored—that is, the further from maturity of the futures contract.

The basis strengthens as the length of the storage period is reduced. The strengthening of the basis over time is the market payment for storing the cash crop. In the previous example, the basis relative to July 2008 futures on November 6, 2007, was −$0.46. Over time, that basis would be expected to become less negative (strengthen), perhaps approaching −$0.05 by June 2008. The expected strengthening of the basis by $0.41 would be the market payment for storing the corn crop for about 7 months.

The price of futures contracts reflects the expected cash price of that commodity at the markets that are designated as delivery markets for settlement of futures contracts. For corn and soybeans, those delivery markets are mostly on the Illinois River. As a futures contract matures, then, the futures price should be very near the cash price at the delivery market (that is, the basis should be near zero) because futures and cash prices reflect the same commodity and the same market location at the same point in time. Basis at maturity of futures contracts at locations other than the delivery market should generally be other than zero because of the cost of transporting the crop to the delivery market from a surplus area or from the delivery market in a deficit area.

Recent Problems with Convergence

The magnitude of the corn and soybean basis and the pattern of change in the basis during the marketing year can and do vary from crop year to crop year. That is because the factors that influence basis vary from crop year to crop year. (For the historical as well as current basis in Illinois, see www.farmdoc.uiuc.edu/marketing/basis/index.asp.)

For producers and other merchandisers to make correct pricing and storage decisions, however, the magnitude and pattern of change in basis during the marketing year has to be more or less predictable. For example, if the change in basis from time A to time B during the marketing year is the market payment for storing the crop, producers and merchandisers must anticipate what that change will be in order to make a judgment about whether to store the crop. That judgment will not always be correct, but to the extent that basis patterns follow a logical, generally predictable, pattern, decisions will be mostly correct.

In addition, if the delivery mechanism for settling futures contracts is performing as intended, cash price at delivery markets and futures prices will converge, becoming equal as the futures contract matures. There have been recent instances of failure of both of these conditions in the corn and soybean (as well as wheat) markets. In several instances, interior basis levels remained much weaker than at any other time in history and weaker than could have been forecast. Cash and futures prices have failed to converge at the maturity of several futures contracts.

First is a brief look at the issue of cash and futures price convergence at delivery markets. We examined the pattern of price convergence at Chicago and the Illinois River markets for corn and soybeans for the December 2001 corn (November 2001 soybean) contract through the September 2007 contracts. For corn, some degree of nonconvergence was observed beginning with the March 2006 contract maturity (nonconvergence in September 2005 was appropriately explained by the disruption of the Illinois River transportation system following Hurricane Katrina). More significant convergence issues emerged with the maturity of the July 2006 contract, but convergence after that was more or less normal until September 2007. At maturity of the July contract, cash prices at Illinois River locations were $0.50 to $0.60 under September futures, well out of the range of acceptability (Table 1).

For soybeans, some issues with convergence emerged with the January 2006 contract and persisted through the September 2007 contract. The magnitude of nonconvergence was extremely large for the July, August, and September 2007 contracts. Cash prices at Illinois River points at the maturity of those three contracts were from $0.50 to $0.90 under futures prices. The pattern of convergence at maturity of the July contract is shown in Table 2. The extent of nonconvergence was unprecedented and unacceptable. Performance was better for the November 2007 contract, with cash prices at Illinois River points at maturity $0.27 to $0.29 under futures. Performance, however, was still not acceptable.

For interior points in Illinois, unusual corn basis behavior was not observed until the summer/fall of 2007 (except for the period in the fall of 2005 following Hurricane Katrina). Basis levels were exceptionally weak in August and September of 2007, but returned to a more normal level by late October 2007.

Table 1 ■ September corn futures prices, cash prices, and basis at Illinois River points, September 2007.

		Illinois River points			
		North of Peoria		South of Peoria	
Date	Futures price	Cash price	Basis	Cash price	Basis
September 4	$3.3675	$2.7475	–$0.6200	$2.8050	–$0.5625
September 5	3.2875	2.7775	–0.5100	2.8275	–0.4600
September 6	3.2325	2.8850	–0.3475	2.9250	–0.3075
September 7	3.3125	3.0150	–0.2975	3.0350	–0.2775
September 10	3.2975	3.0400	–0.2575	3.0625	–0.2350
September 11	3.2450	2.9150	–0.3300	2.9725	–0.2725
September 12	3.3975	2.9525	–0.4450	2.9375	–0.4600
September 13	3.3075	2.7500	–0.5575	2.7225	–0.5850
September 14	3.3650	2.7850	–0.5800	2.8250	–0.5400

Table 2 ■ September soybean futures prices, cash prices, and basis at Illinois River points, September 2007.

		Illinois River points			
		North of Peoria		South of Peoria	
Date	Futures price	Cash price	Basis	Cash price	Basis
September 4	$8.9250	$7.8225	–$1.1025	$8.0375	–$0.8875
September 5	8.8900	8.0000	–0.8900	7.9500	–0.9400
September 6	8.7800	8.0200	–0.7600	7.9750	–0.8050
September 7	8.9100	8.1500	–0.7600	8.1750	–0.7350
September 10	9.0350	8.2900	–0.7450	8.3000	–0.7350
September 11	9.0500	8.3000	–0.7500	8.3225	–0.7275
September 12	9.2500	8.4875	–0.7625	8.4400	–0.8100
September 13	9.2800	8.5050	–0.7750	8.4975	–0.7825
September 14	9.4100	8.6625	–0.7475	8.6925	–0.7175

Issues with the interior soybean basis parallel those of the convergence issues on the Illinois River. For example, the average cash price of soybeans in south central Illinois at the maturity of the July 2007 futures contract remained at $0.50 to $0.60 below the futures price. In the previous 3 years, the basis at maturity ranged from –$0.06 to –$0.28 (Table 3). Basis at interior locations remained very weak at the maturity of the August, September, and November 2007 contracts. Basis at these locations at the maturity of the November 2007 was not as weak as at the maturity of the August and September contracts, but it was much weaker than in recent history. The average south central Illinois basis at maturity was –$0.33, compared to the previous 3-year average of –$0.16.

Consequences of Nonconvergence

The extremely weak basis at maturity of the September 2007 corn futures contract and the July, August, September, and November soybean futures contracts negatively impacted short hedgers. Those holding hedged inventory, anticipating a strengthening of the basis as contracts approached maturity, did not receive the return to storage that would have occurred if basis had strengthened to more normal levels. Storage returns to July, August, and September were easily $0.30 less than if the basis had strengthened to a more normal level. This group included producers and grain elevators holding corn or soybeans forward priced with short futures contracts or with hedged-to-arrive contracts.

Moving forward, the recent basis behavior suggests that there is more basis risk for corn and soybeans than in the recent past. Increased risk in the form of less predictable basis behavior increases the risk of the storage decision. In addition, increased basis risk suggests that crop buyers will be more conservative in making forward bids, passing the basis risk to producers.

Recognizing that "value" of corn and soybeans is ultimately determined in the cash market, it is hard to argue that those holding unpriced inventory in the summer/fall of 2007 were harmed by the unusually weak basis. Holders of that inventory received the price for corn and soybeans that represented value in the cash market. The weak basis gave the appearance that those selling in the cash market received a price below value when, in fact, futures prices were likely overvalued rather than cash prices undervalued.

Long hedgers clearly gained from the unusually weak basis. That is, those owning futures contracts as a hedge for corn or soybeans purchased in the

Table 3 ■ Basis relative to July futures in south central Illinois, 2007, 2006, 2005, and 2004.

	Basis			
2007 date	**July 2007**	**July 2006**	**July 2005**	**July 2004**
June 7	–$0.4750	–$0.2875	–$0.1250	–$0.0650
June 14	–0.4700	–0.2975	–0.1200	–0.0650
June 21	–0.4900	–0.2900	–0.0725	–0.0300
June 28	–0.4625	–0.2600	–0.0725	–0.0250
July 5	–0.5050	–0.2425	–0.0775	–0.0850
July 12	–0.6250	–0.2850	–0.0625	–0.2550

cash market during the period of weak basis paid a lower price for the crops than would have been the case with a normal, stronger basis. This group likely included livestock producers, processors, and exporters.

What Caused the Basis Weakness?

A number of explanations have been offered for the lack of convergence of cash and futures prices at delivery markets at maturity of the July, August, September, and November 2007 soybean futures contracts and at the maturity of the September 2007corn contract. Some point to Exchange storage rates that were below market returns on storage, so that takers of delivery did not ship the grain but chose to hold the delivery instrument to the maturity of the next futures contract in order to capture the carry in the futures market. The failure to ship the grain delivered in satisfaction of the futures allowed the basis to remain weak. Delivery, therefore, did not force convergence of cash and futures prices. This argument may have some validity, but it really does not explain the extent of basis weakness at delivery nor does it explain similar basis behavior under different rates of carry in the futures market.

Another explanation involved higher transportation costs during the summer/fall of 2007. Such arguments help explain a weak interior basis but cannot be valid for delivery markets. In addition, transportation cost increases would presumably impact corn and soybean basis equally, but basis patterns were not the same for the two commodities.

The most compelling explanations involve a combination of "overvalued" futures prices and some issues with the delivery process to settle futures contracts. Overvalued futures prices may have stemmed from the large, long-speculative position of nontraditional commodity speculators. The large ownership position of these traders may have pushed futures prices to levels that could not be supported by the cash market. The overvaluation of futures prices was temporary for soybeans but appeared to persist for soybeans.

Still, there appears to have been a failure of the process that allows delivery as a way to settle futures contracts. The delivery process exists primarily to force convergence. The theory is that if the cash price is below the futures price, merchants will buy the cash commodity, sell futures, and deliver on the contract. If cash prices are above futures, merchants would be expected to buy futures and stand for delivery. This arbitrage process should be conducted in large enough quantities to force the cash and futures prices to converge. That did not occur in the instances cited above.

It is encouraging that basis levels appeared to be returning to more normal levels in November 2007, even though the soybean basis remained on the weak side. However, until the reasons for the breakdown in convergence in the summer/fall of 2007 are known and corrected, basis issues could persist.

There have been some suggestions to eliminate the futures delivery process in favor of cash settlement, similar to that at the Minneapolis Grain Exchange. A cash settlement would certainly address the basis issue by forcing the futures price to the cash price at maturity. However, cash settlement would not force cash prices up to "overvalued" futures prices but would instead force futures prices to cash values. Those who believe they were negatively impacted from an unusually weak basis in the form of cash prices being lower than they should have been will not find remedy in cash settlement.

Is Strip-Tillage Right for You?

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Historically, soil preparation for planting was done with aggressive tillage, such as with a moldboard plow that completely inverted the top 6 to 8 inches of the soil. In the 1930s, the era of the Dust Bowl, people started to become aware that tillage management can have profound impacts on soils. Since that time, efforts to preserve soil by maintaining more crop residue on the soil surface have continued to evolve.

The first step toward soil conservation was the introduction of the chisel plow. Later, less soil disturbance was achieved by using disk plows. During the 1970s, with improvements in herbicide technology and planting equipment, the concept of no-tillage (NT) was introduced. This system brought a radical change in equipment and management that required many years of problem solving and fine tuning.

A new chapter in tillage systems was started in recent years with the adoption of strip-tillage (ST) technology. This type of tillage is catching on quickly across the Corn Belt states.

Definition of Strip-Tillage

Strip-tillage can be considered a compromise, so to speak, between NT and conventional tillage (CT), in which certain benefits of each system are combined. Because ST is relatively new in the Midwest, many ask, "What is ST, and how does it differ from other tillage systems?"

I have probably heard as many definitions of tillage as people talking about it. So, to set the record straight, the Conservation Technology Information Center categorizes tillage systems into three main groups: (1) conventional (or intensive) tillage, (2) reduced tillage, and (3) conservation tillage. Conventional tillage is a full-width tillage that disturbs the entire soil surface prior to and/or during planting and results in less than 15% residue cover after planting. Reduced tillage is also a full-width tillage system involving one or more tillage trips. It disturbs the entire soil surface because it is performed prior to and/or during planting, and it results in 15% to 30% residue cover after planting. Conservation tillage is defined as any tillage and planting system that covers 30% or more of the soil surface with crop residue after planting.

Both ST and NT fall within the description of conservation tillage. Further, ST can be considered a form of NT because NT is defined as a tillage system in which the soil is left undisturbed from harvest to planting except for strips up to one-third of the row width. Strip-tillage is typically done for crops planted in 30-inch rows. The strip, or berm, that is plowed is normally less than 10 inches wide and 3 to 4 inches tall; the space between the strips is left undisturbed.

Comparison of Strip-Tillage and No-Tillage

One of the major drawbacks of NT is the wetter and cooler soil conditions that tend to persist in the spring compared to CT systems, especially under high-crop residue. These conditions can delay planting; restrict hybrid selection; reduce stand uniformity, germination, and development of seedlings; and cause temporary nutrient unavailability due to a reduction in the ability of the root system to take up slowly mobile nutrients (mainly P and K). These conditions have the potential to reduce yield or reduce corn dry-down in the field and have deterred many corn farmers from adopting continuous NT; instead, most prefer to till prior to corn and plant NT soybeans.

Strip-tillage provides soil and water conservation benefits similar to those of NT, but ST has the advantage of overcoming the drawbacks of NT described in the previous paragraph. The strip that is tilled in the fall dries out and warms up faster than the rest of the soil in the early spring, thus creating more favorable conditions for planting and early plant development.

Different studies have reported between 2°F and 4°F higher temperatures in the seedbed for ST compared to NT. The advantage of ST over NT in providing drier soil conditions at planting time is clearly shown in Figure 1.

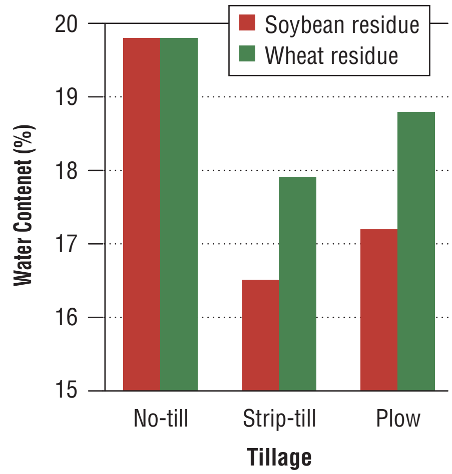

Figure 1 ■ Two-year mean soil water content in the seedbed at planting in fine-textured soils in Ohio with different tillage systems and under different crop residues (source: A. Sundermeier and R. Reeder, 2000).

Strip-tillage for continuous corn has been shown to improve yields compared to NT and has similar yields when compared to other tillage systems, while corn following soybeans typically does not seem to be as responsive to tillage (Figure 2). This is not surprising: Research has repeatedly shown that corn typically yields better when some tillage is performed, especially under continuous corn cultivation. On the other hand, the response of soybean yield to tillage is not as consistent (Figure 3).

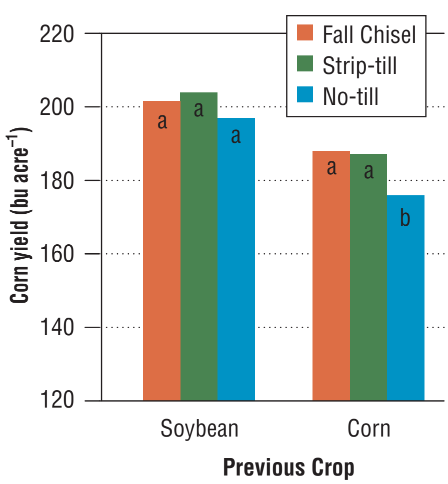

Figure 2 ■ Six-year mean corn yield after soybeans or after corn in a northern Indiana loam soil. Same letters in bars within previous crop group are not significantly different (source: T. Vyn).

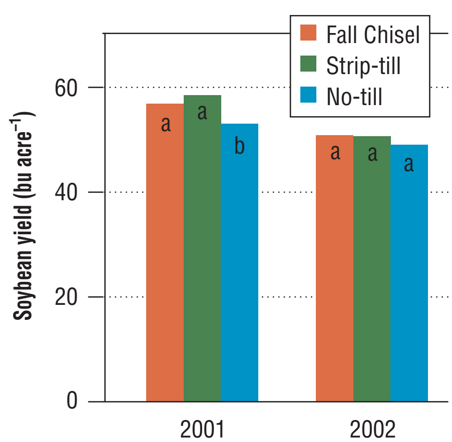

Figure 3 ■ Mean soybean yield affected by tillage system in Wisconsin. Same letters in bars within year are not significantly different (source: R. Wolkowski).

Another benefit of ST is that the creation of the strip can break up surface compaction that sometimes is present in NT systems. Because the strip is created in the fall, precipitation helps to mellow that strip and provides a uniform seedbed, which improves ease of planting compared to high-surface residue in NT systems. Further, the residue-free strip allows the use of older planting equipment that was not designed to handle high-surface residue, which makes it easier to transition from conventional tillage to a conservation tillage system.

While ST can help overcome many of the drawbacks of NT, there are some challenges that could make ST not as attractive. This tillage system is more costly than NT. Strip-tillage requires specialized equipment and a tractor with more horsepower. It also uses more fuel, requires extra time, and has higher labor costs.

Another challenge with ST is tilling correctly under time constraints in the fall, when harvesting is the priority. Some of the potential problems include the possibility of wet soil conditions, snow, or freezing of the soil; the need for an additional trip across the field; and difficulty in creating the strip due to high surface residue.

Strip-tillage can cause soil erosion problems, especially if done under wet soil conditions or in the same direction of the slope of a sloping field. When ST is done under wet soil conditions, smearing of soil surfaces can create a channel for water to move, which can erode soils and transport nutrients into waterways.

Some field operations can be more difficult in ST compared to NT. Planting in an ST system the following spring can be more difficult if an RTK guidance system is not used. Strip-tillage can make it more difficult to spread manure or to perform other field operations without interfering with the strip zone, and it creates a constraint for farmers using narrow planting rows.

Other concerns about ST include crusting of the soil surface, destruction of natural soil structure in the strip, greater weed exposure in the strip, faster loss of fragile residue, dry conditions in the seedbed in dry springs, and performance of unnecessary tillage when spring conditions are suitable for NT.

Under NT systems, slowly mobile nutrients such as P and K are typically broadcast-applied in the surface. This application technique creates a vertical stratification of these nutrients, with higher concentrations in the surface than in the subsurface. This stratification can have negative effects if the high-nutrient surface becomes too dry or if the roots of the crop are not actively growing in that fraction of the soil volume. In this regard, strip-tillage offers more flexibility than NT because it is easy to combine deep placement of nutrients with the tillage operation to make the soil berms. Combining these activities helps spread the workload and can result in fewer trips across the field.

However, it is important to realize that, because fertilizers can be deep-placed with ST, it does not mean that deep placement is a requirement. In fact, studies have shown that the more expensive and time-consuming deep placement of P and K typically does not improve grain yield sufficiently to pay for the added costs of the operation. Further, band application of fertilizers can make it more difficult than broadcast placement to obtain a representative soil sample to determine fertilization needs. On the other hand, shallower placement of dry P and K fertilizers in the strip can have a starter-fertilizer effect that can be more cost efficient than application of liquid starter fertilizers. In wet springs, better growing conditions in the strip can also reduce the need for starter fertilizers.

Strip-tillage is typically done soon after harvest in the early part of the fall. Because high-intensity rainfall prior to about the middle of October can cause excessive flattening of the strips and reduce its warming and drying characteristics the following spring, it is recommended to wait until about the second week of October to perform ST, when soil temperatures are still warm.

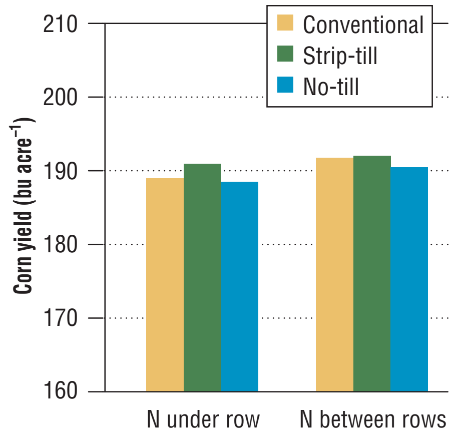

Figure 4 ■ Effect of anhydrous ammonia application in row or between rows for different tillage systems on corn yield in Illinois (source: Guebert et al., 2003).

One of the concerns about ST is the application of N fertilizers in combination with the tillage when soil temperatures have not dropped below 50°F. While combining these activities can save time and be overall beneficial, it is important to wait until soil conditions are adequate for N fertilization. The use of ST does not justify changing the current recommendations for fall N application.

A potential drawback of trying to combine anhydrous ammonia application with ST is that, by the time conditions are adequate for fall N applications, the soil might be too wet for ST operations. Another potential concern is seedling injury from free ammonia, especially when anhydrous ammonia is spring-applied in the strips. However, a 3-year study in DeKalb, Monmouth, and Urbana showed no difference in corn yield when anhydrous ammonia was applied under the row or between the rows for different tillage systems, either in the spring or in the fall (Figure 4)

Comparing Strip-Tillage and Conventional Tillage

Strip-tillage maintains high surface-residue coverage compared to conventional tillage and maintains as much residue as NT in the undisturbed areas between strips (Figure 5). The higher residue of ST compared to CT reduces soil erosion, improves soil health (increases organic-matter content and populations of earthworm and other soil organisms; improves soil structure, penetrability, and soil stability), and helps preserve natural resources.

Water availability is typically a major limiting factor for agriculture in Illinois. Strip-tillage offers an advantage over CT because it reduces soil water evaporation by covering approximately two-thirds of the soil surface with residue. A study showed 3.9 inches of soil water were evaporated from the soil surface in ST compared to 6.4 inches in a CT system (Lascano et al. 1994).

Further, in contrast to CT, in which the entire surface is disrupted, the undisturbed portion of the soil in ST typically contains a greater number of

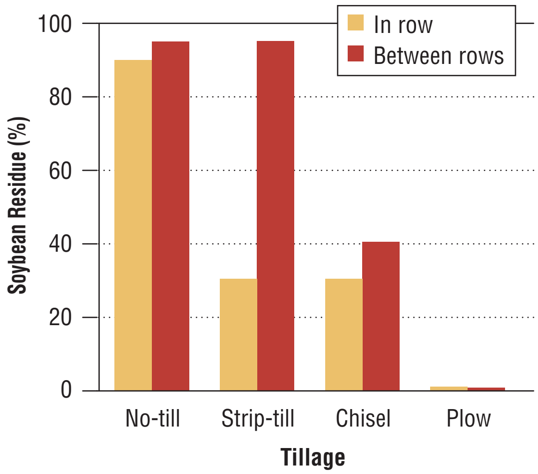

Figure 5 ■ Effect of tillage on soil-surface soybean residue in row and between rows (source A. Sundermeier and R. Reeder, 2000).

macropores, earthworm channels, and other forms of preferential flow paths that can increase rainwater penetration into the soil and reduce the potential for runoff of surface water, nutrients, and chemicals.

On the other hand, CT is easier to perform than ST and makes it easier to manage fields with high-residue content. Also, farmers typically have the necessary equipment for CT, and CT can be done when soils might be getting too wet for ST. While ST can be done in the spring, the real advantage of ST comes when this tillage is conducted in the fall. Strip-tilling in the spring can be more challenging than CT because it can create greater soil compaction between rows, excessively dry seedbed conditions in dry springs, and an uneven surface for planting.

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Corn and Soybean Returns: Past and Present

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In the past several years, Illinois farmers devoted more of their tillable acres to corn production, switching away from soybean production. The profits of this move are evaluated in this paper by examining average profits from corn and soybean production from 2000 up to 2006. In general, corn production was more profitable than soybean production.

This does not necessarily imply that farms devoting a higher percentage of their acres to corn were more profitable than farms raising less corn. Profits on farms devoting different percentages of their acres to corn were evaluated. In general, returns did not differ much among farms with different percentages of their acres in corn. This occurs because farms with a higher percentage of acres in corn have higher per-acre costs than farms with a lower percentage of acres in corn. Higher costs partially offset revenue gains from raising more corn. A key concern when switching to more corn is controlling costs.

Projected returns for 2008 corn and soybean production are also presented. Corn is again projected to be more profitable than soybean production. Devoting more acres to corn may be more profitable if per-acre costs can be controlled.

Past Average Corn and Soybean Profits

Figure 1 shows operator and farmland returns for corn and soybeans on central Illinois grain farms with high-productivity farmland. These data come from farms enrolled in the Illinois Farm Business Farm Management (FBFM) program. Operator and farmland return equals all revenue from the respective crop production minus non-land financial costs. Operator and farmland return represents a return to both the operator and farmland. Subtracting a return for land gives operator returns. Take a cash rent situation in which operator and farmland return equals $220 per acre and the cash rent equals $180 per acre. The operator will have a $40 return ($220 operator and farmland return minus $180 cash rent).

In most years between 2000 and 2007, corn has been more profitable than soybeans. In 2000, operator and farmland return for corn was $173 per acre,

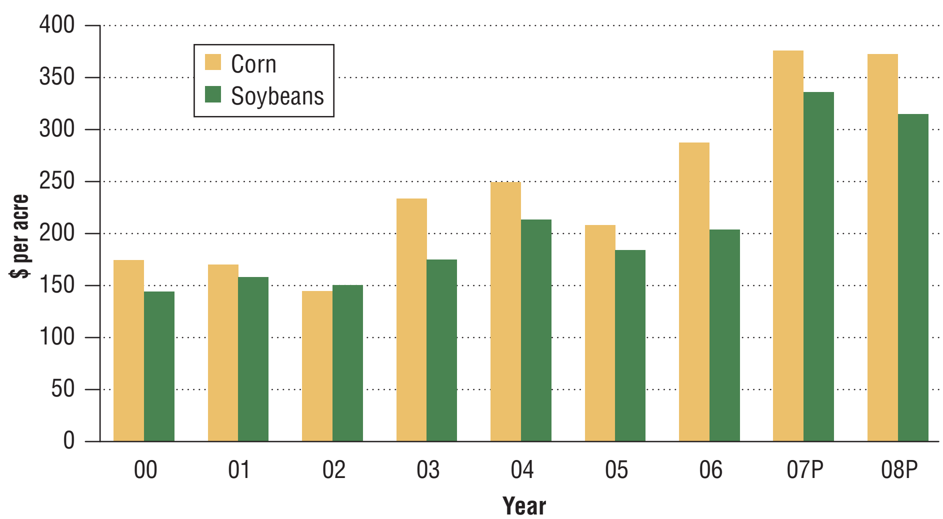

Figure 1 ■ Operator and farmland returns for corn and soybeans, central Illinois high-productivity farmland.

while soybean return was $143 per acre, meaning that corn was $30 more profitable than soybeans. Corn was more profitable than soybeans in 6 out of 7 years: 2001 ($12 per acre), 2003 ($59 per acre), 2004 ($24 per acre), 2005 ($24 per acre), 2006 ($83 per acre), and 2007 ($40 per acre). Only in 2002 did soybean returns exceed corn returns on central Illinois high-productivity farmland. In 2002, soybean production was $6 per acre more profitable than corn production. Over the period from 2000 through 2006, corn returns averaged $35 per acre more than soybean returns.

Difference in corn and soybean returns varied across regions of Illinois. Between 2000 and 2007, corn return minus soybean return averaged $38 in northern Illinois, $35 on high-productivity farms in central Illinois, $19 on low-productivity farms in central Illinois, and $6 in southern Illinois (Table 1). Of these four areas, the northern Illinois and the central Illinois regions with high-productivity farmland have more productive farmland than the central Illinois regions with low-productivity farmland and the southern Illinois regions. In general, corn returns exceeded soybean returns on farms with more-productive farmland. This fact causes the northern and central Illinois regions with high-productivity farmland to have higher differences between corn and soybean returns than the central Illinois regions with low-productivity farmland and the southern regions.

Profits on Farms Devoting Different Percentages of Acres to Corn

Averages suggest that corn has been more profitable than soybeans. However, this does not necessarily indicate that farms growing more corn have been more profitable than farms that have been growing less corn. Farms that have grown more corn may not be more profitable than farms that have grown less corn because yields may decrease or because costs may increase as a higher percentage of acres is devoted to corn.

To evaluate return impacts, operator and farmland returns were calculated for farms with different percentages of acres in corn. Farms included in this analysis were enrolled in FBFM and were located in northern and central Illinois. To be included in this study, a farm had to receive the majority of its gross revenue from grain operations and had to have at least 500 acres in corn and soybeans. In addition, more 90% of their tillable acres had to be devoted to corn and soybean production.

Table 1 ■ Corn return minus soybean return on Illinois FBFM grain farms, 2000 to 2007.

Region	2000	2001	2002	2003	2004	2005	2006	2007P	Average
					$ per acre				
North	31	0	21	62	47	5	99	40	38
Central—high productivity	30	13	–6	59	37	24	83	40	35
Central—low productivity	30	–7	27	–57	52	–11	82	37	19
South	24	4	–34	–11	39	–24	34	16	6

Source: Illinois Farm Business Farm Management.

Table 2 shows operator and farmland returns by different percentages of acres in corn. For example, there is a category for "40.1% to 45%". Farms falling in this category had between 40.1% and 45% of their acres in corn. The rest of their acres were devoted to other crops, with most of the remainder being devoted to soybeans. Operator and farmland returns are given for 4 years from 2003 to 2006.

In 2003, farms with between 70.1% and 75% acres in corn had the highest return, $178 per acre. From a statistical standpoint, however, none of the categories had returns that were statistically different from other categories.

In 2004, farms with between 70.1% and 75% acres in corn had the highest returns. Returns for the 70.1% to 75% category averaged $209 per acre. From a statistical standpoint, the 40.1% to 45% corn category had statistically lower returns than the other categories.

In 2005, farms in the 45.1% to 50% acres in corn category had the highest returns. In that year, farms devoting more of their acres to corn tended to have lower returns.

In 2006, farms in the 65.1% to 70% acres in corn category had the highest returns, with an average of $216 per acre. Like previous years, however, this category did not have statistically higher returns than adjacent categories. In fact, all categories between 50% and 75% had roughly the same level of returns. For example, the 50.1% to 55% category had $212 in returns, 55.1% to 60% had $208 in returns, 60.1% to 65% had $213 in returns, and 70.1% to 75% had $214 in returns. Among the categories between 50% and 75% in corn, returns across the groups averaged only $8 per acre in difference between the high and low categories.

Costs and Yields by Percentage of Corn Grown

These results suggest the percentage of acres did not cause large differences in profitability across farms. Further analysis was conducted to see if costs or yields varied with percentage of acres in corn.

Table 3 shows how costs varied in 2006. Other years had roughly the same trends as 2006. Costs are divided into three categories: (1) crop costs, including fertilizer, pesticides, and seed; (2) power costs, including fuel and oil, machine hire, machine repairs, light vehicle (i.e., expenses related to pickup

Table 2 ■ Operator and farmland returns by percentage of farmland in corn, northern and central Illinois grain farms in Illinois FBFM, 2003 to 2006.

	Year			
Percentage of acres in corn	**2003**	**2004**	**2005**	**2006**
40.1% to 45%	170	182	142	182
45.1% to 50%	171	187	165	199
50.1% to 55%	167	197	158	212
55.1% to 60%	170	200	150	208
60.1% to 65%	177	198	147	213
65.1% to 70%	169	194	150	216
70.1% to 75%	178	209	151	214
More than 75%	162	201	140	190

trucks), and machinery depreciation; and (3) other costs, including labor, building rent and repairs, interest, insurance, and miscellaneous.

Crop costs are higher for corn than for soybeans. Hence, crop costs should increase as more corn is grown. This occurred. In 2006, for example, farms with 40.1% to 45% acres in corn had $115 per acre in crop costs. Crop cost increases over most of the higher percentage categories reached $166 per acre on farms with the more than 75% of their acres in corn.

Power costs also increased, particularly for larger percentages of corn grown. In 2006, power costs averaged $65 per acre for farms with between 55.1% and 60% acres in corn. Power costs increased across higher corn percentage categories, reaching $95 per acre on farms with more than 75% of their acres in corn.

While yield varied across the farms with various percentages of acres in corn, there was no general trend in corn yields as the percentage in corn increased. Because much agronomic research indicates that yields decrease with corn-after-corn, results for 2006 may be abnormal. Farms with higher percentages of acres in corn may face lower yields in years of adverse growing conditions.

Averages from Budgets and Farm Results

At first glance, a discrepancy may appear to exist in the above results. That is, budgets show that corn is more profitable, yet farm results show that farms growing more corn have not been more profitable than farms growing less corn. How can corn be more profitable than soybeans when farms growing more corn have not been more profitable?

The answer lies in cost increases. Farms that grew more corn tended to have higher per-acre costs. This factor can be illustrated with power costs. Power costs averaged $65, $71, $78, $84, and $95 per acre on farms growing corn in the categories of 55.1% to 60%, 60.1% to 65%, 65.1% to 70%, 70.1% to 75%, and 75% or more, respectively (Table 3). In 2006, the average power costs across these grain farms averaged $65 per acre. In the years depicted, farms with a higher percentage of acres devoted to corn tended to have

Table 3 ■ Yields and costs in 2006 by percentage of farmland in corn on grain farms in Illinois FBFM in northern and central Illinois.

Percentage of acres in corn	Costs				Yields	
	Crop[1]	Power[2]	Other	Non-land[3]	Corn	Soybeans
40.1% to 45%	115	63	63	242	172	51
45.1% to 50%	119	63	67	250	174	53
50.1% to 55%	125	62	68	255	176	54
55.1% to 60%	133	65	71	269	179	54
60.1% to 65%	134	71	74	278	179	54
65.1% to 70%	146	78	77	301	184	55
70.1% to 75%	142	84	79	305	179	57
More than 75%	166	95	80	341	177	56

[1] Includes fertilizer, pesticides, seed.

[2] Includes fuel and oil, machine hire, machinery repairs, light vehicle, and machinery depreciation.

[3] Total of crop, power, and other categories.

higher than average costs (that is, their costs were higher than those shown in budgets representing averages).

Profits, Costs, and Percentages of Corn Grown

As percentages of acres devoted to corn increase, higher costs partially mitigate revenue associated with corn. These cost increases suggest that a continuing emphasis on cost control may have important implications for farm profitability. To further examine this possibility, the grain farms in this study were divided into three profit categories. The one-third of farms with the highest operator and farmland returns were place in the "high one-third" category, farms in the middle third were placed in the "mid one-third" category, and the one-third of farms with the lowest operator and farmland returns were placed in the "low one-third" category. Yields, percentages of acres in corn, farm size, and costs are shown in Table 4. Results in Table 4 are for 2006. Similar results exist for earlier years.

The percentage of acres in corn was 54% for the low one-third category, 52% for the mid one-third category, and 55% for the high one-third category. Differences in the percentage of acres in corn did not vary across profit groups. Similarly, there were no statistical differences in tillable acres across profit groups.

There were, however, significant differences in yields across the profit groups. Farms in the low one-third group averaged 170 bushels per acre, farms in the mid one-third group averaged 175 bushels per acre, and farms in the high one-third group averaged 184 bushels per acre. Farms in the higher profit group had higher yields. Yields are important in determining profit group in each year. However, relative yields are not stable across years. Some farms with high relative yields in one year will have lower yields in the next, simply because of weather and because pests impact farms differently across years. Hence, yields will impact which profit group a farm is in.

Costs also were significantly different across the profit groups. Farms in the low one-third group had higher costs than farms in the mid one-third and high one-third groups. For example, power costs averaged $75 per acre for the

Table 4 ■ Yields, percentage of acres in corn, and costs for northern and central Illinois grain farms enrolled in FBFM by profit category, 2006.

	Profit Group		
	Low 1/3	**Mid 1/3**	**High 1/3**
Percentage of acres in corn	54%	52%	55%
Tillable acres	1,096	1,104	1,195
Corn yield (bu/A)	170	175	184
Soybean yield (bu/A)	52	53	54
Crop costs ($/A)	134	120	127
Power costs ($/A)	75	61	61
Other costs ($/A)	72	65	67
Total costs ($/A)	281	246	255

low one-third group. Farms in the mid one-third and high one-third groups averaged $61 per acre in power costs.

Farms with lower costs one year tend to have lower costs the next year. Higher costs were a major reason that farms were in the low one-third group for profits. It is difficult for these farms to overcome these costs and move into the higher profit groups. Farms in the higher profit groups are there because of lower costs. Whether they are in the mid one-third or high one-third groups is determined by yields. Over time, many farms will switch between the mid one-third and high one-third groups due to differences in yields.

These results suggest that cost control has been a more important determinant of profitability than percentage of acres in corn. Farms that increase acres devoted to corn need to control costs; otherwise, revenue gains from additional corn may be offset by higher costs.

Average Corn and Soybean Returns in 2008

Cropping decisions may be more difficult in 2008 than in 2007. In 2007, futures prices used to project returns indicated that corn would be significantly more profitable than soybeans, resulting in large shifts in acres to corn in 2007. Two factors will make cropping decisions more difficult in 2008.

The first is cost increases. Large increases in costs are projected in 2008. For corn in central Illinois, non-land costs for corn are projected to average $364 per acre, an increase of $41 per acre over 2007 non-land costs. For soybeans in central Illinois, non-land costs in 2008 are projected to be $215 per acre—$17 per acre more than in 2007. Because corn costs are projected to increase more than soybeans, soybean returns will increase relative to corn returns.

Second, commodity prices have increased. Compared to 2007 planning prices, both corn and soybean prices have increased, with soybean price increasing relatively more than corn prices. At the time of this writing, conservative 2008 planning prices are $3.80 for corn and $9.25 for soybeans. Relatively higher prices for soybeans narrow the profit differences between soybeans and corn.

Table 5 shows budgets for corn and soybeans in central Illinois. These budgets are summaries from more-detailed reports provided in the management section of farmdoc (www.farmdoc.uiuc.edu). Panel A of Table 5 shows budgets for high-productivity farmland, while Panel B shows budgets for low-productivity farmland.

High-productivity farmland has an expected yield for corn-after-soybeans of 191 bushels per acre, while low-productivity farmland has a 173-bushel expected yield.

For high-productivity farmland, operator and land return is $396 per acre for corn-after-soybeans, $344 for corn-after-corn, and $312 for soybeans. These budgets suggest that corn will be more profitable than soybeans.

For low-productivity farmland, operator and land returns are $323 for corn-after-soybeans, $163 per acre for corn-after-corn, and $291 for soybeans. In this case, soybeans are more profitable than corn-after-corn but less profitable than corn-after-soybeans. This suggests that 50% corn/50% soybean for this type of farmland will be the most profitable in 2008.

Table 5 ■ 2008 budgets for central Illinois.

	Corn after soybeans	Corn after corn	Soybeans
Panel A. Central Illinois (high-productivity farmland)			
Yield ($/A)	191	181	54
Price ($/bu)	$3.80	$3.80	$9.25
		$/A	
Total revenue[1]	753	715	527
Non-land costs	357	371	215
Operator and land return	396	344	312
Panel B. Central Illinois (low-productivity farmland)			
Yield ($/A)	173	163	52
Price ($/A)	$3.80	$3.80	$9.25
		$/A	
Total revenue[1]	682	644	506
Non-land costs	359	373	215
Operator and land return	323	271	291

[1] Includes government payment.
Source: Crop budgets in management section of farmdoc (www.farmdoc.uiuc.edu).

Higher-productivity farmland generally will find corn to be more profitable relative to soybeans. In the budgets described previously, high-productivity farmland corn tends to be more profitable than soybeans. Historic experience on FBFM farms suggests that yields for corn increase more than soybeans on higher-productivity farmland. Hence, farms with more productive farmland will find corn more profitable than soybeans.

Summary

Per-acre returns did not systematically vary across farms that devoted different percentages of their acres to corn and soybeans. While returns did not show a general trend up or down, per-acre costs tended to increase as the percentage of acres devoted to corn increased. These cost increases tend to offset per acre revenue gains from growing more corn.

Budgets suggest that corn will be more profitable than soybeans in 2008. Some farms with highly productive farmland may find that raising corn-after-corn is more profitable than raising soybeans. Before growing more corn, however, consideration should be given to cost increases. Farms must be able to control costs increases before growing more corn will be more profitable than growing soybeans.

Foliar Fungicides for Corn: Just Another Management Tool or the Only Tool Needed?

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Foliar fungicides are valuable disease management tools to the agricultural industry, but, like all tools, they should be used only when the specific job for which they were intended calls for their use (i.e., you use a hammer to drive a nail but not to tighten a screw). In 2007, a record number of foliar fungicides were applied to hybrid cornfields across the Midwest. In many cases, these fungicides were purchased prior to a seed being planted and applied despite no or low disease pressure. Under these low disease–pressure situations, any yield increases due to foliar fungicides will be erratic and will not likely be observed.

Data compiled from foliar fungicide trials conducted in Illinois, Indiana, Iowa, Kentucky, Missouri, and Ohio in 2007 indicated that foliar fungicides were profitable only 27% of the time (24 out of 88 times) and, averaged over all of these trials, the yield increase over the untreated check was 2 bushels per acre (Figure 1). This was based on \$3.50 per bushel marketing price of corn and application costs of the fungicide at \$20 per acre.

When Are Foliar Fungicides Needed in Corn Production?

Fungicides work to protect the crop from yield losses when disease pressure is at a great enough level to cause economic losses. Foliar disease pressure (i.e., gray leaf spot) is driven by many factors:

Environment. Rainfall is important not only for high corn yields, it is also important for the disease cycles of most foliar fungal pathogens of corn. Splashing rain transports fungal spores from residue to leaf or leaf to leaf. Leaf wetness (via rainfall or high humidity/dew) is also necessary for fungal spores to germinate and infect leaves.

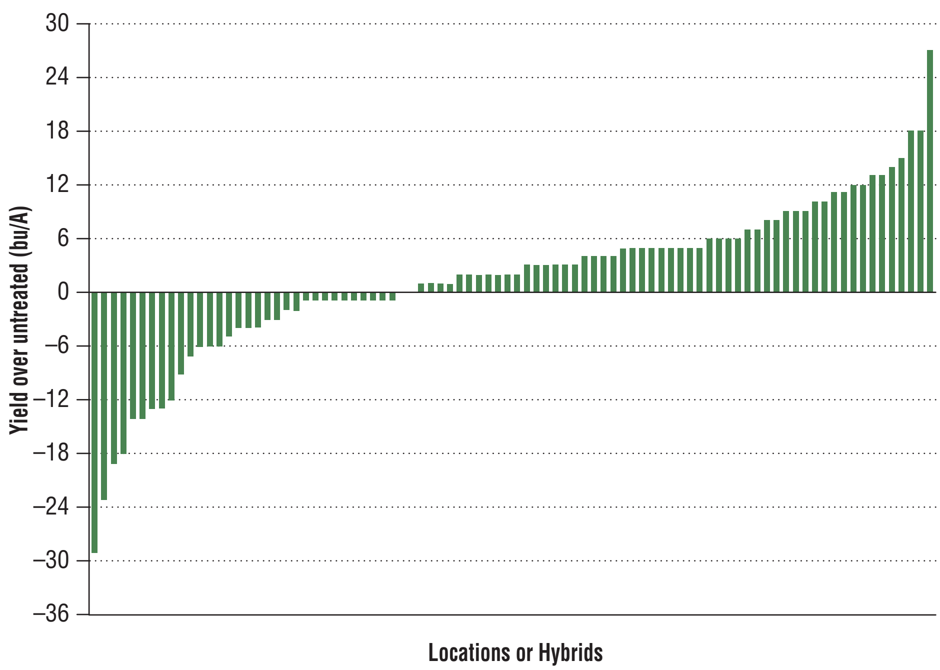


Figure 1 ■ Effect of foliar fungicides on corn yield at different Midwest locations and for different hybrids in 2007.

Previous crop residue. Many of the fungal pathogens that cause foliar diseases of corn survive (overwinter) on the previous corn crop residue. A corn-on-corn situation where conservation tillage practices were used is more likely to result in higher disease pressure under the right conditions.

Hybrid susceptibility. All corn hybrids are not created equally in their resistance to foliar diseases. The more susceptible a hybrid is to a foliar disease, the greater the disease pressure will be.

When these factors that drive disease pressure are present, it is more likely that the use of a foliar fungicide in this instance will be profitable. A foliar fungicide trial was conducted in a corn-on-corn situation with different hybrids that differed in their susceptibility to gray leaf spot. In this trial, one hybrid in particular (Hybrid 7) was very susceptible to gray leaf spot (Figure 2). This was the only hybrid for which there was a statistically significant yield response to foliar fungicides (Figure 3).

Are There Any Risks Associated with Unwarranted Fungicide Applications?

In general, three different fungicide products were applied to cornfields in 2007: Headline (BASF), Quilt (Syngenta), and Stratego (Bayer CropScience). All three of these products contain an active ingredient (either solo or in combination) that belongs to the strobilurin class of fungicides. Strobilurin fungicides have a high risk of fungal pathogens developing resistance to them. Pathogen populations that have become resistant to the strobilurin fungicides have done so via single-step amino acid substitutions. Because resistance can be achieved in only a single-step, the risk is high.

Every time these strobilurin fungicides are used, they apply a "selection pressure" to the pathogen population. This pressure can select out a few

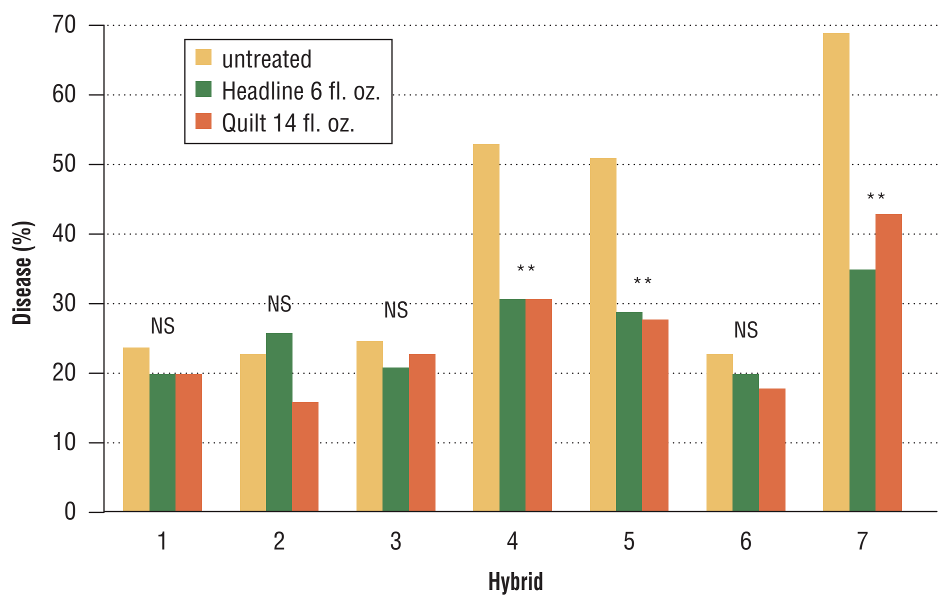


Figure 2 ■ Effect of foliar fungicides on gray leaf spot severity over seven different hybrids planted in Urbana, Illinois, in 2006 (data courtesy of Wayne Pedersen, University of Illinois).

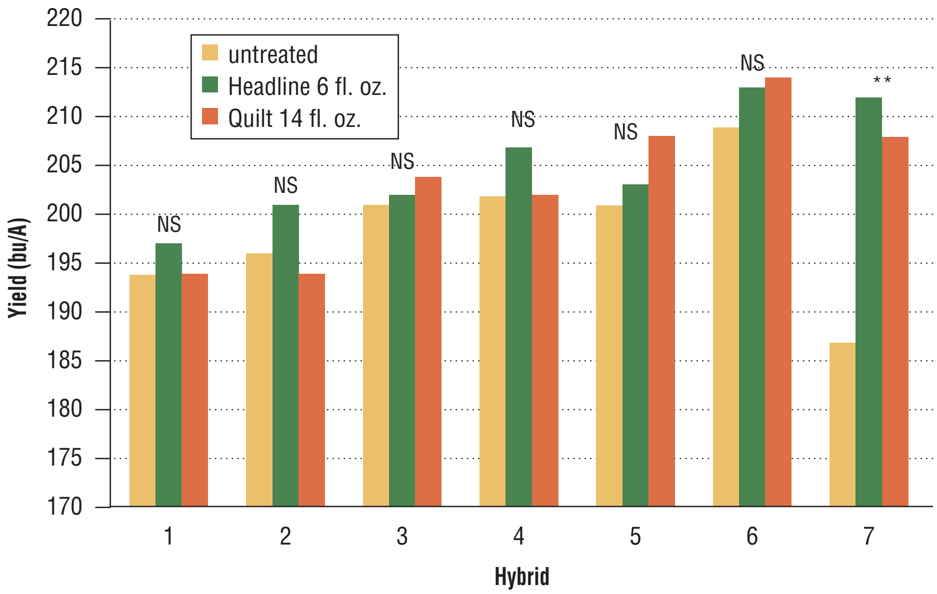


Figure 3 ■ Effect of foliar fungicides on corn yield of seven different hybrids planted in Urbana, Illinois, in 2006 (data courtesy of Wayne Pedersen, University of Illinois).

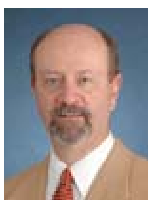
individuals in the pathogen population that may be less sensitive to the fungicide. With a selection pressure applied every year, the likelihood of developing resistance increases.

Conclusions

Foliar fungicides are valuable tools, but they have their place. The use of these tools should be based on certain risk factors and field observations of disease. Using these tools appropriately will increase the chance of being profitable and will increase their longevity (via fungicide resistance management).

Corn Rootworm Management in a Triple-Stack "World"

Michael E. Gray, Kevin L. Steffey, and Ron E. Estes



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In a July 5, 2007, report titled *Adoption of Genetically Engineered Crops in the United States*, the USDA Economic Research Service revealed significant escalation in the use of Bt corn in Illinois and other states. In 2006, 19% of all planted corn in Illinois was characterized as a "stacked gene" variety. In 2007, the use of stacked corn hybrids in Illinois more than doubled and was estimated to be at 40% of planted corn acres. In 2006, 55% of corn planted in Illinois was estimated to be a genetically engineered hybrid (Bt only, herbicide-tolerant only, or stacked gene variety). In 2007, that percentage had increased to 74%. The adoption of this technology is occurring at a remarkable pace.

The availability of YieldGard Rootworm corn hybrids for planting in 2003 marked the beginning of a new era of corn rootworm management. Monsanto Company was the first to obtain registration for transgenic Bt corn (genetic material from the soil bacterium *Bacillus thuringiensis* inserted into the corn genome) for rootworm control. Shortly after the registration of YieldGard Rootworm corn, registrations for rootworm-protected corn were granted to Pioneer Hi-Bred International, Inc./Dow AgroSciences LLC (Herculex RW corn hybrids, available for planting in 2006) and Syngenta (Agrisure RW corn hybrids, available for planting in 2007).

In just 4 short years, the genetic biotechnology for rootworm control has been combined with genetic biotechnologies for caterpillar control and herbicide resistance or tolerance to create double-, triple-, and quad-stacked corn hybrids that address a lot of producers' concerns about both insect and weed management. The news release from Monsanto and Dow AgroSciences announcing the forthcoming registration of SmartStax corn hybrids (hybrids with an eight-gene stack) is undoubtedly a foreshadowing of a dizzying array of combinations of genetic traits that will have a significant impact on pest management. So, the future for management of currently the most economically destructive corn insect pests looks bright. But, as we have learned so many times in the past, advances in insect-control technology that provide excellent opportunities in agriculture almost always usher in amplified or new issues.

In spite of the overall excellent root protection afforded by Bt corn rootworm hybrids in most producers' fields, we have observed some Bt hybrids with significant levels of root pruning (Figure 1). Our observations have been discounted by some who argue that because we plant our corn rootworm treatments into a trap-crop area, we expose the products to unrealistically high densities of corn rootworm larvae.

Despite this concern raised by some critics, let's be clear: We have observed severe root pruning to some Bt corn rootworm hybrids in fields other than those devoted to a trap crop. For instance, in 2007, Joe Spencer, an entomologist with the Illinois Natural History Survey, alerted us to one of his experiments located near Urbana that had severely lodged plants and excessive root pruning (Figure 2). The field had been planted to corn in 2006 (not a trap crop).

Figure 1 ■ Pruning to rootworm Bt corn hybrid (HxXTRA Mycogen 2T787) caused by rootworm larvae, Urbana, Illinois, July 9, 2007 (University of Illinois).

How Meaningful Is the Node-Injury Rating Scale in Evaluating Corn Rootworm Products?

During the past several years, we have observed greater-than-expected levels of root pruning on some Bt hybrids (across multiple events). Most of the acute injury has occurred in our Urbana efficacy experiments. Despite root pruning that, in some instances exceeded one node of roots destroyed, yields were often exceptional for certain Bt treatments.

These observations have caused us to carefully examine the value of traditional root evaluations to measure corn rootworm product worth in the marketplace. In our corn rootworm product efficacy trial conducted last year (2006) in Urbana, the soil insecticides performed very well (with the exception of Force, node-injury rating = 1.01) in spite of very heavy corn rootworm pressure (node-injury rating in check = 2.95). Yet, when it came to yield, the YieldGard RW treatment (node-injury rating = 0.96) outperformed all the soil insecticide treatments by a large margin (approximately 56 bushels per acre, on average across four granular soil insecticides).

This lopsided yield edge in favor of the Bt treatment occurred even though the soil insecticide treatments were applied to the isoline of the Bt corn rootworm hybrid. Results such as these have been reported by other investigators as well. Questions that we have raised are as follows:

- Is the current 0 to 3 node-injury scale the most appropriate scale to compare soil insecticides and transgenic corn rootworm hybrids?
- Does it make sense to use any root-injury scale to compare the performance of soil insecticides and transgenic corn rootworm hybrids?

Figure 2 ■ Root pruning on Bt rootworm corn plants (DeKalb 63-74, YieldGard Plus) in Joe Spencer's plots near Urbana, Illinois, July 26, 2007 (University of Illinois).

- Isn't it a bit like comparing apples to oranges when we use a root-injury scale for both soil insecticides and Bt corn rootworm hybrids?
- Why have such large yield differences occurred when some Bt hybrids are compared with their isolines that have been treated with soil insecticides at planting? This occurs in some instances, even when the Bt treatment has more root injury.
- Should we develop a new root-injury rating scale for Bt corn rootworm hybrids?
- Are root-injury rating scales relevant for Bt corn rootworm hybrids?

On July 2, 2007, we observed a considerable height advantage for one of the Bt corn rootworm hybrid treatments in our Urbana experiment. Even though plants in this Bt treatment were showing no aboveground signs of stress, an evaluation of the root system revealed considerable pruning. The level of pruning was well above 1 node of roots destroyed. In previous years, we had not encountered this degree of excessive pruning on a Bt corn rootworm hybrid until late July or early August. An examination of the root systems dug from soil insecticide treatments revealed much less pruning, particularly on the brace roots. Yet the aboveground symptoms (tightly rolled leaves) of those plants treated with soil insecticides revealed considerable drought stress.

Node-Injury Rating Results for 2007

The root evaluations from our corn rootworm product efficacy experiments were conducted at the University of Illinois Research and Education centers located near DeKalb, Monmouth, Perry, and Urbana. As occurred in 2006, the level of root injury at the Orr Research and Demonstration Center was very low, so these data will not be reported. It remains unclear to us why we have not been able to generate adequate densities of corn rootworm larvae at this site. Soil type may play a role. Despite the disappointing results of the past 2 years, we will continue to establish corn rootworm efficacy trials at this research facility in order to share more localized product efficacy data with our western Illinois clientele. Root injury in Monmouth also was lower in 2007 compared with 2006. Therefore, we will highlight only those data from DeKalb and Urbana where the root injury was greater.

The level of root injury in our overall check (DKC 61-73) was 2.74 (nearly three nodes of roots destroyed) and 2.18 (slightly more than two nodes destroyed) for Urbana and DeKalb, respectively. The root protection provided by the soil insecticides varied considerably across locations. At the Urbana site (Figure 3), the location with the most severe rootworm injury, the soil insecticides provided superior root protection compared with two of the Bt treatments, HxXTRA (Mycogen 2T787) and YieldGard VT (DKC 61-69). The mean root ratings of these two Bt treatments were 1.04 and 0.84, respectively, and were not statistically different from each other. The HxXTRA (Pioneer 33T59) treatment had a root injury rating of 0.49 (one-half node of roots pruned). This root-rating mean was not statistically different from the soil insecticide treatments. The two HxXTRA treatment means (0.49 and 1.04) were statistically different from each other. The mechanism or mechanisms behind the variation in product performance of Bt hybrids, engineered to provide corn rootworm control, need to be explored more fully.

In DeKalb (Figure 4), several of the granular soil insecticides had approximately one node of roots pruned, such as Aztec 2.1G (0.81), Counter 15G (1.0), and Fortress 2.5G (0.96). We suspect that very dry conditions following planting may have contributed to these performance issues. These soil insecticides were applied during planting on May 3. By May 24 (3 weeks later), only 0.31 inch of rain had fallen on these plots. In July, more than 8 inches of rain occurred at the DeKalb site. The transgenic Bt treatments

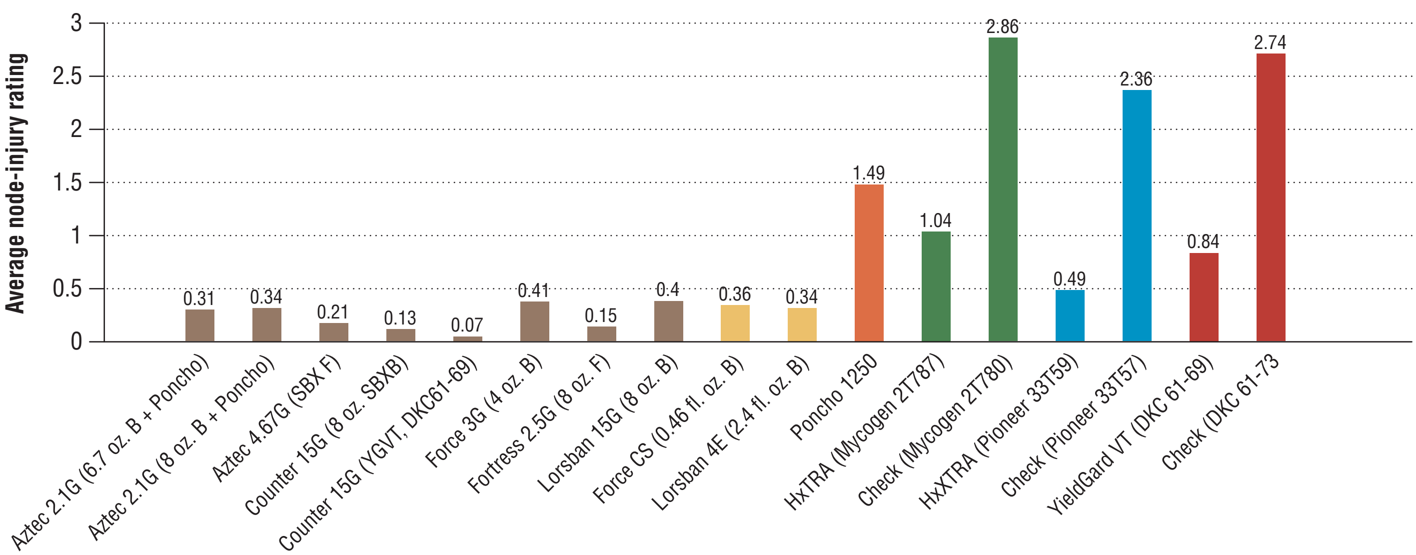

Figure 3 ■ Node-injury ratings from a corn rootworm control trial, Urbana, Illinois, 2007. Planting date—May 1, root evaluation date—July 9, DeKalb 61-73 used for all soil insecticides.

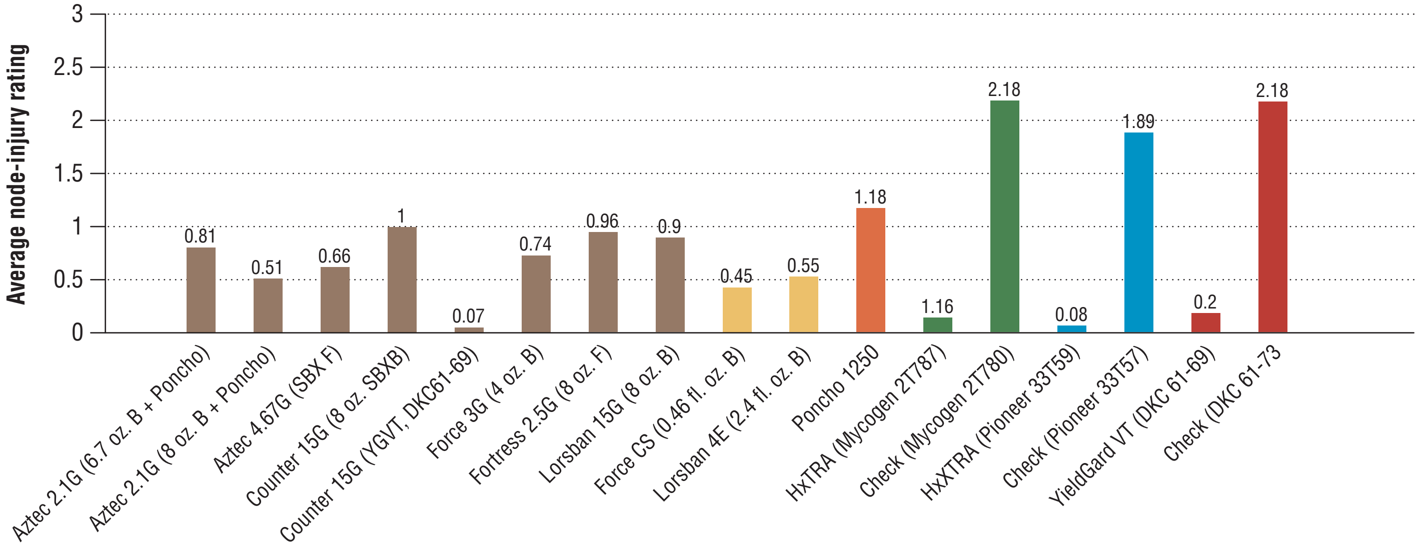

Figure 4 ■ Node-injury ratings from a corn rootworm control trial, DeKalb, Illinois, 2007. Planting date—May 3, root evaluation date—July 16, DeKalb 61-73 used for all soil insecticides.

performed very well at DeKalb with root ratings of 0.08, 0.16, and 0.2 for HxXTRA (Pioneer), HxXTRA (Mycogen), and YieldGard VT, respectively.

Producers typically expect equal root protection across Bt corn rootworm hybrids. These expectations may not always be fulfilled, even though transgenic hybrids with the same Bt event have been used. We have previously shown that root protection of Bt hybrids (YieldGard Rootworm, MON 863, Cry3Bb1) varies. Why was the root protection offered by Bt hybrids not up to par at the Urbana site? Why does this phenomenon occur most frequently at the Urbana location? The answer remains elusive. However, we have previously hypothesized that the variant western corn rootworm may be more injurious to Bt corn rootworm hybrids than the nonvariant population of this species. This hypothesis requires further testing.

Unlike in previous years, the root-rating means for our second evaluations (August 6 and 7) at DeKalb, Monmouth, and Urbana were not strikingly different from the first evaluations. Western corn rootworm emergence was very early this season (mid-June for central Illinois) and, by mid-July, we may nearly have reached the maximum level of root pruning that was going to occur. In general, the lack of notable increases in injury across our checks supports this idea.

Yield Results for 2007

As the yield data from 2007 attest, mean node-injury ratings may once again have not been the best predictors of yield. Although the mean yields from all plots with rootworm control products were significantly greater than the mean yields from the untreated check plots in Urbana (Figure 5) and DeKalb (Figure 6), the mean yields and node-injury ratings among rootworm control products did not necessarily line up. For example, the mean yield for Counter 15G at DeKalb was 237 bushels per acre, despite a mean node-injury rating of 1.0. Comparatively, the mean yield for Fortress 2.5G was significantly lower

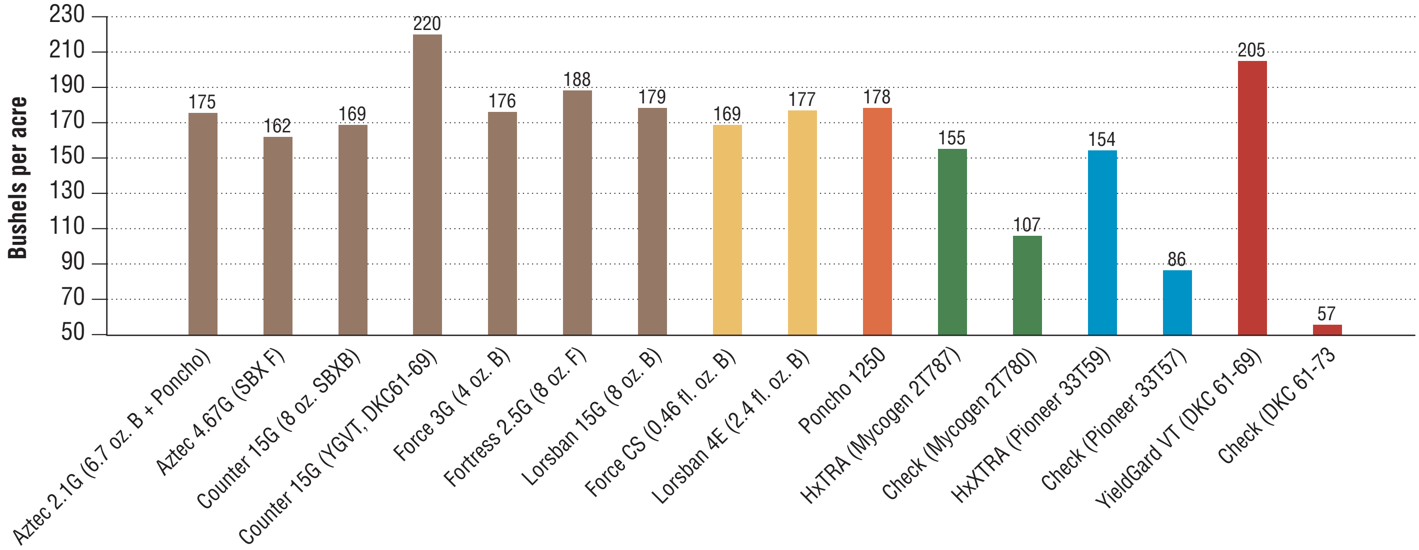

Figure 5 ■ Yields from a corn rootworm control trial, Urbana, Illinois, 2007. Planting date—May 1, harvest date—September 27.

than the mean yield of Counter 15G, despite similar mean node-injury ratings (0.94 and 1.0, respectively).

The mean yield of YieldGard VT was 226 bushels per acre, and the mean yield of HxXTRA (Pioneer) was 216, despite comparable mean node-injury ratings of 0.2 and 0.08, respectively. And, despite a mean node-injury rating of 0.84 at Urbana, the mean yield for YieldGard VT was 205, significantly larger than the mean yield of HxXTRA (Pioneer) (154 bushels per acre), with a mean node-injury rating of 0.49.

Conclusions

The use of stacked Bt hybrids for corn insect control will continue to sweep across the agricultural landscape to such an extent that it remains unclear how traditional IPM tactics "fit" into this modern crop protection "puzzle."

Without doubt, the integration of diverse management tactics is under siege with respect to the corn insect pest complex in general. Concerns regarding the longevity of Bt hybrids continue to be fueled by reports of inadequate refuge deployment. Resistance development to Bt by any insect pest of corn, particularly corn rootworms, would be a major loss to our industry. Should we begin to view the concept of "integration" with respect to IPM implementation in commercial field crops differently?

Some entomologists are beginning to view integration as the insertion of multiple genes (pyramiding) responsible for the expression of different Bt proteins within the same corn plant. This strategy may be effective in delaying the onset of resistance and also require the U.S. Environmental Protection Agency to re-evaluate the present 20% refuge requirement for Bt products.

In the meantime, Bt corn rootworm hybrids should not be viewed as "bulletproof" as our results, particularly from Urbana, have consistently been for several years. Producers are encouraged to evaluate the root protection afforded by their Bt rootworm hybrids and let us know if any widespread and excessive root pruning (more than one node of roots destroyed) is observed on

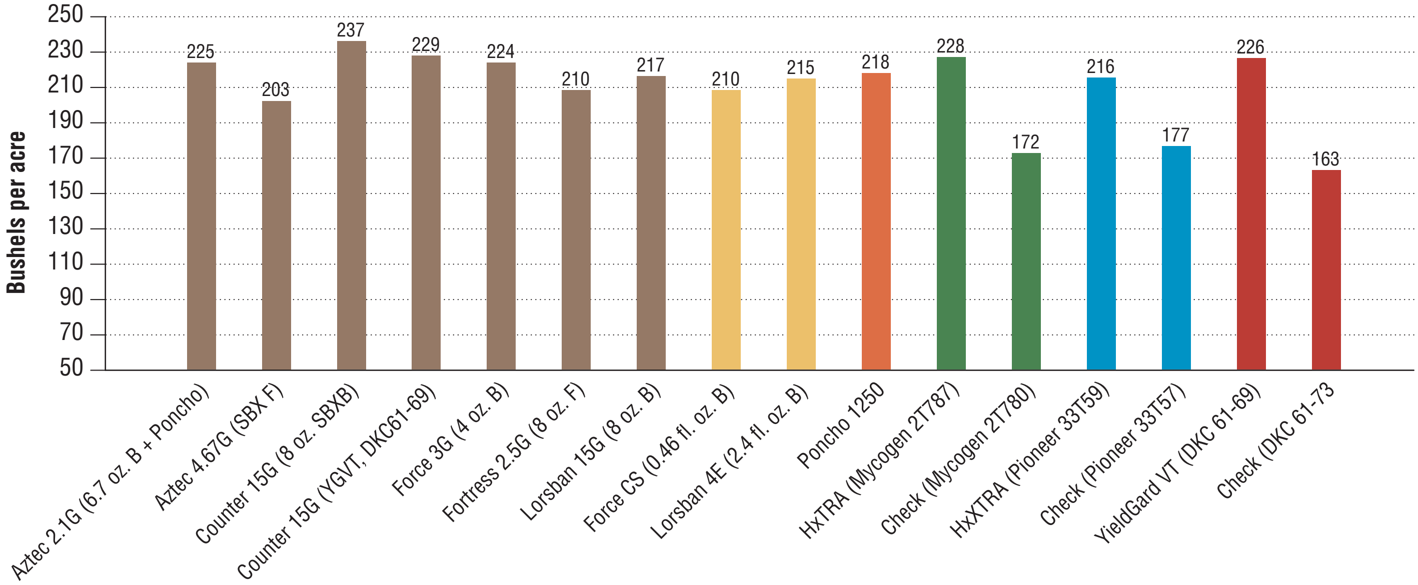

Figure 6 ■ Yields from a corn rootworm control trial, DeKalb, Illinois, 2007. Planting date—May 3, harvest date—October 1.

their farms. In addition, proper refuge deployment is critical to prolong the durability of this remarkable technology.

Portions of this paper have been extracted from previously published articles written by these authors in the *Pest Management and Crop Development Bulletin*, as well as from a proceedings paper presented by Kevin Steffey at the Crop Management Conference, Iowa State University, in December 2007.

Secrets of Interpreting Nematode Lab Results for Corn and Soybean

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Reports from labs that offer nematode analysis can be utterly mystifying, which can interfere with, rather than aid, the design of appropriate integrated pest management strategies. Turning these often incomprehensible reports into useful guides for consultants and growers is a challenge.

Nematodes ≠ Nematodes

The first thing to know, before even looking at a nematology lab report, is that nematodes shouldn't be lumped into a mental category labeled "nematodes" any more than corn rootworm and soybean aphid should be lumped into an "insects" file. Each plant-parasitic nematode group (class, genus, or species) must be treated as a different pest, as we do with economically important insects. This may seem obvious, but we find many situations in which confusion related to managing nematodes is related to failure to appreciate the differences among groups. One of the reasons that nematodes are lumped together is that scouting (soil sampling) and sample processing is done essentially the same way—bringing us back to the role of reports, which encourage lumping by putting all the nematode numbers in one tidy box.

Every crop production field contains uncountable trillions of nematodes. Most of these are what we call bacterivores, which impact plants because they are involved in regulating the rate of nutrient cycling. Other nematodes are fungivores, predators, or omnivores. A subset in every field is called herbivores by some, but they are more correctly called plant parasites.

Each crop has its own set of plant-parasitic nematodes, and each group of nematodes has different characteristics. Not only do they feed in different parts of the plant (Figure 1), but they have different effects on the plant and on other organisms, and different interactions with the soil environment.

Nematodes = Nematodes

Three characteristics (with some exceptions, of course) do allow us to treat plant-parasitic nematodes as a single target:

- they are in the soil,
- they have a patchy distribution, and
- the damage they do depends on the number present when the crop is planted.

These characteristics allow us to sample soil, process it, and make a guess as to the nematodes' potential for reducing yields.

Soil Sampling

All the research on optimal sampling for nematodes boils down to two conclusions: sampling details depend on the purpose of sampling, and the quality of the soil sample determines the quality of the information in the lab report. The purposes for

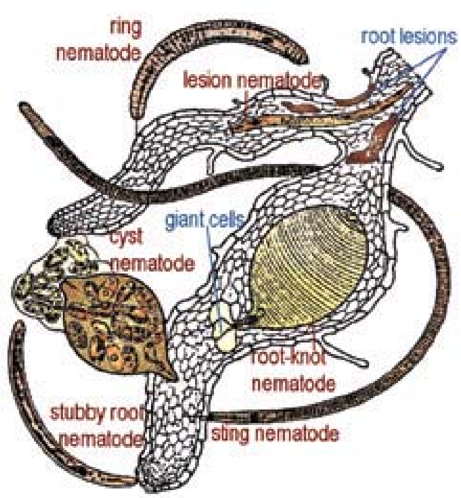

Figure 1 ■ A diagram of the locations in or on a root and the types of damage caused by common plant-parasitic nematodes.

which soil might be sampled include diagnosis, research, assessment of control tactics, and others. The quality of the soil sample is a more complex issue and includes such things as time of year, depth, distribution of subsamples, moisture, physical treatment of the sample, and much more. For this short introduction to sampling, however, most of the complexities will be ignored.

Horizontal and vertical nematode distribution • The soybean cyst nematode (SCN) is a good model for showing the patchiness of nematode distribution in a field (Figure 2). In this study, conducted by Greg Tylka at Iowa State University (Niblack et al. 2006), the same field was assessed for SCN population densities, symptoms, and yield. Clearly, SCN population density and soybean yield were closely associated, but symptoms were not a good guide for where to sample. In addition, it is clear that sampling in one area of the field could easily lead to a seriously flawed estimate of the average population density in the field.

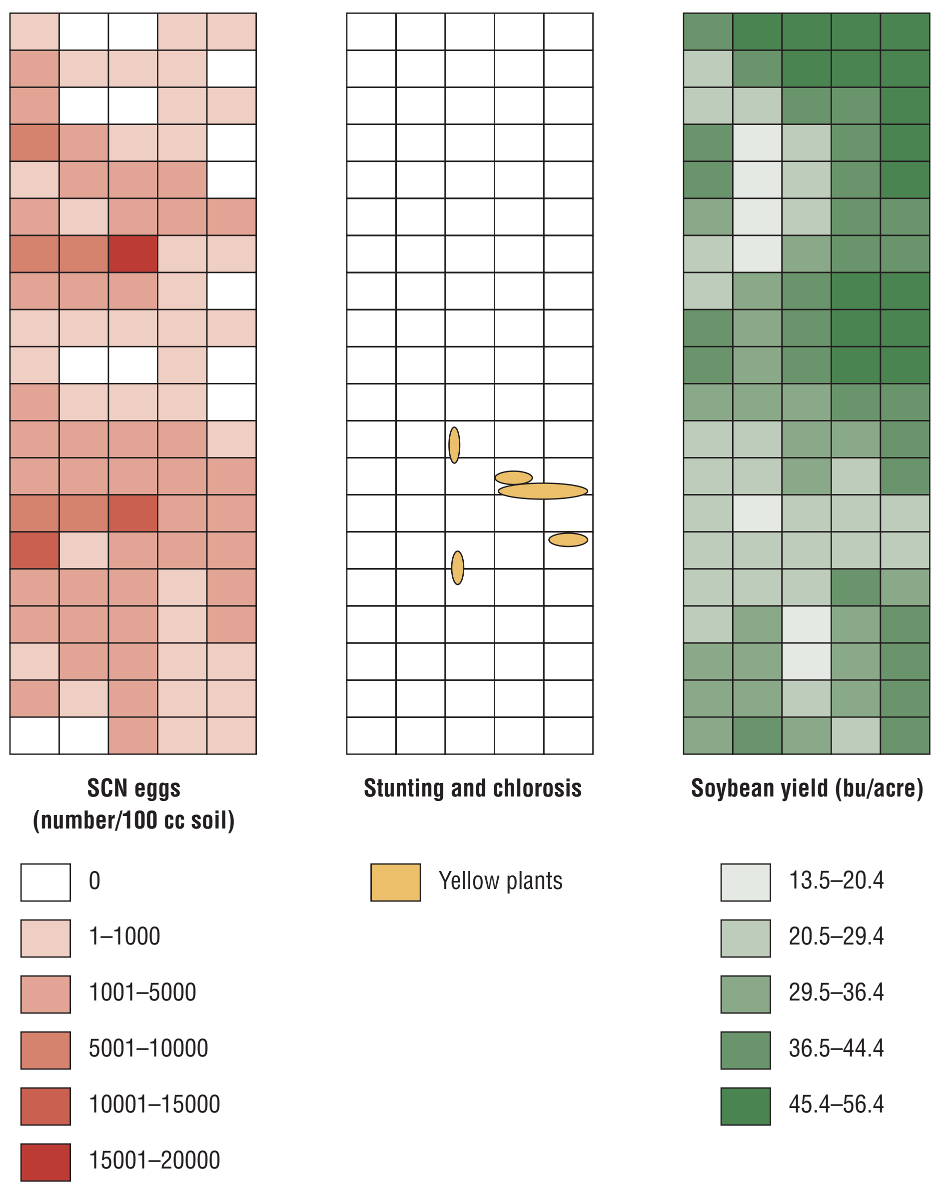

Figure 2 ■ A schematic of the distribution of soybean cyst nematode eggs, plant symptoms, and soybean yield in the same field (Niblack et al., 2006).

The rules of thumb that are accepted generally by nematologists are these:

- A single soil sample should not represent more than 10 acres (fewer is better); don't try to sample an entire farm, but focus on one or more areas.
- A structured sampling pattern, such as a zigzag (Figure 3) or W-shape, is acceptable.
- Nematode populations tend to be highest in the fall.

Note that the standard sampling depth of 6 inches is not appropriate for most purposes—SCN is the one exception. Distribution of root-feeding nematodes depends on distribution of the roots, so, generally speaking, the depth of the sample should be determined by the depth of the active root zone, which varies by time of year and crop (Figure 4; Pudasaini et al. 2006).

Time of sampling • Yield loss due to plant-parasitic nematodes depends on the number of nematodes present when the crop is planted (Figure 5). But nematodes are always present in the soil, and they can't move out of an area or even around within an area to much extent. All biological complexities aside, the time to sample is the time when it makes most sense *to the grower*. Some obvious examples:

- A grower who has never had a census done for corn-parasitic nematodes can submit a portion of the same soil collected for nutrient analysis to a lab for nematode analysis, so that nematode analysis becomes a part of the regular corn management routine.
- A grower who is looking for diagnosis of a problem can submit a sample at the time the problem appears.
- A grower who knows about an SCN infestation and wants to choose a resistant variety, or determine whether management tactics are working, should sample in the fall.

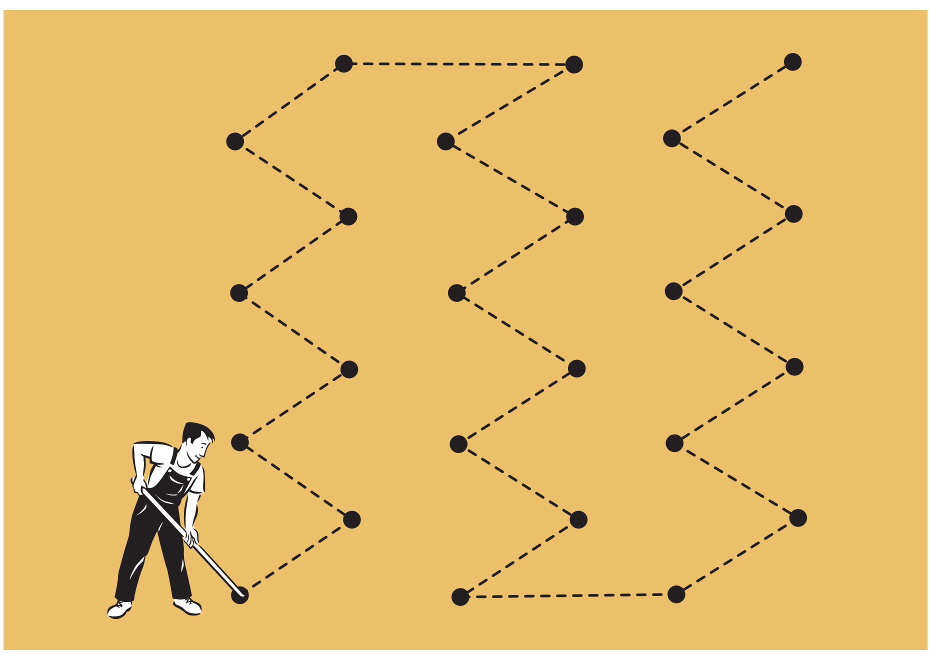

Figure 3 ■ A diagram of a common soil sampling pattern for plant-parasitic nematodes. Each point represents one subsample. The subsamples should be combined into a single sample. The area represented by a single sample can be any size up to 10 acres.

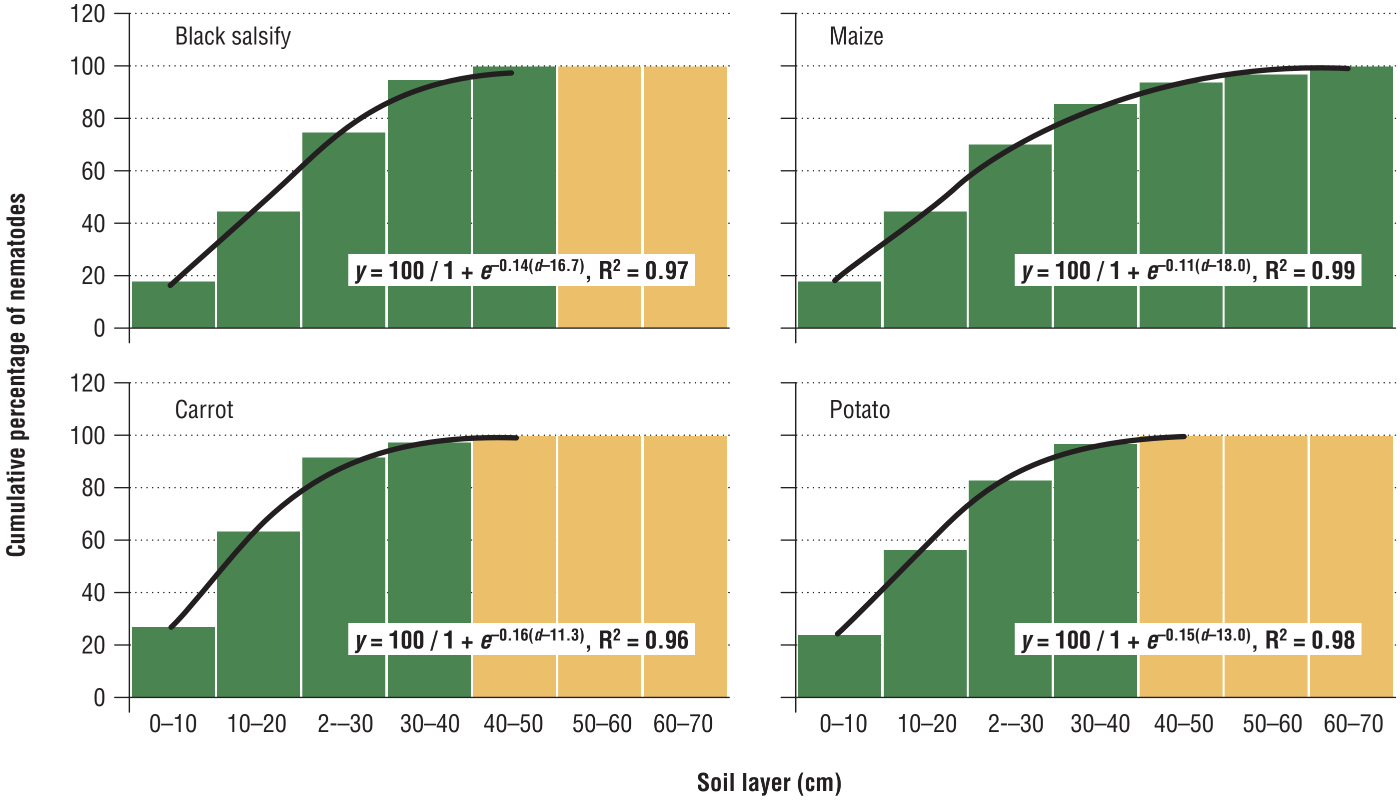

Figure 4 ■ A graphic representation of the effect of depth of soil sampling and crop on the recovery of nematodes from soil (Pudasaini et al. 2006).

Nematology Lab Reports

Labs that perform nematode analyses in the Midwest may offer two separate assays: an SCN count and a vermiform nematode analysis. A vermiform nematode analysis, sometimes called a corn nematode test, is a set of procedures for determining the identities and population densities of nematodes that do not form survival structures similar to cysts. The term "vermiform" simply refers to the fact that these nematodes are worm-shaped, rather than cyst-shaped.

These two types of analysis, SCN and vermiform, can be done at the same time, but it is important that the lab be informed beforehand which analysis is wanted. This is because the procedure for assaying vermiform nematodes requires several more steps than the procedure for SCN, and, if the lab does not prepare for the additional steps at the first step, the vermiform nematodes will be lost during processing.

SCN analysis: Cyst and egg counts • Analysis of samples for SCN may consist of a cyst count, an egg count, or a type test (similar to what used to be called a "race test"). Cyst counts are the easiest to do and will answer the question "Is this field infested with SCN?" unless the count is very low (one to a few cysts). Determining whether a cyst from a field with a low count is actually SCN is rarely an issue in Illinois if a reasonable crop history has been provided, but it should be mentioned that Illinois is home to several other cyst nematode species.

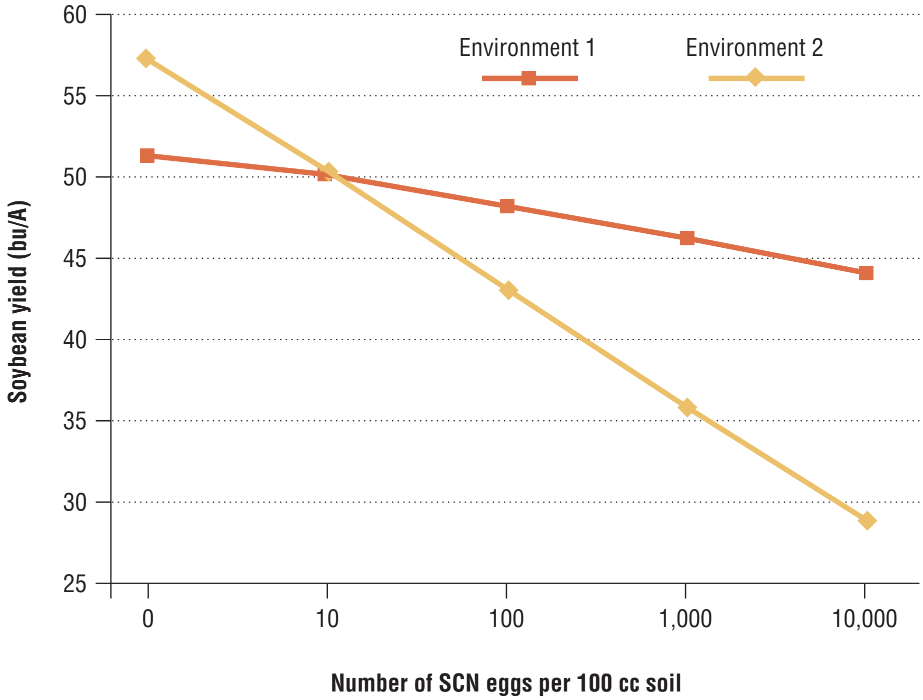

Figure 5 ■ The relationship between nematode numbers and soybean yield in two different environments.

Egg counts are preferable to cyst counts for several reasons. First, SCN eggs are much better predictors of yield loss than are cyst counts. Eggs represent the actual potential for parasitic juveniles to hatch and infect roots, whereas cysts are simply the dead remains of female nematodes. Second, most of the SCN populations in Illinois are able to infect resistant varieties, but the number of eggs (not cysts) they produce is the real test of how much of a threat they are to yield. The bottom line: Growers with a known history of SCN infestation should ask for egg counts only.

SCN analysis: Type testing • Type testing an SCN population is the only way to determine whether it is a threat to SCN-resistant varieties. There are two type tests available: the HG Type test, which is used for research purposes only; and the SCN Type test, which is used to make management recommendations.

- The Illinois SCN Type test is tailored for use in Illinois (Figure 6). Interpretation of this report is simple and based mainly on one piece of information: the type recorded in the bold box titled IL SCN Type.
- If the Illinois SCN Type is 0, then any SCN-resistant variety may be used in the field from which the sample was collected.
- If the Illinois SCN Type is 2, then look at the number listed in the Female Index column. If the number is greater than 50, then the grower should limit choices of SCN-resistant varieties to those with a PI 548402 (Peking) or PI 437654 (Hartwig or CystX©) source of resistance. Sources of resistance may be found in the Varietal Information Program for Soybeans (VIPS) booklet or through its Web site at http://web.aces.uiuc.edu/VIPS.

- If the Illinois SCN type is any number other than 0 or 2, then the lab should be contacted for additional help interpreting the results.

Vermiform nematode analyses • A vermiform nematode census will almost always include a list of nematodes and the numbers per volume of soil. The actual form of the report will vary from lab to lab, but the identities of the nematodes will be similar. The nematode list used by the Worm Lab at the University of Illinois is shown in Figure 7.

To simplify interpretation of this report, a guide to have handy is the one shown in Figure 8, produced by the now-retired USDA-ARS nematologist from Illinois, Dale Edwards. Compare the numbers in the lab report to those in the columns labeled insignificant, minor, moderate, severe, and very severe to determine the potential for yield loss.

Conclusion

Corn and soybean yields are affected by the identities and numbers of nematodes present in the soil at planting. Knowing this, it would seem only

Date received: Condition of sample:

Number of eggs/250 cc soil: ____________

Dates of population increase (if required): In____________ Out____________

Dates of IL SCN Type test: In____________ Out____________ Inoculum level:____________

Results:

Number of females on Lee 74: ____________

Number of females on Essex: ____________

IL SCN Type:

Indicator Line:	Female Index:	+ or –
1 PI 548402		
2 PI 88788		
3 PI 437654		

Figure 6 ■ Excerpt from the Illinois SCN Type report form from the University of Illinois Nematology Lab.

Figure 7 ■ Excerpt from the Vermiform Nematode Analysis form from the University of Illinois Nematology Lab.

Date received: Condition of sample:

	Sample ID				
	Number of nematodes/100 cm^3 soil				
Spiral (*Helicotylenchus*)					
Cyst (*Heterodera*)					
Root-knot (*Meloidogyne*)					
Lesion (*Pratylenchus*)					
Lance (*Hoplolaimus*)					
Stunt (*Tylenchorhynchus*)					
Dagger (*Xiphinema*)					
Ring (*Criconemella*)					
Pin (*Paratylenchus*)					
Other					
Tylenchid					
Aphelenchid					
Bacterivore					
	Number of nematodes/g dry root				
Lance (*Hoplolaimus*)					
Lesion (*Pratylenchus*)					

reasonable that soybean and corn growers would pay as much attention to their nematode populations as they do to soil nutrient analysis. One reason they don't is that the reports they get back are difficult to interpret.

The purpose of this short contribution is to demystify nematode lab reports, and it should be evident that the reports are fairly straightforward if you know what to look for. Making management recommendations based on nematode reports is another story altogether!

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Pudasaini, M.P., C.H. Schomaker, T.H. Been, and M. Moens. 2006. Vertical distribution of the plant-parasitic nematode, *Pratylenchus penetrans*, under four field crops. *Phytopathology* 96:226–233.

GENERALIZED POPULATION THRESHOLDS FOR DAMAGE BY PLANT-PARASITIC NEMATODES IN ILLINOIS[1]

	Threshold numbers per 100cc of soil for degrees of problem severity[2]				
Nematode, common and generic names	Insignificant[3]	Minor[4]	Moderate[5]	Severe[6]	Very Severe[7]
Cyst (*Heterodera*), cysts, soybeans only	---	---	1-5	6-25	>25
Foliar (*Aphelenchoides*), per g fresh wt	---	---	1-5	6-25	>25
Stem (*Ditylenchus*), per g fresh wt	---	---	1-5	6-25	>25
Sting (*Belonolaimus*)	---	1-5	6-20	21-50	>50
Needle (*Longidorus*), corn only	---	1-5	6-20	21-75	>75
Stubby-root (*Paratrichodorus*)	1-5	6-20	21-50	51-100	>100
Root-knot (*Meloidogyne*), larvae	1-10	11-40	41-80	81-150	>150
Root-knot (*Meloidogyne*), galls per root system	1-5	6-10	11-20	21-50	>50
Root-lesion (*Pratylenchus*), preplant only	1-10	11-25	26-50	51-100	>100
Root lesion (*Pratylenchus*), per g dry roots	1-50	51-200	201-500	501-1000	>1000
Dagger (*Xipinema*)	1-10	11-25	26-50	51-100	>100
Lance (*Hoplolaimus*)	1-10	11-40	41-75	76-75	>150
Stunt (*Tylenchorhynchus*)	1-10	11-50	51-100	101-200	>200
Spiral (*Helicotylenchus*)	1-75	76-150	11-300	301-500	>500
Ring (*Criconemoides*)	1-75	76-150	151-300	301-600	>600
Pin (*Paratylenchus*)	1-50	51-100	101-500	501-1000	>1000

Revised: 2003 Dale I. Edwards

[1]Figures are guidelines only; thresholds often must be increased or decreased substantially, depending on plant weather conditions, sampling and extraction methods, and other biotic and abiotic factors.

[2]Based on soil analysis unless otherwise indicated; figures in each column subjectively correspond to trace, low, moderate, heavy, and very heavy nematode population levels, respectively.

[3]Population of no consequence during present growing season; potential for increase to damaging level remote in subsequent years.

[4]Population of little consequence at present; potential for increase to damaging level remote during present growing season but good on highly susceptible, monocultured hosts in subsequent years.

[5]Borderline situation with soil nematodes; measurable damage from nematodes alone highly dependent on present and future weather conditions and fertility level; nematodes possibly a contributing factor in a disease complex with fungi, bacteria, viruses, and/or other nematodes; control measures may not be economically practical; strip test recommended; continued monocultured may result a in severe problem. Eventual mortality of parts or all of plant can be expected with foliar and stem nematodes; treatment or destruction of plant recommended.

[6]Population sufficiently high to cause severe economic damage and some plant mortality; established planting may not be salvageable; control measure mandatory.

[7]Population sufficiently high to cause severe economic damage and some plant mortality; established planting may not be salvageable; and control mandatory.

Figure 8 ■ Summary of plant-parasitic nematode damage thresholds for Illinois (courtesy of Dale Edwards).

Is Corn Following Corn the New "Standard"?

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Corn following corn has been grown on some Illinois farms for decades, usually on more-productive fields, and occasionally in "corn yield contest" fields. At the same time, planting corn following a crop other than corn—usually a legume, so usually soybeans in recent decades—has been considered by most as the "standard" way to produce corn. Having corn follow soybeans (SC) has generally meant higher and more stable corn yields than when corn follows corn (CC).

In recent years, some seed companies and, increasingly, some producers in Illinois are beginning to assert that the problems of lower and less stable yields of corn following corn have been "fixed" by newer hybrids and management and that we need no longer consider corn rotated with soybeans as the "ideal" system under which to grow corn. In addition, recent increases in corn prices and high corn yields have many looking to corn as the crop most likely to maximize profits. Figure 1 shows the acreage changes that have taken place as a result. Projecting only a small increase in corn acreage from 2007 into 2008, we can estimate that at least 40% of the Illinois corn crop in 2008 will follow corn.

Does Corn Following Corn Still Yield Less Than Corn Following Soybeans?

If we expect corn following corn to become a new "standard" for corn production, it should provide yields and yield stability as great as the system that it replaces (corn following soybeans). For nearly 10 years, we have been running trials that allow us to compare CC and SC directly, in the same set of fields. Though there are signs that the "yield penalty" for CC compared to SC might be decreasing, we cannot yet be confident that this yield difference has disappeared.

In one ongoing study, we have compared CC and SC in a nitrogen rate trial; therefore, differences in N rate responses do not complicate the results.

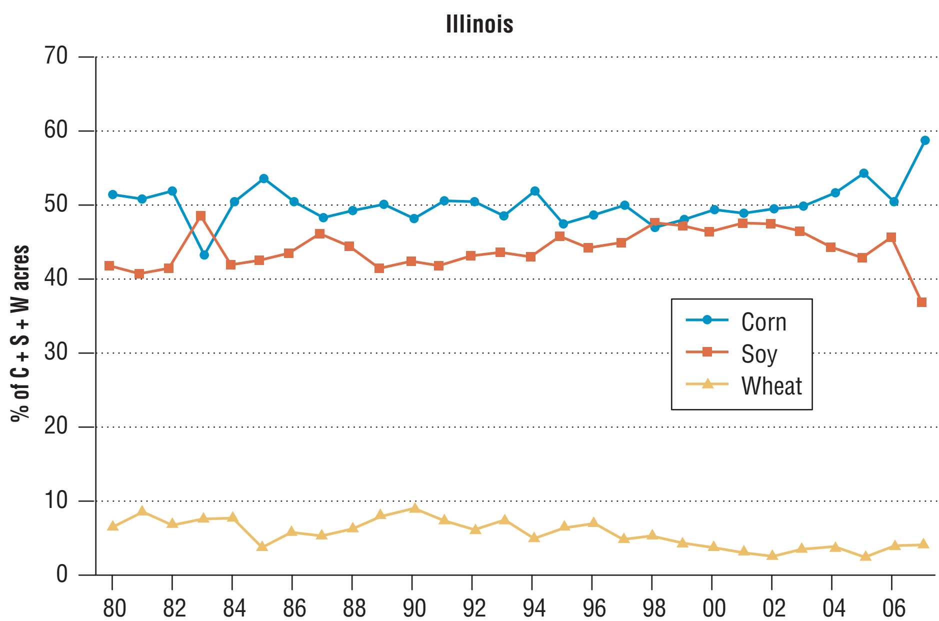


Figure 1 ■ Acreages of corn, soybeans, and wheat in Illinois, 1980–2007 (source: NASS).

Data over the past 9 years have shown that SC yields more than CC about 80% of the time (Figure 2). Most of the sites where CC yields more than SC (bars below the line on Figure 2) are from Perry in western Illinois, where CC outyielded SC in 7 of 9 years. The average difference was about 11 bushels per acre, or about 7% more yield for SC compared to CC.

The average yield advantage of SC over CC is greatly influenced by those few times when SC yielded much more than CC. This difference was more than 50 bushels per acre in four of the 61 environments, and all of these were in the northern half of Illinois, with three at Monmouth and one at Urbana. Without these, the average yield loss was only 7 bushels per acre, or 5%. While the last such "disaster" occurred under dry conditions at Monmouth in 2005, SC yields ranged from 176 to 201 over these four high-loss environments, so they were not so dry that SC yields were greatly reduced. Rather, it appeared that stress was slightly greater in CC in these environments and that the crop ran out of water at a critical time compared to SC. While such large losses in CC have not occurred within the past 2 years (Figure 3), it is too early to proclaim that this problem has been solved.

When Does Corn Following Corn Become "Continuous"?

While this question is somewhat a semantic one, many people distinguish between a crop that is only in its second or third time following corn and corn that has been in the same field for more than 4 or 5 years. Part of that might just be a change in intention—a continuous corn field might be one that is simply designated to have corn in it each year for the foreseeable future. But for many, "continuous" corn is considered more "settled" than second- or third-year corn, with fewer problems and higher yields than when corn first follows corn.

Some cite the fact that corn yield contest fields are highly productive and often in continuous corn, so perhaps continuous corn might produce even a

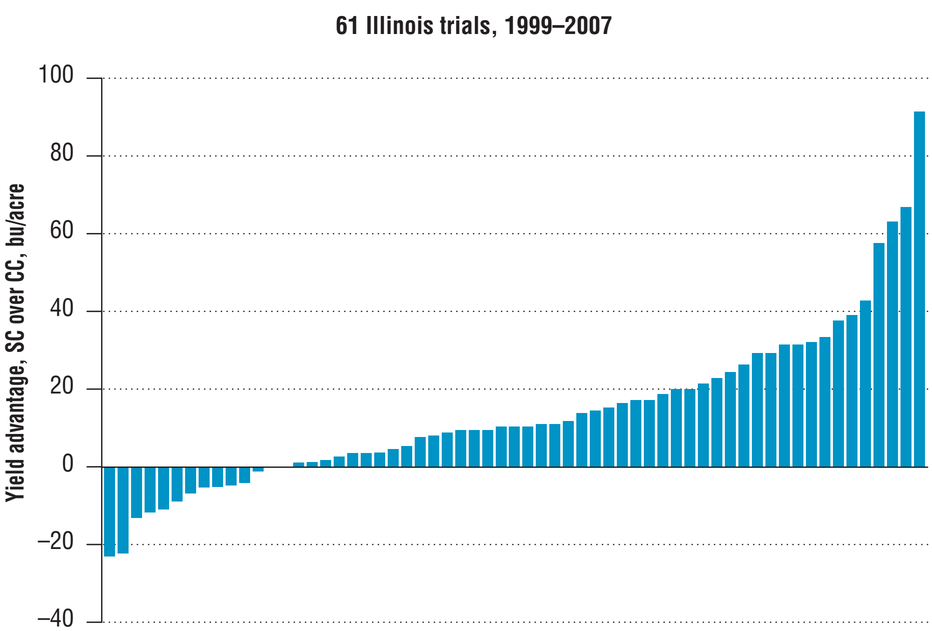


Figure 2 ■ Yield advantage of corn following soybeans (SC) over corn following corn (CC) in 61 comparisons in Illinois, 1999–2007.

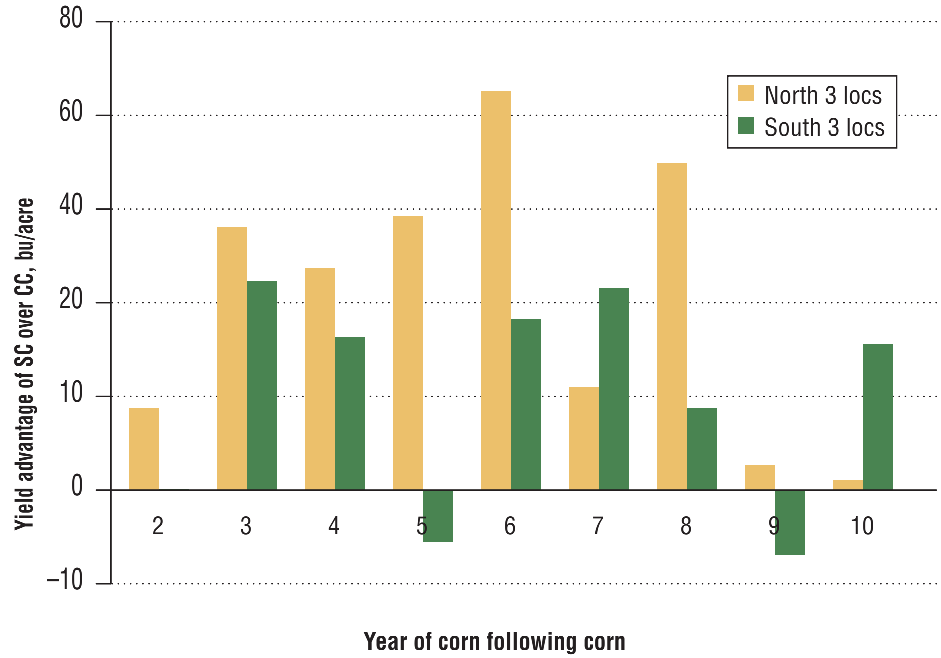


Figure 3 ■ Yield advantage of corn following soybeans (SC) over corn following corn (CC) in three southern and three northern Illinois sites over years.

positive effect on corn yield, at least once it's been in that field for some years. How might this happen? Perhaps beneficial insects or microbes could build up over time, organic matter might accumulate to provide soil-related benefits, or negative factors related to sequential corn crops might somehow diminish or disappear. It has not been easy to document such developments over time, and, in fact, there are little or no data showing that corn yields increase (relative to SC yields) as corn is grown more years in sequence in the same field. Instead, as shown in Figure 3, yields of CC compared to SC tend to fluctuate over years, with no clear trend.

In more "normal" fields, some consider second-year corn to be especially problematic and believe that corn yields start to recover only after the second corn crop has been harvested. In one of our Illinois studies, we have continuous corn, corn following soybeans, and both first-year and second-year corn in a corn–corn–soybean rotation, all compared over a 4-year period at a number of sites. Continuous corn yielded statistically the same as second-year corn in both sets of experiments, though there was a tendency for second-year corn to yield slightly more than continuous corn (Table 1). As expected, corn following soybeans yielded the same, whether it was in a 2-year or a 3-year rotation. Compared to the yield of second-year corn, more years of continuous corn clearly did not cause yields to rebound.

Other data, especially from some long-term studies in Minnesota and Wisconsin, confirm what we are seeing in Illinois: From a yield standpoint, corn is "continuous" the first year it follows corn, and it makes no discernible difference whether corn is in its second, fifth, or twentieth year when it comes to yield. Corn following corn is just that—corn following corn.

Table 1 ■ Crop rotation effect on corn yield in Illinois trials. Continuous corn followed at least 3 years of corn in the same plots.

Rotation	12 northern Illinois sites	7 southern Illinois sites
	bushels per acre	
Continuous corn	178	139
Corn–soybeans	197	149
1st-year corn in CCS	196	144
2nd-year corn in CCS	184	145
Significance	*	NS

Can We Stabilize Corn Following Corn Yields by Changing Management?

So far, we have had limited success in finding ways to manage continuous corn to reduce or eliminate the yield penalty compared to corn following soybeans. The fact that this penalty has been small in most of our trials in 2006 and 2007 suggests that changes in hybrids, in particular the addition of the Bt trait for corn rootworm control, might be helping to reduce the problems associated with CC. In the 2007 corn hybrid trials at Monmouth, however, there was not an obvious effect of traits on relative performance in the SC and CC trials (Table 2). This contrasts with results at that location in 2006, when RW Bt hybrids yielded about 70 bushels per acre more than non-RW Bt hybrids in the CC trials.

We compared planting date and plant population responses of both SC and CC at a number of sites in 2007 and found no consistent difference. Tillage has tended to increase yields in continuous corn more than in rotated corn in a number of trials, especially in northern Illinois, but this effect is not very consistent. Foliar fungicide has not been found to increase yield more in CC than in SC, even though there can, in some cases, be more disease inoculant produced in corn residue in CC. Nitrogen requirements of CC tend to be greater than those for SC, but the data we accumulated to run the N rate calculator (http://extension.agron.iastate.edu/soilfertility/nrate.aspx) show that, in central Illinois, an "average" CC field may in fact need little more N to optimize yield than does an "average" SC field.

Table 2 ■ Yields in the Monmouth, Illinois, CC and SC corn hybrid trials, comparing hybrids common to both trials. Derived from data found at http://vt.cropsci.uiuc.edu.

Trait	No.	SC average	CC average
		bushels per acre	
Bt corn borer	5	248	237
Bt rootworm	6	251	242
CB + RW	43	243	234
Maturity, days			
106–109	14	240	228
110–112	26	247	239
113–116	14	246	236

Anticipating that we might at some point start to harvest cornstalks for processing into ethanol in the future, we initiated a trial in 2006 to see if residue removal, combined with tillage and N rate, might affect the yield of continuous corn. Averaged over five sites with deep, prairie-derived soil, tillage increased yield when previous crop residue was present but not when all the residue had been removed (Figure 4). Removing residue also decreased the amount of N needed to optimize yield and produced a small increase in grain yield. In the short run, it appears that removing some residue will not have a negative effect on yield—and might even improve profitability by reducing the need for N and by increasing yield.

So, Is Continuous Corn the New "Standard" Crop Sequence?

While many people have produced yields of corn following corn that rival those of corn following soybeans, it is premature to declare that all problems associated with continuous corn have been solved. There are clearly no "magic bullets" to make CC perform in all respects like SC. At the same time, equal yields in the two systems have become more common in farmer fields in recent years, and we may not be far from the time when we can indeed consider CC to be as stable, and as high-yielding, as SC has been in recent years.

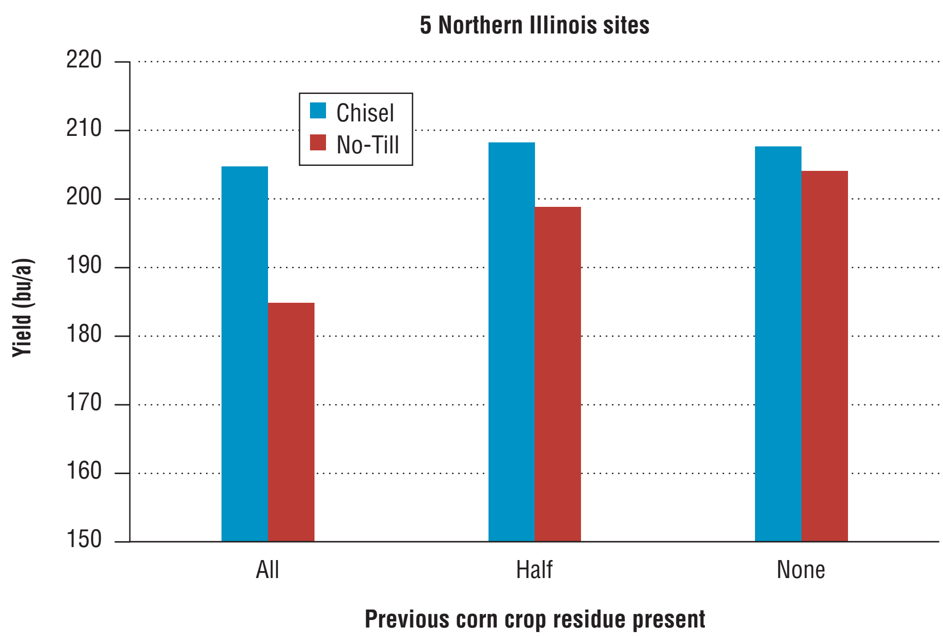
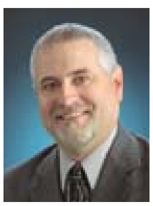


Figure 4 ■ Effect of previous corn crop residue level on the response of corn yield to tillage. Data are averaged over N rates and over five Illinois sites.

Soybean Aphids and Soybean Defoliators—Are We Making Progress?

Co-authors: Mike Gray, Ron Estes, Nicholas Tinsley, and Joshua Heeren, Department of Crop Sciences



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The answer to the question posed in the title is, "Yes, we are making progress," if the question pertains to all entomologists currently conducting research on soybean aphids. Since 2001, when soybean aphid management research was initiated, we have made excellent progress—producing sampling protocols, economic injury levels and economic thresholds, and support for control recommendations. And the future for soybean aphid management research and recommendations looks bright, too, with biological control and host plant resistance help on the way. We expect full speed ahead, with entomologists working cooperatively across state lines to address the most important recurring insect threat to soybean production.

If, on the other hand, we ask the same question about soybean defoliators, … well, not so much. With the exception of some research that has addressed bean leaf beetles and their transmission of bean pod mottle virus, very little midwestern research sheds much new light on management of soybean defoliators. Experience with Japanese beetles over the past few years has prompted many soybean producers to wonder whether the percentage defoliation thresholds are still valid for modern soybean varieties grown for high yields with modern production practices.

The intent of this paper is to provide an overview of field research and related activities that were accomplished in Illinois in 2007, with some references to research being conducted elsewhere. Emphasis is on soybean aphid research, but some discussion of defoliators is included. The research results and future plans will be placed in the context of current status of and future scenario for soybean insect management.

Acknowledgments

It may seem unusual to place acknowledgments near the beginning of a paper, but we wish to emphasize that recognition for supports is not an afterthought. During the past several years, we entomologists in the Midwest have been fortunate to receive consistent funding from soybean associations, allowing us to address insect management questions posed by soybean producers. The North Central Soybean Research Program (NCSRP) has provided funding to support two major multistate, multifaceted research and education efforts—"Soybean Aphid Management in the North Central States," directed by David Ragsdale, University of Minnesota, and "Biological Control of the Soybean Aphid," directed by Bob O'Neil, Purdue University. Illinois entomologists have been involved in research and education activities associated with both projects. The Illinois Soybean Association also has provided funding annually to support field research and development efforts for insect management, most recently for the projects "Management Research, with Emphasis on Soybean Aphid and Defoliators" and "Survey of Soybean Diseases and Pests in Illinois." Without this support, we would not be able to address the most relevant and practical aspects of soybean insect management, some of which are included in this paper. We thank the soybean producers, particularly the Illinois Soybean Association, for their commitment to our program. We also thank the many companies who have provided support for insecticide efficacy experiments, enabling us to answer near-term questions about insect control in soybeans.

Progress Toward Improved Management of Soybean Aphids, 2006 and 2007

Before 2006, most of our soybean aphid research efforts focused on efficacy of seed- and foliar-applied insecticides. In 2006, we became involved in several additional projects with multiyear and multistate implications. Many of the projects continued in 2007, and some new efforts were initiated:

- Sixth year of assessment of the efficacy of seed- and foliar-applied insecticides to control soybean aphids, with their effects on yield.
- Second year of weekly surveys of commercial soybean fields to correlate in-field densities of soybean aphids with captures of soybean aphids in suction traps in the fall, with expectations for improving our ability to predict outbreaks.
- Second year of assessing the efficacy of soybean varieties with putative resistance to soybean aphids.
- First year of a focused assessment of the interaction of soybean aphid-resistant varieties, natural enemies, and seed- and foliar-applied insecticides.
- First year of a release of a parasitoid, *Binodoxys communis*, imported from China. The release was approved by USDA-APHIS and occurred simultaneously in several states.
- First year of a research project to validate a method of subsampling for soybean aphids that would make scouting and research efforts more efficient.

The space available in these proceedings will not allow us to share all of the results generated from these efforts. In fact, the release of *Binodoxys*

Figure 1 ■ Erecting a cage for the anticipated release of a parasitic wasp, *Binodoxys communis,* that may help regulate populations of soybean aphids.

communis (Figure 1) was preliminary in nature, and the subsampling project produced no useful results in Illinois, so neither project is discussed further in this paper. Consider the brief discussions that follow as "snapshots" of a larger venture.

Monitoring the Soybean Aphid Population in Illinois in 2007

Widespread outbreaks of soybean aphids in the Midwest have occurred primarily during odd-numbered years. Soybean aphid populations in Illinois in 2007 were no exception to the established pattern. Many soybean fields in northern and central counties were treated with insecticides because densities of soybean aphids approached, reached, or exceeded the economic threshold of 250 aphids per plant. In hindsight, however, results from our sampling efforts and research projects suggest that insecticides may not have been necessary, at least in some fields.

From mid-June through early September, we sampled 26 commercial soybean fields—ten fields in Woodford County, ten fields in Stephenson County, and one field in each of six additional counties (Bureau, Lee, Marshall, Ogle, Putnam, and Whiteside). Figure 2 shows densities of soybean aphids in five of the 26 fields—three fields in Woodford County and two fields in Stephenson County. One of the fields in Stephenson County (S1) had the largest density of soybean aphids (1,196 aphids per plant on 14 August) we observed in all of the 26 fields sampled in 2007. Note, however, that the soybean aphid population in field S1 "crashed" to 133 aphids per plant by 23 August. Population crashes occurred in all fields sampled that were not treated with insecticides. We observed similar population crashes in all of our experiments in Whiteside County.

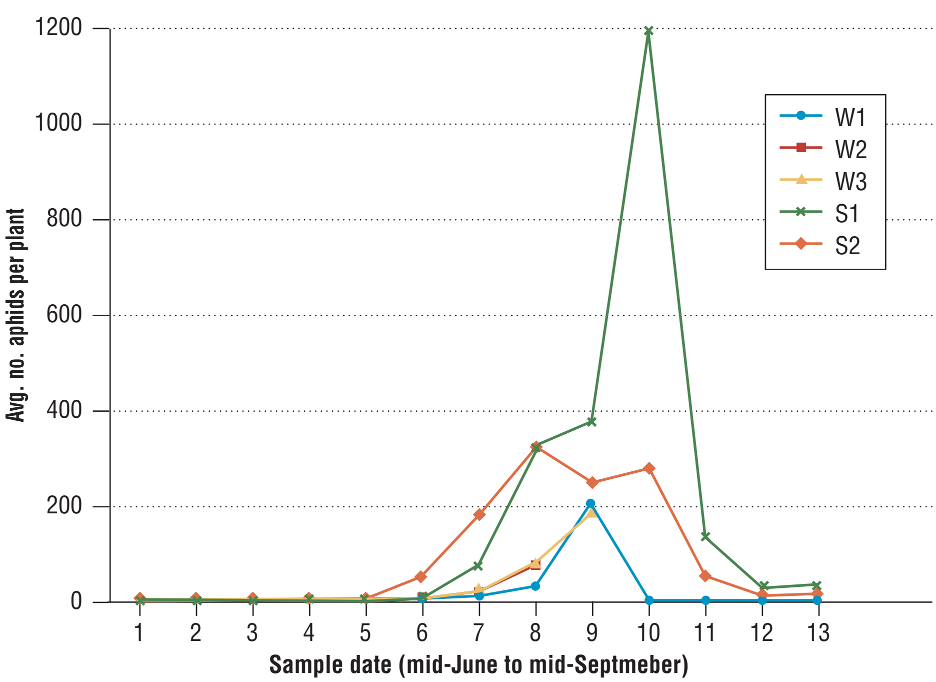


Figure 2 ■ Average numbers of soybean aphids per plant in three fields in Woodford County (W1, W2, W3) and two fields in Stephenson County (S1, S2), mid-June through early September 2007.

Fields W2 and W3 in Woodford County were treated with insecticides when the densities were only 75 and 188 aphids per plant on 30 July and 9 August, respectively. Based on the soybean aphid population crashes observed in other fields in Woodford County and in untreated strips in sampled fields, it is likely that these fields did not need to be treated. The densities of soybean aphids in a few of the fields reached or exceeded the economic threshold of 250 aphids per plant but did not reach the economic injury level (cost of control = value of yield loss) of slightly more than 600 aphids per plant.

Insecticides: Were They Effective Against Soybean Aphids in 2007?

We established an insecticide efficacy trial in Whiteside County. There were 21 treatments in the trial, including individual seed- and foliar-applied insecticides, tank mixes of foliar-applied insecticides, experimental insecticides, and two untreated checks. Soybean aphids were sampled before foliar insecticides were applied on 3 August, and 7, 14, and 21 days after foliar insecticides were applied (days after treatment, DAT). Yields were estimated on 11 October. Average densities of soybean aphids and average yields are presented in Figure 3 for individual (no tank mixes) registered products and the untreated check (average from two untreated checks). All of the data from all treatments can be viewed in the 2007 edition of *on Target* (www.ipm.uiuc.edu/ontarget), our annual summary of field crop insect management trials.

On 1 August, 2 days before foliar insecticides were applied to designated plots, densities of soybean aphids exceeded the economic threshold of 250 aphids per plant in most plots, with an average of 371 aphids per plant in the untreated check plots. Densities of soybean aphids declined in all plots, including the untreated checks, by 10 August (7 DAT). By 17 August (14 DAT, data not shown), the density of soybean aphids in the untreated checks

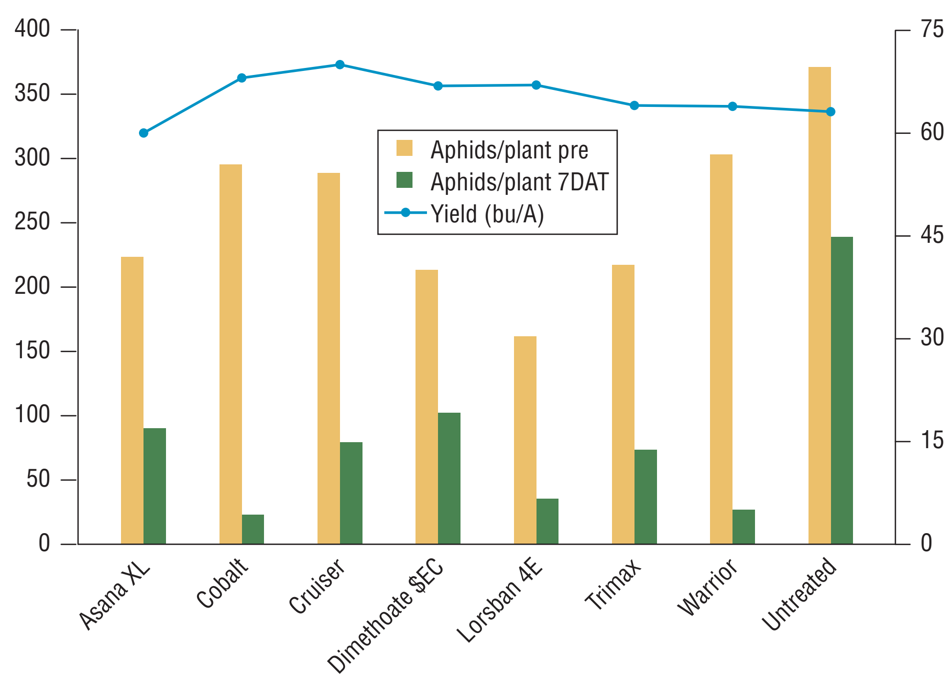


Figure 3 ■ Average numbers of soybean aphids per plant pre-treatment and 7 days after treatment (7 DAT) in an insecticide efficacy trial, Whiteside County, Illinois, 2007.

had declined to an average of 77 aphids per plant. Although the density of soybean aphids exceeded the economic threshold in the untreated checks, it never reached the economic injury level. Densities of soybean aphids were never large enough to cause any statistically significant differences in yields between the insecticide-treated plots and the untreated plots.

Soybean Varieties Resistant to Soybean Aphids: A Potential Management Tool

We established an experiment in Whiteside County to examine the efficacy of soybean varieties with putative resistance to soybean aphids. Resistant lines from the University of Illinois, Kansas State University, Michigan State University, and South Dakota State University were included in the trial (a total of 22 treatments), but only the data from the Illinois varieties are presented.

Three University of Illinois varieties (from Brian Diers' breeding program) with putative resistance to soybean aphids were compared with three aphid-susceptible isolines. Half of the seed of each variety (three resistant and three susceptible varieties) was treated with Cruiser; the other half of the seed of each variety was not treated with a seed-applied insecticide.

Figure 4 shows the average numbers of soybean aphids per plant for two of the soybean aphid-resistant varieties (LD05-16060 and LD05-16529) and the two respective soybean aphid-susceptible isolines (SD01-76R and LD05-16519), both treated and not treated with Cruiser, on 8 August, when numbers of soybean aphids were at their peak. All data for all treatments on all dates when soybean aphids were sampled can be viewed in the 2007 edition of *on Target*.

The largest density of soybean aphids detected was 904 aphids per plant on 8 August in the susceptible variety LD05-16519 not treated with Cruiser.

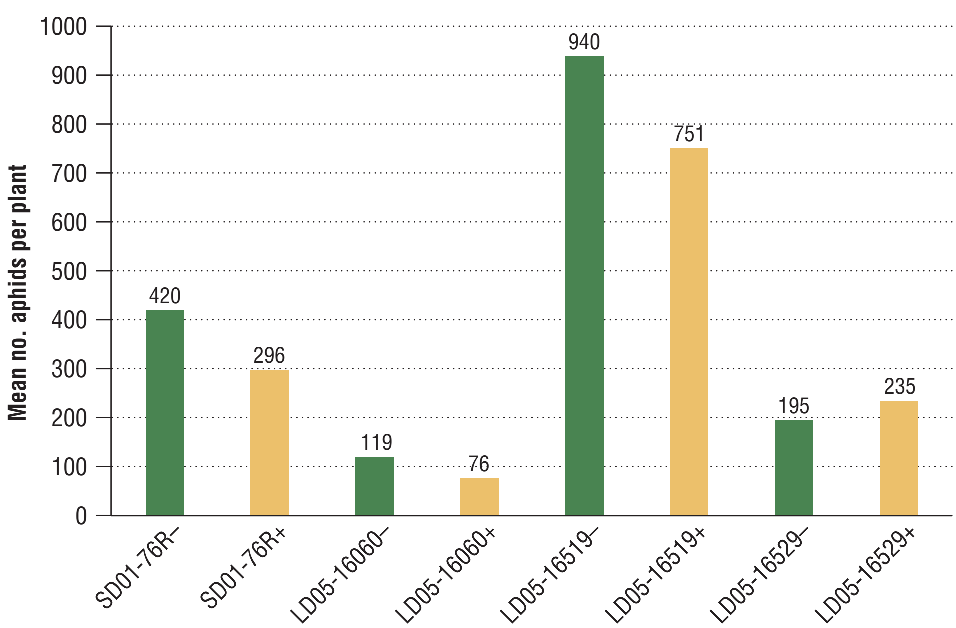


Figure 4 ■ Average numbers of soybean aphids per plant on soybean aphid-susceptible and soybean aphid-resistant varieties not treated (–) or treated (+) with Cruiser, Whiteside County, Illinois, 8 August, 2007.

The data in Figure 4 reveal that numbers of aphids on the resistant varieties were statistically smaller than the numbers of aphids on their respective susceptible isolines. Although the data are not shown, there also were statistically smaller numbers of aphids on the resistant variety LD05-16611 than on its susceptible isoline LD05-16621, and statistically smaller numbers of soybean aphids on the four resistant varieties from Michigan State University, one resistant variety from Kansas State University, and one resistant variety from South Dakota State University than on the susceptible varieties.

Populations of soybean aphids crashed in all plots on 15 August, with an average of 13 aphids per plant on the susceptible "control" variety. As previously indicated, the same crash was observed in other experiments in the same field and in commercial soybean fields in northwestern and central Illinois.

How Do Insecticides, Natural Enemies, and Resistant Varieties Interrelate?

An experiment to determine the interaction of seed- and foliar-applied insecticides, aphid-susceptible and aphid resistant-varieties, and predators on populations of soybean aphids was established in Whiteside County. A lot of data were generated from this experiment, so in the interest of conserving space, the data are not presented in this paper. However, some discussion follows.

The density of soybean aphids peaked at an average of 1,144 aphids per plant in the commercial soybean variety, Midwest Seed Genetics GR-2332, on 8 August. Although Warrior was applied to designated plots on 10 August, the population of soybean aphids had crashed by 15 August to numbers well below the economic threshold in all plots, including plots not treated with Warrior. However, on individual plants that had been caged to exclude predators, the numbers of soybean aphids continued to increase through August and into September. Based on evidence obtained from the numbers of predators counted on yellow sticky traps, *Orius insidiosus*, the insidious flower bug, may have been at least partially responsible for the population crash in this experiment. Yields of GR-2332 treated with Warrior twice and Warrior (twice) + Cruiser were not statistically different from yields of GR-2332 not treated with an insecticide.

Progress Toward Improved Management of Soybean Defoliators

As indicated in the introductory paragraph, very little midwestern research has been conducted to determine the effect of insect defoliation on modern soybean varieties with modern expectations for yield. The percentage defoliation thresholds associated with insect pests served us well from the 1970s through the 1990s, but most entomologists now agree that these thresholds are not very practical any more. Rather, treatment decisions should be based on leaf area indices or light interception. Unfortunately, there currently are no practical guidelines that support this preferred method of decision making for defoliators of soybeans. So, we continue to use the percentage defoliation thresholds as a contingency.

In 2007, we were involved in a preliminary study to learn more about the effects of soybean defoliators (and soybean disease organisms) on the yields of modern varieties of soybeans. We cooperated with plant pathologists to assess the impact of seed- and foliar-applied insecticides and fungicides on several insect pests and plant pathogens and on the yields of two soybean varieties in an experiment in Piatt County. Unfortunately, densities of soybean defoliating insects were small, and differences in insect densities among plots did not contribute to differences among yields. We will expand our efforts in 2008 and thereafter.

Soybean Insect Management Now and Then

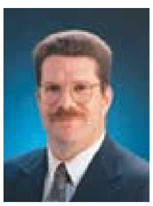
With the exception of the guidelines for managing soybean aphids, soybean insect management guidelines in 2007 are not much different from what they were in the early 1980s. In fact, the principal guidelines are still the same—scout to assess the densities of insect pests and treat with an insecticide, if necessary. What has changed quite dramatically is the attitude regarding management of insect pests of soybeans. Many soybean producers now use seed- or foliar-applied insecticides to prevent insect problems, assuming that the yield benefit will more than offset the cost(s) of the product(s). Promotions of fungicides and insecticides to improve "plant health" encourage belief in such an assumption. However, data generated from multiple experiments conducted throughout the Midwest during 2007 suggest otherwise.

The future for managing soybean aphids with resistant soybean varieties, with the help of both native and introduced natural enemies, looks promising. However, unnecessary use of insecticides could alter the ecology of soybean fields significantly, counteracting the economic benefits expected for nonchemical tactics. Consequently, we continue to encourage a rational approach for insect management to optimize, rather than maximize, soybean yield.

Some of the research described in this paper was supported by funding from the Illinois Soybean Association.

ILLINOIS SOYBEAN ASSOCIATION

Consternations of the Waterhemp Conundrum



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The hearts of countless Americans skipped a beat at 9:05 P.M. Central Standard Time April 13, 1970, when 55 hours, 55 minutes, 20 seconds after the launch of the Apollo 13 space mission, John Swigert uttered the now famous words, “Houston, we’ve had a problem.” This phrase, first spoken to report a potentially life-threatening situation, is nowadays commonly used as a mere humorous anecdote. Herein, far removed from Houston and a NASA space mission—and certainly as more than a mere humorous anecdote—we endeavor to retool this time-tested phraseology to describe the current status of herbicide resistance in Illinois waterhemp populations: “Hey folks, we have a serious problem.”

The chronology of herbicide resistance in Illinois waterhemp populations began in the 1990s, when widespread utilization of ALS-inhibiting herbicides led to intense selection for waterhemp populations resistant to these products. So thorough was this selection that the utility of an entire class of herbicides for waterhemp control was lost. While not as predominant as ALS resistance, waterhemp populations resistant to triazine herbicides populate innumerable fields across the vast expanse of Illinois (moreover, at least two mechanisms of triazine resistance are present in the Illinois waterhemp population).

When ALS-inhibiting herbicides failed, soybean farmers ultimately had to rely on PPO-inhibiting herbicides for postemergence control of waterhemp prior to the commercialization of glyphosate-resistant soybean varieties. Pursuit plus Cobra or Status were popular tank mixes during the mid 1990s when Pursuit alone no longer controlled this “strange pigweed.” Soon enough, waterhemp resistant to PPO-inhibiting herbicides followed the precedents set by these other herbicide classes.

Glyphosate was initially heralded as a potential “savior” herbicide following the introduction of glyphosate-resistant soybean varieties in 1996. No longer would soybean farmers be plagued with waterhemp that could not be controlled with other postemergence soybean herbicides. Glyphosate application rates and timings brought unparalleled flexibility to waterhemp control programs, so much so that the utilization of other waterhemp management tools became almost negligible.

Over the past decade, many practitioners have become very proficient at controlling waterhemp but perhaps less proficient at managing waterhemp. Potentially serious repercussions are poised to plague Illinois soybean farmers in 2008 due to the widespread adoption of *weed control* in lieu of *weed management*. A specific consequence of widespread weed control is the selection of Illinois waterhemp biotypes resistant to glyphosate (Figure 1).

A pertinent question to consider is this: How will Illinois soybean farmers manage a waterhemp population no longer susceptible to glyphosate or diphenylether herbicides, the only postemergence soybean herbicide options for waterhemp control?

Weed scientists at the University of Illinois have conducted field, greenhouse, and laboratory research with an Illinois waterhemp population that is not controlled at field-use rates of glyphosate-containing products. Although evidence to date indicates this *particular* population is in fact resistant to glyphosate, it is altogether likely that other populations of glyphosate-resistant waterhemp exist within Illinois.

If the herbicide-resistance profile of a particular waterhemp population is known, appropriate changes in herbicide selection and utilization (particularly

Figure 1 ■ Glyphosate-resistant waterhemp seedlings in an Illinois soybean field, 2007.

postemergence soybean herbicides) can be made well before the beginning of the growing season. However, apart from the general assumption that most Illinois waterhemp populations are resistant to ALS-inhibiting herbicides, the vast majority of populations remain uncharacterized with respect to their susceptibility to the limited number of postemergence soybean herbicides that control waterhemp. We speculate that glyphosate-resistant and PPO-resistant waterhemp biotypes might be encountered across large geographical areas of central and south central Illinois during the 2008 growing season. Additionally, it is altogether possible that waterhemp biotypes resistant to both glyphosate and PPO inhibitors soon will be discovered. These biotypes represent a worst-case scenario, in that there are *no postemergence herbicide options for their control in soybeans.*

The University of Illinois offers the following recommendations for management of glyphosate-resistant waterhemp in the 2008 soybean crop. These recommendations assume glyphosate-resistant soybeans are planted. The considerations and justifications employed to develop these recommendations are based on current and previous research on waterhemp biology and management and are discussed after each respective recommendation. The recommendations are specific to herbicides, but weed management practitioners should strongly consider the benefits of utilizing practices that increase the competitive ability of the soybean crop (such as practices that hasten crop establishment and canopy development).

Recommendation 1: Apply a full labeled rate (according to label guidelines for soil type and organic matter content) of a soil-residual herbicide not sooner than 7 days before planting or later than 3 days after planting.

Justification:

- If a waterhemp population is resistant to *both* PPO inhibitors and glyphosate, there are no other postemergence herbicide options that will control this population. In this scenario, soil-residual herbicides are the only effective herbicide options for waterhemp management. Waterhemp is competitive with soybean, and, left uncontrolled, continues to reduce soybean yield potential for several weeks after emergence (Table 1).

- Research has demonstrated that germination and emergence of waterhemp often extend further into the growing season than is common for other summer annual weed species. A reduced or "set-up" rate of a soil-residual herbicide often can provide some amount of early-season control or suppression, but a full rate generally extends residual control. Even where a full rate of a soil-residual herbicide is used, it is altogether possible that waterhemp emergence will occur at some point after soybean emergence (Table 2). The later into the season that waterhemp emergence can be delayed, the greater the potential for achieving maximum or near-maximum soybean yield.
- Certain soil-residual herbicides are labeled for application several weeks prior to soybean planting. However, considering the extended emergence characteristics of waterhemp, herbicide application closer to planting generally protracts residual control later into the growing season. Conversely, some of the most effective soil-residual herbicides for

Table 1 ■ The interference potential of waterhemp in soybeans. Waterhemp plants were allowed to compete with soybeans for 2, 4, 6, 8, or 10 weeks after emergence and then removed from the crop. Data are averaged over 3 years (Hager et al. 2002a).

Removal timing (weeks after emergence)	Soybean field (bu/A)	Yield reduction (% of weed free)
Season-long weed free	51	—
2	50	1
4	44	13
6	41	19
8	36	34
10	29	43
$LSD_{0.05}$	4	8

Table 2 ■ Influence of soil-residual herbicides on waterhemp control 4 weeks after soybean planting. Regardless of herbicide selection, complete waterhemp control was not achieved at 4 weeks after soybean planting. However, all treatments reduced waterhemp density compared with the nontreated control. Data are averaged over four environments (Hager et al. 2002b).

Herbicide treatment	Waterhemp control (%)	Waterhemp density (plants/m^2)
Sulfentrazone	93	4
Metolachlor	80	22
Pendimethalin	79	23
Dimethenamid	77	39
Linuron	77	28
Metribuzin	72	39
Nontreated	0	180
$LSD_{0.05}$	8	18

waterhemp control can cause significant soybean injury if applied after soybean emergence, so applications should occur no later than 3 days (or sooner, if specified on the product label) after soybean planting.

Recommendation 2: The initial postemergence application of glyphosate (alone at 0.75 to 1.0 pound acid equivalent per acre) *must* be made when waterhemp is 3 to 5 inches tall.

Justification:

- We have only limited data on control of glyphosate-resistant waterhemp with glyphosate + PPO inhibitor tank mixes. Additionally, questions remain about the potential for antagonism with these tank mixes and about which additive(s) should be recommended. For example, nonionic surfactant (NIS) is the preferred additive for certain glyphosate formulations, while crop oil concentrate (COC) is the preferred additive for foliar-applied PPO inhibitors. Would NIS be sufficient for the PPO inhibitor tank mix partner to control a glyphosate-resistant waterhemp population? Would COC antagonize glyphosate sufficiently that it fails to control a PPO-resistant waterhemp population (or other weed species that may also be present)?
- Field research conducted in 2007 on a confirmed glyphosate-resistant waterhemp population suggested resistant plants were not adequately controlled with glyphosate at labeled in-crop application rates. Increasing the application rate to the maximum rate allowed by label (1.5 pounds acid equivalent per application) did not *consistently* improve control compared with lower application rates. Across two application timings (4- or 12-inch waterhemp), control of glyphosate-resistant waterhemp was 50% or less with glyphosate at rates labeled for in-crop application (Table 3).
- Applying glyphosate before waterhemp exceeds 5 inches tall generally provides more consistent control compared with applications made to larger plants. Previous research has shown that waterhemp less than 5 inches tall is very sensitive to glyphosate at 0.75-pound acid equivalent. Waterhemp plants that survive 0.75- to1.0-pound glyphosate acid when treated at 5 inches or less should be closely monitored.

Table 3 ■ Response of a glyphosate-resistant waterhemp population to labeled in-crop application rates of glyphosate (University of Illinois field research, 2007).

Glyphosate rate		WH size	% control (days after treatment)		
(lb a.e./A)	(product)	(inches)	7	14	21
0.77	22 fl oz	4	30	43	33
1.54	44 fl oz	4	40	47	50
		$LSD_{0.05}$	5	8	6
0.77	22 fl oz	12	40	42	40
1.54	44 fl oz	12	40	48	47
		$LSD_{0.05}$	6	9	8

Recommendation 3: Fields *must* be scouted 7 days after the initial glyphosate application to determine treatment effectiveness.

Justification:

- Field research in 2007 also indicated glyphosate-resistant waterhemp plants continued to grow at near-normal rates following treatment with glyphosate. Few, if any, herbicide injury symptoms became noticeable on treated plants, and, by the end of the season, treated plants were virtually indistinguishable from nontreated plants. With this in mind, if the initial application of glyphosate is made when waterhemp plants are 3 to 5 inches tall, it is quite possible that 7 to 10 days might elapse after application before lack of control becomes obvious. During this interval, glyphosate-resistant waterhemp plants will, in all likelihood, continue to grow and possibly could attain an additional 6 to 8 inches in height.

Recommendation 4: If waterhemp control is inadequate and retreatment is necessary, consider applying a PPO-inhibiting herbicide (lactofen, fomesafen, or acifluorfen) at a full labeled rate (with recommended additives) as soon as possible.

Justification:

- The only remaining herbicide recourse for control of a glyphosate-resistant waterhemp population is application of a PPO-inhibiting herbicide. Optimal control of waterhemp with PPO inhibitors is usually achieved when plants are 5 inches tall or less, but some control of larger plants is possible. If recommendations 1 through 3 were followed, it is anticipated that waterhemp would range between 8 and 12 inches tall by the time a PPO inhibitor is applied.

Recommendation 5: Re-scout the treated field within 10 to 14 days to determine effectiveness of the PPO-inhibiting herbicide treatment. If scouting reveals that plants treated with a second herbicide application might survive, implement whatever tactics are available or feasible to rogue these surviving plants from the field *before* they reach a reproductive growth stage.

Justification:

- Previous research has shown that the PPO-resistance trait can be transferred via pollen. If PPO-resistant male plants reach a reproductive growth stage, the pollen produced could facilitate the spread of this resistance trait to sensitive waterhemp populations. Currently, it is not known whether the trait conferring glyphosate resistance is transferred via pollen, seed, or both.
- Female waterhemp plants can produce a tremendous amount of seed. Previous research indicates that waterhemp may produce in excess of 1 million seeds per plant. If a glyphosate-resistant female plant laden with seeds is mechanically "harvested" along with the crop, seeds of a resistant population might be sown in all fields subsequently harvested with the combine (Figure 2).

Figure 2 ■ The early stages of a herbicide-resistant waterhemp infestation usually begin as small patches of uncontrolled plants.

These recommendations are, in reality, an illustration of the need for an integrated approach to waterhemp management. Integrated weed management introduces multiple tactics to control weeds and to slow the rate at which weeds are able to adapt to a single control tactic. Introducing an integrated waterhemp management approach into glyphosate-resistant cropping systems may well stave off some potential new challenges, enhancing the long-term effectiveness of this valuable weed control strategy.

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